SEESAC

SALW ammunition destruction

- environmental releases from open burning (OB) and open detonation (OD) events

SEESAC

South Eastern Europe Clearinghouse for the
Control of Small Arms and Light Weapons

The South Eastern Europe Clearinghouse for the Control of Small Arms and Light Weapons (SEESAC) has a mandate from the United Nations Development Programme (UNDP) and the Stability Pact for South East Europe (SPSEE) to provide operational assistance, technical assistance and management information in support of the formulation and implementation of SALW co-ordination, control and reduction measures, projects and activities in order to support the Stability Pact Regional Implementation Plan, thereby contributing to enhanced regional stability and further long-term development in South Eastern Europe.

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SALW ammunition destruction - environmental releases from open burning (OB) and open detonation (OD) events, **SEESAC, 2004**

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Introduction

To date the demilitarisation and destruction of ammunition within the South Eastern Europe region appears to have been based purely on national requests, with little technical evidence being provided to justify destruction priorities. Small arms ammunition[1] often has priority as donors have budgets to support the destruction of these particular natures. It is only recently that the destruction of the large stockpiles of other generic ammunition natures has been identified as a humanitarian and security priority.

It is highly unlikely that the international donor community can fund the destruction of all surplus SALW and ammunition within South Eastern Europe, let alone the much larger stockpiles within Central and Eastern Europe. This unfortunate fact means that prioritisation for future ammunition destruction should be developed based on:

a) the identification of SALW and ammunition that pose the greatest risks to the civilian community in terms of explosive safety;

b) ensuring the physical security of SALW and ammunition in order to reduce the risks of proliferation;

c) the destruction of SALW (weapons only) in order to reduce the risks of proliferation;

d) the destruction of that ammunition that presents a direct explosive safety risk to the civilian population, and can therefore be justified on humanitarian grounds alone;

e) the destruction of ammunition that is at greatest risk of proliferation or is ‘attractive’ to terrorists and criminals. The detailed ammunition natures will inevitably be subject to the judgement of national governments and individual donors; and

f) the capacity building of national institutions to continue the longer-term nationally financed, safe, efficient and effective destruction of SALW and ammunition to appropriate technical standards.

The physical destruction techniques available range from the relatively simple open burning and open detonation (OBOD) techniques to highly sophisticated industrial processes. The selection of the most suitable technique or technology by a national authority will depend primarily on the resources available, the physical condition and quantity of the stockpile, the national capacity and the applicable environmental and explosives legislation. The most influential factor is likely to be economies of scale, in that the more ammunition that requires destruction, the larger the economies of scale, and therefore the wider range of available technology.

Within South Eastern Europe there is very limited industrial demilitarization capacity, and insufficient identified resources to develop such a capacity in the near term. The development of such a capabilty takes time, whereas open burning and open detonation operation activities can usually be developed in a much shorter time scale. Therefore open burning and open detonation operations will inevitably continue to play a major part in the near to mid term destruction of ammunition stockpiles; particularly for that ammunition and propellant that has been identified as presenting the major risk of undesired explosive events in ammunition storage areas.

For open burning the products of combustion produce a degree of air and ground pollution, but the Volatile Organic Compounds are destroyed if burn temperatures in excess of 850°C are produced. Particulate matter is introduced into the atmosphere, but the toxicity of this is dependent on the raw materials used in the design of the ammunition. Open burning is legislated against in some countries in Western Europe, but acceptable in others if a supportive environmental impact assessment is formulated. Similarly, open detonation can also produce a degree of air and ground pollution and atmospheric particulate matter.

It would be irresponsible to suggest that open burning and open detonation is an environmentally benign destruction methodology for all ammunition natures, yet substantial scientific research has taken place over the last decade that suggests that the environmental impact of the destruction of some ammunition natures is relatively benign.

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[1] Ammunition of 20mm calibre and below.

The impact of ammunition destruction on the environment can only be realistically assessed if the 'full environmental system model' is examined. For open detonation and open burning this is relatively straighforward, as only the impact of the target explosive, donor explosive and transport fuels need to be determined. For industrial demilitarization processes [2] it becomes more complex, as the environmental impact of; 1) the fuel necessary to produce the power to operate the processes, 2) the subsequent use of any commercial explosives produced during ther process; and 3) the transport fuels, all need to be determined.

Therefore this study aims to examine the available scientific evidence and provide the information necessary for the formulation of an environmental impact assessment for open burning and open detonation operations. The study is not designed to examine all of the advantages and disadvantages of industrial demilitarization versus open burning and open detonation for ammunition stockpiles of varying levels. This is a complex and inter-relational problem for which guidance can be found in the International Mine Action Standards (IMAS) and the SEE Regional Micro-Disarmament Standards / Guidelines (RMDS/G).

Adrian Wilkinson
Team Leader SEESAC

Belgrade, 30 May 2004

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[2] Of course the recycling opportunities and cost efficiency of industrial demilitarization very large stockpiles of ammunition should not be under-estimated.

Executive Summary

Background

Until the mid-1980s, almost all surplus and unserviceable munitions and propellants (energetic materials (EM)) were either dumped at sea or destroyed by open burning (OB) or detonation (OD). These disposal techniques were chosen because of their simplicity, low cost, effectiveness and safety. As our knowledge and understanding of the chemical and biological processes essential to the health and well-being of humans and ecosystems expanded, the perception arose that the dusty, brown plumes produced by OB and OD could endanger human health and the environment (HH&E).

As a result, a number of countries developed alternative technologies for disposing of energetic materials and either prohibited or severely restricted using OB and OD for routinely disposing of surplus energetic material. Although these alternative disposal methods are more protective to human health and the environment than OB and OD, they are considerably more expensive. The alternative methods also require more technical knowledge and skills and are more labour intensive than OB and OD. Plus, they really apply only to the carefully stored, well-inventoried stockpiles of un-degraded energetic material found mostly in the developed countries. With the exception of incineration and detonation in a vented chamber, these alternative technologies require removal of the EM from its casing before treatment. For incineration, prior disassembly of ammunition larger than 50 or 60 mm is still required. They also lack the universality and throughput advantages of OB and OD and produce their own set of potentially hazardous waste streams.

While the industrial countries have the infrastructure, skills and fiscal resources to build and operate the disposal facilities using these alternative methods, most developing and underdeveloped countries do not. Many of these latter countries are burdened with widely dispersed stockpiles of poorly inventoried, degraded energetic materials that are being stored under conditions that foster further degradation. They also lack the transportation infrastructure needed to safely transport most of their energetic materials to a central disposal facility assuming the energetic materials are sufficiently stable to be transported. Because of the large ammunition stockpiles, these countries cannot afford to build demilitarization facilities at each storage site. Thus, for many countries OB and OD remain the only practical means for destroying their surplus, unserviceable and possibly unstable ammunition stocks.

At the same time, the staff of the organizations and donors assisting them demilitarize their stockpiles, are justifiably concerned about the short term and long term consequences that OB and OD will have on human health and the environment. Addressing these concerns taxes the capabilities and capacities of the country owning the ammunition stockpile and consumes an undesirable portion of the limited time and fiscal resources available. They often lack the knowledge needed to find the information required to evaluate the true risk that OB or OD presents to human health and the environment that is necessary to support an environmental impact statement.

The staff of the South Eastern Europe Clearinghouse for the Control of Small Arms and Light Weapons (SEESAC) have been assisting the countries in South Eastern Europe in destroying the numerous, widely dispersed SALW and ammunition stockpiles. They became concerned about the delays in destroying the energetic materials and the debates caused by the environmental concerns and uncertainties associated with OB and OD activities.

They were aware that the United States Environmental Protection Agency (EPA) had compiled the results from a number of OB and OD emissions characterisation studies into a database which EPA then used to show that OB and OD were environmentally safe disposal methods for a large number of ammunition natures in the USA stockpile. They were also aware that the original EPA database had recently been expanded in terms of its content and applicability through a cooperative effort between the U.S. Army and Chemical Compliance Systems Incorporated, Lake Hopatcong, New Jersey. This expansion included the addition of emissions characterisation data for twelve, large-scale OB and OD tests and new information on the compositions of the energetic materials on which the EPA database was founded.

In the expectation that this expanded database could be useful for identifying those ammunition natures in the SEE stockpiles that could be destroyed by OB and OD in an environmentally benign manner, SEESAC contracted with Bill Mitchell and Associates (BMA), LLC of Durham, North Carolina USA to convert this expanded database into one that they and the governments of the SEE countries could use to expedite their demilitarization efforts while remaining fully protective of HH&E.

The Study

Because of the public good that would result from this effort, Chemical Compliance Systems Incorporated made its proprietary database and associated documentation available without charge. BMA then conducted a literature search which identified two OD emissions data sets which were had not been included in the Chemical Compliance Systems database. These were added to the database and then an in-depth review of the expanded database was conducted to identify and perform the actions required to develop a statistically robust database that would fully meet the needs of the UNDP.

Project Accomplishments and Products

A fully documented, easy to understand and use, statistically robust emissions factor database was developed. This database can be used in conjunction with the chemical composition data on the energetic materials in a stockpile to accomplish the following.

- Quickly and decisively identify the ammunition natures and components in the stockpiles that could be destroyed by OB or OD without endangering HH&E.
- Expedite the destruction of those items that present either the greatest direct explosive safety risk to the population or are attractive to terrorists and criminals.
- Identify the items in the stockpiles for which OB and OD are not suitable based on HH&E considerations, so that the resources needed to develop the technologies or procedures for destroying these energetic materials could be solicited.
- Serve as a source of input data for conducting environmental impact and health risk assessments.
- Allay the concerns of the general public and of donor countries about the environmental safety of OB and OD for certain ammunition types.

Contents

SALW ammunition destruction - environmental releases from open burning (OB) and open detonation (OD) events[3]

1 Background

Ammunition Destruction by Open Detonation (Carbon and Dirt in Plume)

Until the mid-1980s, almost all surplus and unserviceable ammunition and propellant (energetic materials, (EM)) was destroyed by either open burning (OB) or detonation (OD) in an open field. These disposal techniques were chosen because of their simplicity, low cost, effectiveness and safety. That is, the energetic material could be simply placed in a pile and destroyed quickly with minimum handling. In the mid-1980s, as our knowledge and understanding of the chemical and biological processes essential to the health and well-being of humans and ecosystems expanded, concerns emerged over the dangers that the dusty, brown plumes produced by OB and OD might have on human health and the environment (HH&E). Scientists had demonstrated that many of the heavy metals in energetic material and the particles, nitrogen oxides, sulphur oxides, and some of the volatile organic compounds (VOCs) and polycyclic aromatic compounds (PAHs) present in combustion plumes posed a serious risk to the health of some individuals and ecosystems.

Because of these concerns a number of the industrialised countries began developing other disposal methods (alternative technologies) for energetic materials. As these alternative technologies became available, many countries prohibited using OB and OD for routinely disposing of surplus energetic material and others restricted their use, but all continued to allow the use of OD when the energetic material could not be moved safely.

Although these alternative technologies are more protective to HH&E than OB and OD, they are considerably more expensive and knowledge and skill intensive to operate and maintain. Plus, they truly apply only to the carefully stored, well-inventoried stockpiles of un-degraded ammunition found mostly in the developed countries. With the exception of incineration and detonation in a vented chamber with air pollution controls, all of the operating alternative technologies require removal of the energetic material from its casing before treatment, and even incineration requires disassembly of ammunition larger than 50mm or 60mm before incineration. They also lack the universality and throughput advantages of OB and OD. For example, the operators of explosive waste incinerators (EWIs) have limits on the quality, size, energetic content and throughput rate they are willing to destroy and the incineration process can has been shown to generate dioxin and furan compounds. Further, disassembling munitions, particularly when the identity or condition of the energetic components are unknown, exposes personnel to the risk of a spontaneous detonation and usually produces multiple waste streams, which must be treated individually.

While the industrial countries have the infrastructure, skills and fiscal resources to build and operate these alternative technologies, most developing and underdeveloped countries do not. Many of these latter countries are burdened with widely dispersed stockpiles of poorly inventoried, degraded ammunition that is being stored under conditions that fosters further degradation. Besides the obvious risk of an autocatalytic or spontaneous explosion of one munition setting off the entire stockpile, there are also security and terrorism risks associated with these stockpiles. These countries also lack the roads and transport infrastructure needed to safely transport most of their ammunition to a central facility for disposal and, because of the numerous, widely distributed stockpiles, they cannot afford to build sophisticated demilitarization facilities at each storage site.

For many countries OB and OD remain the only practical means for destroying their surplus and unserviceable ammunition. However, their citizens and the organizations and donors helping them destroy these stockpiles are justifiably concerned about the short term and long term consequences that OB and OD activities will have on HH&E. Addressing these concerns severely taxes the capabilities and capacities of those demilitarizing the ammunition stockpiles and consumes an undesirable portion of the limited time and fiscal resources available.

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[3] Full title of the study is: 'Predicting the environmental releases from open burning (OB) and open detonation (OD) events - a review and evaluation of the available emissions characterisation data on OB and OD'

Ammunition awaiting logistic destruction by Open Detonation

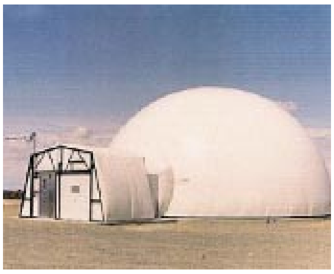
Often they lack the knowledge needed to find and evaluate OB and OD emissions data that applies to the situation at hand, and if they do find it, lack the skills needed to use the information to evaluate the true risk that OB or OD presents to HH&E.

South Eastern Europe (SEE), whilst being scientifically capable of environmental analysis, is one of the regions of the world where there are undesirable, and potentially dangerous delays, in the demilitarization of surplus and degraded ammunition. It is awash with ammunition left over from the Cold War and recent conflicts and the governments lack the resources required to employ many of the viable alternative environmentally safe industrial technologies. Further, because much of the ammunition in the stockpiles is very appealing to terrorist organizations, a potentially active grey and black market exists in SEE for the ammunition in the stockpiles. Also, much of the ammunition is stored under conditions that invite a spontaneous or deliberate detonation.

The staff of the South Eastern Europe Clearinghouse for the Control of Small Arms and Light Weapons (SEESAC) has been actively assisting the countries in SEE seek solutions for destroying these stockpiles.They are aware that some potential donors require environmental impact assessments before supporting ammunition destruction projects and therefore commissioned this study to assist in the preparation of such environmental impact statements. SEESAC was also aware that the U.S. Department of Defense (DOD) had conducted a number of studies in inflatable detonation chambers (Bang Boxes) which had identified the substances in the plumes produced when 0.2 to 2.2kg quantities of 43 different generic ammunition natures were open burned and open detonated. They also knew that in 1998, the US Environmental Protection Agency (EPA) had compiled the results from a number of these studies into an emissions (factors) database, which was then subjected to an in-depth analysis.

Based on their analysis, EPA reached a number of conclusions about the impact of OB and OD on HH&E. Two of the most far reaching of these conclusions were:

- **OB and OD were environmentally safe disposal methods for a large number of ammunition natures in the US stockpile.**
- **The emissions measurement unit traditionally associated with OB and OD needed to be replaced with one that related the emission products to the chemical composition of the ammunition being destroyed. These and the other significant conclusions made by EPA are summarised in Table 1.**



The Dugway Proving Ground (USA) 'Bang Box' for trials

The SEESAC staff were also aware that the original EPA database had recently been expanded in terms of its content and applicability through a cooperative effort of the US Army Defense Ammunition Center and Chemical Compliance Systems Incorporated [4]. The expansion included the addition of emissions characterisation data for twelve, large-scale OB and OD tests [5] and new information on the chemical composition data on the

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[4] Mitchell W J, G R Thompson and T L Boggs, *Derivation of Emission Factors for Toxic metals for Use in NAVAIR HRA.* In the proceedings of the Demil Users Group Meeting, Atlanta, USA. 28 - 30 October 2003;

Mitchell W J, *Efforts by the Defense Ammunition Center to Broaden the Use and Acceptance of Demilitarization Process Emissions Data.* Invited paper presented at the Technology Focus Group Meeting, Army Environmental Center, Aberdeen, USA, 23 - 24July 2002;

Thompson G, *Recent Improvements in the MACS-1 Chemical Release Database*. In the proceedings of the 10th Global Demilitarization Symposium and Exhibition, Lexington, USA, May 2002;

[5] *Executive Summary of Phase I Demonstrations - Detonation of Conventional Weapons: 155-mm High Explosive M107 Projectiles.* Lawrence Livermore National Laboratory Report Number UCRL-ID-131252, pp 38, prepared for US Army Defense Ammunition Center, McAlester, USA. July 1998. *Individual Test Reports, Appendix B, Draft Detonation Summary Report for the Nevada Test Site,* report prepared by Radian International LLC, Oak Ridge, USA for Lockheed Martin Energy Systems, August 1997;

Executive Summary of Phase II Demonstrations: The Low-Pressure Rocket Motor Burns in X-Tunnel, Sandia Report Number SAND2000-8202, pp 34, January 2000. Report prepared for US Army Defense Ammunition Center.

Individual Test Reports, Appendix B, Draft Rocket Motor Summary Report for the Nevada Test Site, report prepared by Radian International LLC, Oak Ridge, USA for Lockheed Martin Energy Systems, October 1997;

M Johnson, *Development of Methodology and Techniques for Identifying and Quantifying Products from Open Burning and Open Detonation Thermal Treatment Methods - Field Test Series A, B and C, Volume 1 (Test Summary).* US Army, AMMCOM, Rock Island, IL 61299-6000, January 1992.

energetic materials contained in the EPA database [6]. At the time the EPA compiled their database, this detailed compositional data was not available for most energetic materials in the U.S. inventory and EPA had noted how much more definitive its analysis could have been if this detailed composition information had been available.

One of the significant advances accomplished by CCS and the US Army was inclusion of a reporting unit in the database that related the mass of the emission product to the mass of a specific substance in the EM detonated or burned. Traditionally, emissions factors (EF) data for OB and OD had been reported in a unit that related the mass of the emission product to the explosive mass (Net Explosive Quantity, NEQ) detonated or burned. This EF unit was developed for the mining industry in the 1920s when the emission products of concern were simple, inorganic gases and the explosives were dynamite and a mixture of ammonium nitrate and fuel oil (ANFO). For a number of reasons, some of which are contained in Table 1, EPA had noted that this traditional unit was not useful for today's environmental needs. Its major deficiency was that it did not provide the information required to conduct EIAs (Environmental Impact Assessments) and HRAs (Health Risk Assessments). This was particularly true regarding the releases of the Persistent Organic Pollutants (POPs) and Heavy Metals (cadmium, lead and mercury). These substances are of high concern because they persist in the environment and bio accumulate through the food chain and pose the risk of adversely impacting HH&E.

In response to EPA's recommendation to replace the tradition unit, CCS developed an alternate reporting unit, which it designated as the Environmental Fate Factor (EFF). Because this new unit linked the masses of the emissions products to the masses of specific substances in the EM, it addressed EPA's concern. It was derived by multiplying the traditional unit (for example kg Lead / kg NEQ) by the average NEQ detonated or burned in the emissions characterisation studies, and then dividing the product by the mass of the relevant species (for example kg of lead) in the ammunition nature.

In the expectation that this new database could be helpful in identifying those ammunition natures in the SEE stockpiles that could be destroyed by OB and OD, SEESAC contracted with Bill Mitchell and Associates (BMA) to convert the CCS database into one that they and the governments of the SEE countries could use for the following purposes:

- To identify the items and munition components in the ammunition stockpiles that could be destroyed by OB or OD without endangering HH&E, thereby avoiding the need to spend scarce donor funds on developing new or expanding existing demilitarization capabilities.
- To expedite the destruction of those ammunition natures that present either the greatest direct explosive safety risk to the population or are attractive to terrorists and criminals.
- To identify the items in the ammunition stockpiles for which OB and OD are unsuitable based on HH&E considerations, so that the resources needed to develop the technologies or procedures for destroying these energetic materials could be solicited.
- To serve as a source of input data for conducting environmental impact and health risk assessments.

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[6] Mitchell W J and Suggs J C, *Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD), EPA Report Number* EPA/600/R-98/103, pp 130, August 1998.

Table 1: Findings and recommendations in the EPA Report

Carefully planned and conducted OB and OD can be an environmentally safe way to dispose of energetic materials and EM components which cannot be recycled or are too hazardous to handle or transport - provided the OB event proceeds rapidly and at a high temperature and the OD event is high order and unconfined. Fossil fuel or wood-supported open burning of energetic materials containing plastics and chlorides should be avoided whenever possible because of the chance that dioxin and furan compounds will be formed.
OB and OD produce the same predominant emission products. The emission products from most energetic materials destroyed by OB and OD processes will be adequately represented by the following analytes: CO_2, CO, NO, NO_2, N_2, H_2O, ethane, propane, i-butane, n-butane, acetylene, ethylene, propene, benzene, toluene, and particulate matter (PM) and metals
98% of the carbon in the energetic material characterised was converted to CO_2 and CO and less than 2% of the nitrogen in the EM was converted to nitrogen oxides. In addition, although the emissions data for heavy metals is limited, the data indicate that only a small percentage of the metal in an EM enters the plume when energetic materials are detonated or burned.
With the exception of small quantities of naphthalene and its alkylated sister compounds, emission products larger than the molecules in the EM were not found in the detonation and burn plumes. This is consistent with detonation theory and chemical kinetic mechanisms. It also confirms that collisions between CxHy- radicals (molecular fragments produced by the detonation/deflagration) are the source of the aromatic hydrocarbons. Thus, polycyclic aromatic hydrocarbons containing three or more aromatic rings are not likely to be produced by OB and OD events.
Most of the emission products from OB and OD are species commonly found in the environment from natural and human causes. This made it difficult to adjust some of the emissions characterisation study results for the contribution from substances in the chamber air and on the surfaces of the chamber.
The traditional reporting unit for OB and OD emissions data (mass of emission product / mass of explosive (NEQ) treated) is unsuitable for use in risk assessments because it provides no information on either the composition of the EM or the relationship between an emission product and its source in the EM detonated or burned. Yet, common sense and actual emissions data clearly indicate that there is a relationship between: (1) the carbon-containing emission products and the carbon in the EM; (2) the NOx emissions and the nitrogen in the EM; and (3) the metal emission products and the mass and location(s) of the metal in the EM. The traditional unit needs to be replaced with one that provides this information.
Although the emissions data examined were derived by detonating and burning energetic materials in chambers, the agreement of the results to detonation theory and the similarity of the emissions products across all of the energetic materials characterised, imply that the emissions data in the database should be suitable for estimating (predicting) the emissions from real world OB and OD events.

The SEESAC contract specified that the final report would contain the following information:

- Thorough documentation on the sources and decisions used in the construction of the database.
- A comparison between the air emission risks from demilitarizing ammunition by OB and OD and the most stringent environmental legislation in Europe and North America regarding emissions from the same ammunition when treated by an appropriate alternative industrial demilitarization technology.

2 Approach

Because of the public good that would result from this effort, CCS made its proprietary database and associated documentation [7] available without charge to BMA and the UNDP. (BMA had assisted CCS and the US Army in expanding the original EPA database and was knowledgeable of the changes that had been made and the basis for making them.) BMA then conducted a literature search and contacted researchers to determine if there were additional OB or OD emissions data sets available which had not been included in the CCS database. Two additional Bang Box data sets were found [8]. These data sets, which were produced by detonating aluminised double base propellants, were evaluated against the EPA guidance [9] and found suitable for inclusion in the database obtained from CCS.

Next, BMA conducted an in-depth review of the database and its documentation to determine the actions required to create a database the satisfied the requirements and objectives specified by SEESAC. Based on this review, two of the fifty-one data sets were deleted from the starting database because they did not represent real world OD practices. Upon completion of the final database, hereafter referred to the UNDP - EDB, BMA examined the environmental regulations of the EU, its member countries, UK, Canada and USA to identify the environmental regulations that should be used for the comparison specified in the contract.

The final database and the actions taken in creating it are described in detail below in the section entitled ‘A Development of the UNDP-OB/OD Emissions Database’ and the regulations and the results of the comparison are presented below in the section entitled ‘A Comparison of the Emissions from OB and OD to EU and North American Emission Limits’.

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[7] *Procedures Used in Developing and Validating the Open Burn - Chemical Release Database (OB - CRD),* report prepared for the US Army by Chemical Compliance Systems, November 2003;

Procedures Used in Developing and Validating the Open Detonation - Chemical Release Database (OD - CRD), report prepared for the US Army by Chemical Compliance Systems, November 2003.

[8] *Sampling Results for C3 and C4 Propellant Emissions Characterisation Tests,* report prepared for Hill Air Force Base, Utah, USA by Radian Corporation, (now URS Corporation), June 1998.

[9] *Procedures for Preparing Emissions Factor Documents,* US Environmental Protection Agency, Office of Air Quality Planning and Standards, Durham, USA, EPA Report 454/R-95-015 (Revised), September 1997.

3 Development of the UNDP - OB/OD emissions database

To understand some of the actions taken in developing the UNDP - EDB, it is necessary to have a basic understanding of how the decomposition (e.g.: detonation and deflagration) processes proceed in explosives and of the procedures normally used to handle non-detectable (ND) values when compiling emissions databases. In order to provide a knowledge baseline for readers of this document the following introductory materials have been prepared.

3.1 Overview of the Detonation and Deflagration (Open Burning) Processes

Explosives are generally identified as high explosives or low explosives. TNT, RDX, Comp B and PETN are examples of high explosives and nitrocellulose (NC) and nitroguanidine (NQ) are examples of low explosives. Nitro-glycerine (NG) by itself is a high explosive, but when added to NC, it becomes a low explosive.

In high explosives the decomposition process (detonation) proceeds through the entire material at a supersonic speed. The rate of decomposition is determined by the velocity of the shock wave and not by the rate of heat transfer. In contrast, in low explosives (propellants) the decomposition process (deflagration) occurs at subsonic speed on the surface of the explosive and there is no shock wave. The rate determining factors of the deflagration process are; 1) the rate of heat transfer into the propellant itself from the decomposing surface; and 2) the rate of decomposition of the propellant formulation [10].

The amount of energy released by (open) burning low explosives is comparable to that released when a high explosive of the same mass is detonated, but the two processed differ in the rate at which the energy is released. In high explosives, a fast reaction produces a very high-pressure shock in the surrounding medium, which is capable of shattering objects. In contrast, the deflagration process associated with low explosives produces a much lower pressure wave but it extends over a much longer time frame than a detonation.

High explosives produce peak pressure of 36,000 to 360,000 atmospheres in less than 4 microseconds and the pressure wave radiates through the material at a velocity (detonation velocity) between 2,500 and 10,200 m/s. The detonation also produces a 2 to10 second fireball (after burn), which has initial dimensions 1.2 to 1.5 times the dimensions of the material detonated. Low explosives (propellants), on the other hand, seldom produce peak pressures in excess of 3,500 atmospheres. For both types of explosives, the initial release of energy results from intramolecular adiabatic, oxidation-reduction processes involving oxidant (e.g.: $-ONO_2$, $-NO_2$, $-NHNO_2$) and reductant (e.g.: CxHy-) radicals within the energetic compound itself.

Between 1961 and 1981, Ornellas and co-workers [11] conducted a series of experiments on explosives for the purpose of developing a data set that could be used to predict the (explosive) performance of C, H, N, O, Al based explosives. These experiments involved detonating 25g pellets of 43 energetic materials in a 5.3 litre bomb calorimeter at Lawrence Livermore National Laboratories. Most of the detonations were done with the calorimeter evacuated, but a few were done when the calorimeter was pressurised with either CO_2 or O_2. Some of the detonations were done with the energetic simply suspended by a string (unconfined detonation), whilst others were done with the energetic encased in glass or metal cylinders. In addition, in some experiments the ends of the cylinders were open (partially-confined detonation) and in others they were closed (fully-confined detonation). Approximately 90 minutes after the detonation, gas samples were taken from the calorimeter and analyzed for N_2, CO, CO_2, H_2 H_2O, CH_4, NO, NO_2, HCN, HCl, C_2H_2, C_2H_4, C_2H_6, and CH_2O, as appropriate. The calorimeter was also rinsed out and the rinse then analysed for solid carbon, HCl, HF and Al, as appropriate.

His studies produced the following information about the detonation and deflagration processes.

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[10] M A Cook and G Thompson, *Chemical Explosives - Rocket Propellants*, Chapter 19 in Riegel's Handbook of Industrial Chemistry, Seventh Edition. Van Nostrand Reinhold, New York, 1974.

[11] D L Ornellas, *Calorimetric Determinations of the Heat and Products of Detonation for Explosives; October 1961 to April 1982*, Lawrence Livermore Laboratory Publication UCRL-52821, University of California, Livermore, USA, April 1982. (Available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield VA 22161).

- The major reaction products from an unconfined detonation are primarily the fully oxidized, thermodynamically stable compounds: N_2, CO_2, and H_2O. The detonation also produces small quantities of incompletely oxidized, combustible products, such as, elemental carbon (soot), CO, H_2, CH_4, NO, NO_2, HCl, C_2H_2, C_2H_2, C_2H_6, and CH_2O. However, as the fireball expands these latter products react with O_2 in the air or with each other to form CO_2, N_2, and H_2O. The oxidation (after burn) of these initial products releases energy, which helps support additional combustion. After the burning gaseous mass cools to about 1800^0 K, the reaction rates fall to a point where further chemical change takes hours or longer to occur.

- The actual composition of initial detonation products depends on a variety of factors; one of the most important of which is the amount and form of oxygen in the energetic molecule. If the energetic is oxygen-balanced or only slightly oxygen-deficient, most of the carbon is converted to CO_2 and most of the hydrogen is converted to H_2O at the instant of detonation. As the oxygen-balance becomes more negative, the amount of soot, CO and other incompletely oxidized products formed increases and the fireball must occur if these products are to be converted to CO_2, N_2, and H_2O. Also, if the oxygen in the energetic is bonded with nitrogen, the energy released upon detonation is much greater than that released when the oxygen is bonded to hydrogen.

- Generally, at least 97% of the nitrogen in the energetic compound is released as N_2; almost all the rest is released as NO and NO_2.

- As noted earlier, the initial release of energy by an explosive results from an intramolecular oxidation - reduction mechanism. This within-molecule, oxidation - reduction process was dramatically demonstrated through a set of experiments which used a 20:80 blend of isotopically labelled and unlabeled ammonium nitrate (AN) and TNT, that is, unlabeled AN (contained 99.8% $_{14}N$), labelled AN (contained 99.1% $_{15}N$ isotope) and unlabeled TNT (contains 99.8% $_{14}N$). In one of the experiments he made a slurry of TNT and AN in toluene, dried the slurry, blended it, sieved it through a 30-mesh screen and pressed the resulting powder into 12.7 mm diameter pellets, which he then detonated in the calorimeter. In the other experiment he detonated a 12.7 mm diameter AN pellet containing a 6.4 mm diameter core of labelled AN and an annulus of unlabeled AN. After each detonation, Ornellas measured the isotopic content of the N_2 formed, i.e., $_{14}N_{14}N$, $_{14}N_{15}N$, and $_{15}N_{15}N$. The two experiments yielded similar results, for example, only about 13% of the nitrogen in the TNT and the AN mixed, thereby establishing conclusively that the detonation was an intramolecular process which proceeded so fast that the atoms from one molecule were not able to freely react with those in another.

- If an oxygen-deficient energetic is detonated in an oxygen-enriched environment, the final products will be CO_2, N_2 and H_2O. On the other hand, the products formed by detonating an energetic in an inert atmosphere (e.g.: CO_2) will be essentially the same as those formed when the energetic is detonated in a vacuum, regardless of the degree the energetic is oxygen-balanced. The oxygen-rich atmosphere will also yield a much higher total energy release, because of the heat released when the incompletely oxidised radicals are oxidised by the oxygen.

- The metals in the explosives are converted to the metal oxide when explosive compounds deflagrate or detonate.

- The number of aromatic compounds produced per g of carbon in the EM is essentially the same across all the EM materials. That is, the nitroaromatic energetic molecules (which contain one nitrated benzene ring) produce approximately the same number of (single benzene ring) aromatic compounds as those that contain alternating carbon and nitrogen atoms and no benzene ring. These data indicate that small CxHy-radicals and not the energetic compound itself are the source of the aromatic organic emission products.

3.2 Procedures used to handle non-detect values when compiling Emissions Databases

In compiling emissions databases, the standard practice is to replace non-detect (ND) values with a numerical value equal to some multiple of the measurement system's minimum detection limit (MDL) so that statistical analysis techniques can be used on the database. Traditionally, a value equal to 50% of the MDL is based on the following line of reasoning. If the ND value is replaced with zero and the compound (analyte) was present, then a negative bias is introduced into the data set. On the other hand, if the ND value is replaced with one equal to the MDL, then a positive bias is introduced. If the value is deleted, it reduces the number of values used in the statistical analysis and thereby reduces the (statistical) degrees of freedom. Therefore, the ND value should be replaced with a numerical value greater than zero but less than the MDL. The value least likely to bias the data set is one halfway between zero and the MDL, that is, 1/2 MDL. The fundamental assumption here is that the analyte was present and its average concentration is normally distributed. In other words, when the analyte is present at a concentration below the MDL, the average concentration over time will be 50% of the MDL value.

This approach for handling ND values was developed over 60 years ago when the environmental media (matrices) of concern were soils, drinking water and waste-water and most of the analytical methods measured one analyte. For these media, the analytes and their concentrations are usually well characterised and constant over time within the same geographic area. Thus, when the analyte wasn't detected, there was a high probability that it was present in the sample and it was reasonable to replace the ND value with one between zero and the MDL.

In contrast, today it is common to use the same measurement system to simultaneously analyse for 20 to 100 analytes and the concentrations capable of being measured are much lower than the earlier methods. In fact, the sampling and analysis methods are so automated, that it costs less to scan the sample for a suite of analytes than to scan it for just a few analytes within the normal suite of analytes that the system is programmed to measure routinely. Although this provides many advantages when attempting to characterise environmental media, it also has some downsides. For example, the laboratory report will contain a large number of analytes marked as ND, or BDL (below detection limit), or TIC (Tentatively Identified Compound) and there will be no discussion in the report as to the real probability of an analyte being present in the sample. Because most analytical laboratories are now data generators and not data generators/interpreters, rare for an analytical laboratory to take the time (assume the liability?) to stipulate which of the ND/BDL compounds could actually have been present in the sample. Standard practice is to pass the responsibility for making this decision onto the client. But, usually the client does not feel qualified to make the decision or, is afraid of the consequences of failing to report an analytical result to the regulatory agency that has no responsibility to remove analytes.

Consequently, many environmental data sets now contain more letter code than numerical values. For example, EPA noted that the seven test reports used in compiling the initial OB/OD emissions factor database encompassed 100,000 data points covering 283 analytes, but less than 20,000 of the data points were numerical values. When EPA finished validating the database, it contained only 12,000 values covering 83 analytes [12].

Although EPA and other regulatory agencies have published guidance which recommend replacing ND values with values equal to 1/2 MDL, the guidance does permit changing ND values to zero when it was not possible for the analyte to have been in the sample. But, what if the there was only a 5% or 10% chance that the analyte was present in the sample? How should one handle ND-type values in this situation? There is no guidance available! Nor is there any guidance on compiling databases using MDL values that are markedly different for compounds whose concentrations should be related because they form through similar reaction pathways. For example, in the OB/OD plume characterisation studies used to compile the UNDP - EDB, the MDL for the dioxin and furan analytes, which are chlorinated PAHs, was 100,000 lower than that for the related polycyclic aromatic analytes (PAHs) and both form by similar chemical reaction pathways. So, if neither dioxins, furans or PAH compounds were detected in the plume, it does not seem logical to replace a PAH ND value with a MDL value 100,000 times larger than the one used for the dioxin or furan analytes?

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[12] Mitchell W J and Suggs J C, *Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD),* EPA Report Number EPA/600/R-98/103, August 1998.

3.3 Compilation of the Basic UNDP - OB/OD Emissions Database (UNDP - EDB)

The CCS database was developed to provide the environmental community with a fully documented, versatile database of emissions factors that could be used for a wide range of applications. Some examples of these are: pollutant fate and transport modelling; pollutant control strategy development; preparation of Toxic Release Inventory (TRI) reports; identification of the substances in EM which produced substances of environmental concern to form in OB and OD plumes; demilitarization workload planning at depots and arsenals; and the development of green or environmentally benign (green) munitions. The CCS database was compiled and validated in conformance with EPA guidance [13] and CCS and it was assigned an EPA Data Quality Rating of 'Above Average' based it having the following properties:

- First, the emissions data had been collected under conditions which were reasonably representative of normal (OB/OD) processes and the EM treated (open burned/detonated) was representative of the type of energetic materials that would be destroyed by (OB/OD) processes.
- Second, the plumes had been characterised using sound and credible sampling and analysis methodologies.
- Third, the database was supported by credible documentation regarding the test conditions under which the emissions data were collected, the number of plumes sampled, the elemental or chemical composition of the EM treated, and the sampling and analysis methodology used to characterize the plume.

With the addition of the two data sets [14], the initial database contained over 17,000 data points covering 47 energetic materials and 146 detonation and burn plumes. Approximately 55% of the 16,000 data points were expressed in the traditional EF unit (kg emission product per kg NEQ) and the remaining 45% were expressed in the alternate EFF unit (kg emission product per kg of a related substance in the EM treated). However, 45% of the data points were letter codes entries (indicating no emission data available) and another 46% were numerical values indistinguishable from the normal variations of the compound observed in urban area parcels [15]. In fact, 95% of the numerical values notably different from normal ambient air concentrations were associated with just the following 16 elements and compounds: CO, CO_2, NOx, acetylene, ethylene, propene, ethane, propane, butane, benzene, toluene, naphthalene, aluminium, lead, and hydrogen chloride.

The many letter code and (essentially) zero entries in the database combined with the presence of emissions factors for harmless hydrocarbon species was understandable because CCS and the us Army had developed the database for a highly diverse set of applications which ranged from the development of new energetic materials to the destruction of existing and yet to be developed energetic materials. On the other hand, they made it very difficult to understand and apply the database to the demilitarization of the types of energetic materials of concern to UNDP and the citizens and governments of developing and underdeveloped countries, although, to be fair, this factor was not considered during development.

Therefore, the study decided to develop a scaled-down version of the expanded CCS database, one that would contain only the emission products of real environmental concern. This scaled down database was derived as follows.

3.3.1 Carbon Oxides

All 44 CO and 44 CO_2 EFF values (which related the mass of the carbon oxides to the mass of carbon in the EM treated) were placed in the UNDP-EDB and the corresponding EF values were excluded.

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[13] *Procedures for Preparing Emissions Factor Documents,* US Environmental Protection Agency, Office of Air Quality Planning and Standards, Durham, USA, EPA Report - EPA 454/R-95-015 (Revised), September 1997.

[14] *Sampling Results for C3 and C4 Propellant Emissions Characterisation Tests*, report prepared for Hill Air Force Base, UT by Radian Corporation (now URS Corporation), June 1998.

[15] Mugica V, Vega E, Arriaga J L and Ruiz M E, *Determination of Motor Vehicle Profiles for Non-Methane Organic Compounds in the Mexico City Metropolitan Area,* Journal of the Air and Waste Management Association, 48, 1060 -1068,1998.

Watson J G and DuBois D W, *Aerometric Monitoring Program for the California Regional PM-2.5/PM-10 Air Quality Study,* report prepared for the California Regional PM-2.5/PM-10 Air Quality Study Technical Committee, Sacramento, CA, December 1998.

Singer B C, Kirchstetter T W and Kendall G R, *A Fuel-Based Approach for Estimating Motor Vehicle Cold-Start Emissions,* Journal of the Air and Waste Management Association, 49, 125 B 135, 1999.

3.3.2 Nitrogen Oxides

The 38 NOx (as NO_2 equivalent mass) EFF values (which related the mass of NOx to the mass of nitrogen in the energetic treated) were placed in the UNDP -EDB. The corresponding NO and NO_2 EFF values used to derive the Total NOx values and the NOx, NO and NO_2 EF values were excluded.

3.3.3 Sulphur Oxides

Sulphur dioxide (SO_2) was detected in some of the OB and OD plumes characterized at concentrations above ambient levels. Since sulphur is present in small quantities in many Energetic materials either as part of an energetic (e.g., black powder) or as explosive modifier, it was likely an emission product from the EM treated. Because there still was no information available on the mass of sulphur in any of the Energetic materials treated, there were 14 SO_2 EF values and no EFF values in the database. These 14 EF values were placed in the UNDP - EDB.

3.3.4 HCl and Cl_2

There database contained four sets of HCl and Cl_2 data, two from open burning of ammonium perchlorate (AP) propellants and two from detonating mixtures of Al, AP, nitroglycerin (NG) and nitrocellulose (NC). Each set of data was expressed in both the traditional (EF) and the new (EFF) reporting units. The EFF values (kg Cl (as HCl) /per kg Cl in the EM treated) were placed in the UNDP - EDB and the corresponding EF values were excluded.

3.3.5 Aromatic VOC

The full database contained EF and EFF values (kg aromatic compound/kg carbon in the EM) for 11 aromatic hydrocarbon compounds (single ring hydrocarbons). However, benzene and toluene together represented 95% of the mass for all of the aromatic compounds. Since benzene is the most toxic aromatic compound, we decided to convert the toluene EFF values to the equivalent mass as benzene, sum the values within each set of emissions test data and place the sum in the UNDP - EDB and designate these values as aromatics (as benzene equivalent). This action reduced the size of the database without compromising the aromatic hydrocarbon values.

3.3.6 Saturated and Unsaturated Hydrocarbon Compounds

The starting database contained EF and EFF values for 42 saturated (no double-bonded carbon) and unsaturated (one or more double-bonded carbon) hydrocarbons, but most of the values were equivalent to concentrations found in urban air. In addition, 78% of the mass for the saturated hydrocarbons was comprised of just three compounds (ethane, propane and butane) and 92% of the mass for the saturated hydrocarbons was also comprised of just three compounds (acetylene, ethylene and propene). It was therefore decided to convert the masses of the three predominant saturated hydrocarbon compounds in each data set to their equivalent mass as ethane and to convert the masses of the three predominant unsaturated hydrocarbons to their equivalent mass as ethylene, sum the values and enter a single value for each data set in the UNDP - EDB. This action was carried out as follows. First, the acetylene and propene EFF values were converted to the equivalent mass of ethylene and the ethane, propane and butane values were converted to the equivalent mass of propane. Second, the values for each hydrocarbon class were then summed for each data set and the sums were entered into the UNDP - EDB under the designation unsaturated hydrocarbons (as ethylene equivalent) and saturated hydrocarbons (as ethane equivalent).

Note: These compounds pose no risk to HH&E. They were included in the UNDP – EDB because they provide useful information to the user as to the environmental fate of the carbon in the EM.

3.3.7 Methane

Although methane (CH_4) is a harmless compound in the concentrations found in OB and OD plumes, the EFF methane values (kg CH_4 / kg C) provide useful information on the efficiency of the detonations or burns used in producing the emissions data. Therefore, the 10 EFF values for methane were entered into the UNDP - EDB.

3.3.8 Other hydrocarbon compounds

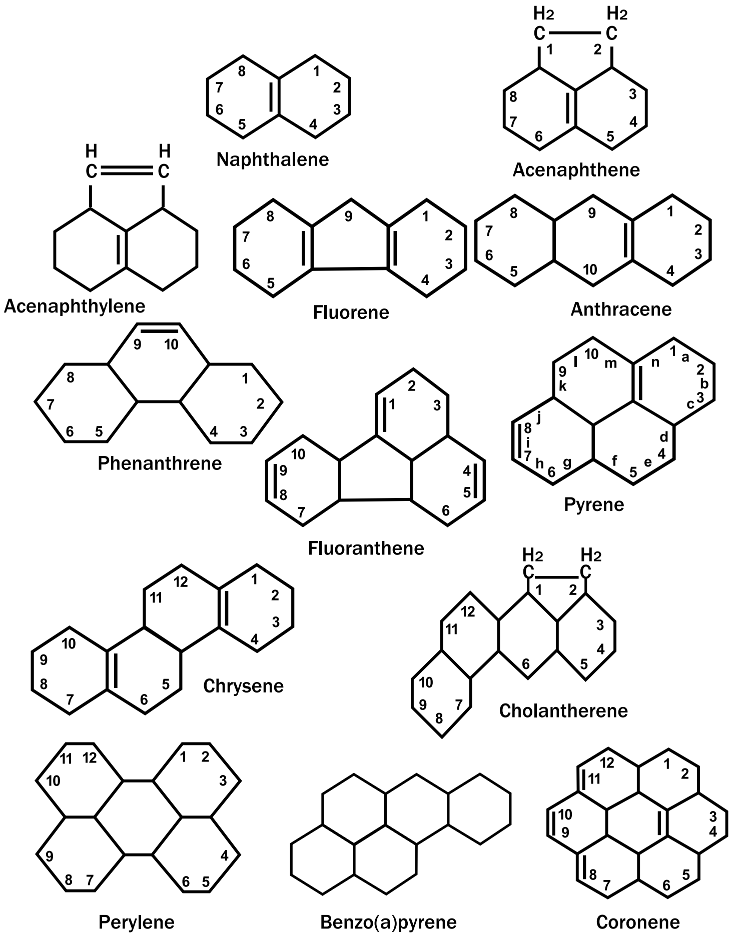
The only other hydrocarbon compounds in the starting database were the following five chlorinated hydrocarbons, all of which are common air pollutants: alkyl chloride, chloromethane, chloroform, methylene chloride and tetrachloroethylene. Almost all of the chlorinated hydrocarbon values had been derived from plume concentrations that were equivalent to normal ambient levels and the magnitude of the values were on the order of 1E-05 kg analyte/ kg NEQ. In addition, none of these compounds was found in more than four plumes and in some cases, the EM did not contain chloride. Therefore, it was decided to exclude the chlorinated hydrocarbon compounds from the UNDP - EDB.

3.3.9 Semi-Volatile Organic and Polycyclic Aromatic Hydrocarbons (PAHs)

The starting database contained EF and EFF values for four PAHs (benzo(a)pyrene, benz(a)anthracene, dibenzofuran and naphthalene) and two semi-volatile organic compounds (dimethylphthalate and diethylphthalate). Approximately 25% of the naphthalene EF and EFF values were 10 to 100 times above normal ambient air concentrations and the remainder had been produced by substituting a value equal to 1/2MDL for the zero or ND value originally reported. This replacement by CCS was justified on the basis that naphthalene was a possible PAH emission product. For example, as noted earlier, the aromatic compounds are formed from CxHy- radicals colliding and it is easy to visualize how the radicals could collide with benzene to produce naphthalene, the structure of which is shown in Figure 1.

Figure 1.

Structures of Selected PAH's



None of the other three PAH compounds had been detected in the emissions from more than three energetic materials. CCS had entered numerical values only for the energetic materials in whose plumes the compound had been detected. For the remaining energetic materials, they had entered a letter code indicating that the compound had not been detected and was not considered a possible emission product. CCS made this decision based on the following rationale. These three PAH compounds were not detected in any of the plumes from the two, 3000-kg propellant waste materials which were open burned in pans on the test range at DPG where the MDL value of the PAH measurement system was over 1000 times lower than for the Bang Box tests. They also were not found in the ash and the sputter from the burns. Further, because these compounds would be formed from collisions between CxHy hydrocarbon radicals, the complexity of their structures (Figure 1), the electron pi clouds above or below the molecule and the rapid dilution that occurs in OB and OD plumes would prevent PAHs containing more than two rings from forming in the plumes.

The two phthalate compounds were detected in the detonation plumes from three energetic materials at concentrations above normal air concentrations. CCS included these numerical values in the database, but decided not to replace the ND values for the other energetic materials with a value equal to 1/2MDL because they believed that the phthalate emission products were actually caused by sample contamination [16]. Their rationale for suspecting sample contamination was as follows. First, phthalate compounds were not present in the three EM materials in whose plumes they were detected. Second, all three energetic materials were characterised during the same week and phthalates were frequently detected in laboratory and field blanks across all of the emissions characterisation studies. (Phthalates have been used in a large number of commercial products for years and they are indigenous in the environment.) Third, the phthalates were not detected in any of the plumes or the ash produced when 3,000-kg quantities of two propellants containing phthalates were open burned at DPG in 1990 in a situation where the measurement system had a MDL at least 100 times lower than the one which detected the phthalates. Fourth, when the phthalates were detected in the plume samples, the concentrations were 10 to 50 times greater than the concentrations of the aromatic compounds, which was contrary to detonation theory and chemical kinetic reaction pathways. (The phthalates, which are structurally more complicated than the aromatic compounds, are formed from the same molecular fragments as the aromatic compounds. Thus, if they had been produced by the decomposition of the energetic materials, they should have been found at concentrations lower than the aromatic compounds.)

Based on the above considerations, it seemed reasonable to assume that naphthalene and some of the alkyl naphthalenes would be the only PAH compounds likely to be generated during OB and OD events. Because 75% of the naphthalene values were 1/2MDL values and because the MDL value for the PAH measurement system was 100 times higher than that for benzene, it seemed likely that the naphthalene EFF and EF values were biased high. It was therefore decided to use naphthalene as a surrogate for all of the double ring PAH compounds and to enter the naphthalene EFF values (kg naphthalene /kg C) in the UNDP - EDB under the heading APAHs (As Naphthalene Equivalent Mass).

3.3.10 Energetic compounds

The expanded CCS database contained EF and EFF values for the following energetic materials: TNT, RDX, HMX, PETN, 2,4-dinitrotoluene, 2,6-dinitrotoluene, diphenylamine, trinitrophenol (Explosive D), ammonium perchlorate (AP), nitroglycerin (NG) and nitroguanidine (NQ). (Although nitrocellulose was a constituent of many of the energetic materials, it cannot be measured in air at the concentrations that it would likely be present in the plume, so no attempt was made to measure it.) Because the biological activity and rate of degradation and transport through the environment varies among the energetic compounds, some of them are of more concern than others to the environmental community. Therefore, the 65 EFF values (e.g., kg TNT/ kg TNT detonated) were entered into the UNDP - EDB. However, it should be noted that 38 of these values had been derived using 1/2 MDL values, and for a number of reasons, the estimates are probably biased high.

3.3.11 Dioxin and Furan compounds

The full database contained 21 polychlorinated dioxin and furan compounds (PCDD/PCDF) covering 13 Energetic

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[16] Procedures Used in Developing and Validating the Open Detonation - Chemical Release Database (OD - CRD), report prepared for the US Army by Chemical Compliance Systems, November 2003

materials, but all of the values were either 0.0E+00 or a letter code. The letter code indicated that no attempt had been made to measure the PCDD/PCDF content of the plume for that EM and the 0.0E+00 values indicated that, if these compounds were present in the plume, they were present at concentrations below the minimum detection limit (MDL) of the sampling procedure. (Measuring dioxins and furans in air costs $3,000 to $6,000 per sample, so sampling for these compounds was done only when the EM treated contained both chlorine and plastics, two of the essential substances required for these compounds to form.) Since PCDDs and PCDFs were not in the energetic materials detonated and burned, the database contained only EF values. Because 0.0E+00 is not a very informative value and in consideration of the concerns of the international community about the effects of PCDD and PCDF compounds on HH&E, it was prudent to place more definitive information on these compounds in the UNDP - EDB. Therefore, it was decided to use the most toxic of these compounds (2, 3, 7, 8-tetrachlordioxin, TCDD) as a surrogate for all of the PCDD/PCDF compounds and to enter a value equal to 2 of the MDL (i.e., 2E-12 kg (As TEQ) / kg NEQ) in the UNDP - EDB for each EM where an attempt had been made to measure these compounds.

3.3.12 Particulate matter

The full database contained 45 EF values for particulate matter, but no EFF values. Some of the EF values were designated as Total PM, others as PM-10 and the remainder as PM-2.5, the latter designations signifying that the PM value represents a subset of the PM found in the plumes. That is, PM-10 indicates that particles having aerodynamic diameters greater than 10 microns were deliberately not collected and PM-2.5 indicates that particles having aerodynamic diameters greater than 2.5 microns were not collected. The PM-2.5 values had been determined from open detonating 900kg quantities of explosives at ground level and open burning 1,900 to 3,200-kg quantities (in steel pans) at DPG, UT(9) and the remaining PM values had been determined in a detonation chamber with a concrete floors. The PM-2.5 OD values were all noticeably larger than the other OD PM values, which would expected since they were produced by detonating the EM on the open range. The OB PM-2.5 values were slightly smaller than the PM and PM-10 values, but this would also be expected since PM-2.5 is a subset of the PM-10 and the burns had been conducted in steel pans (which minimized the entrainment of soil particles into the plumes. Since particles in the PM-2.5 aerodynamic size range are of higher regulatory concern than those in the PM-10 size range and the percentage of PM-2.5 particles transported off-site would be greater than that for PM-10 particles, the PM-2.5 values were placed in the UNDP-EDB.

3.3.13 Metals

The starting database contained numerical EF and EFF values for aluminium, barium, chromium, copper, iron, lead, manganese, and zinc and letter codes for cobalt. There were no values for arsenic, mercury or beryllium because these metals are present in only a few Energetic materials and when present are in quantities to small to measure. For example, the CCS documentation noted that a search of the Army Munitions Inventory Disposal Action System (MIDAS), which contained the chemical composition of 6,500 Energetic materials, did not find any EM containing mercury or arsenic and found only five Energetic materials containing beryllium. Further, the beryllium was present in these five Energetic materials as a copper alloy (1.9% Be) and the total mass was less than 5 milligrams.

It is well documented that the actual location of the metal in an EM detonated or burned plays an important in role in determining the quantity of the metal that is released into the plume, (see many of the previous footnote references). For example, a greater percentage of the metal is released into a detonation plume when the metal is an integral part of the energetic compound than when the same metal is contained in the casing of a projectile. However, the 45 EF values in the starting database did not identify the matrix from which a metal emission product was released into the plume. Because of the importance of the matrix on the emission rate, it was decided to enter each EFF into the UNDP - EDB in one of the following three categories (matrices); 1) casings, rotating bands and interior metal components; 2) paints, platings and other protective coatings; and 3) energetic. This was accomplished using information in the CCS documentation, the original test reports, the EPA report and the US Army Munitions Inventory Disposal Action System (MIDAS) database. The underlying premise was that each EFF represented a credible estimate of the percentage of the metal in that matrix that would be released into the plume. Thus, a robust estimate for each matrix (casing, coatings, energetic) could be derived using the EFF values within each category.

3.4 Contents of the final UNDP - OB/OD Emissions Database

The OB portion of the UNDP - EDB, which resulted from this study is presented in Annex B and the OD portion is presented in Annex C. These annexes also identify the type of EM treated and the masses of the major constituents and chemicals of concern in each EM to the extent this is known. A more detailed description of each EM and the test conditions under which its emissions were characterised can be found in Annexes D (OB) and E (OD). Annex F describes the sampling and analysis methods used in all of the emissions characterisation studies.

3.5 Selection of EFF and EF values for estimating air emissions from OB and OD events

There are no absolute rules concerning how to apply emissions data in EIAs and HRAs, except that using an individual test report rather than mean or median value is strongly discouraged [17]. The mean value or a multiple of the mean is usually selected when it has been derived using seven or more individual test results and the median value is usually selected when the mean has been derived using six or less values. The decision on whether to use the mean or a multiple of the mean is made based on the following considerations: the agreement between the mean and the median values, the number of values in the data set derived using MDL values, and the difference between the highest and lowest values in the data set in relation to the mean value. When the mean has been derived using less than seven test results, the median value is usually used because it is much less sensitive than the mean to the distribution of the individual values. Thus, the median is more likely to provide a better representation of the centre of the, (statistical distribution), of the data set [18].

So, which value should be selected for each emission product / emission product category? Tables 2 and 3 present the relevant summary statistics for the OB and OD portions of the UNDP - EDB, respectively. Table 4 identifies the specific EF and EFF values the study recommends for generating emission estimates for use in EIAs and HRAs.

These recommendations are based on the following assumptions and considerations.

3.5.1 CO and CO_2

The means are recommended for estimating the carbon oxide emissions from OB and OD activities because of the large number of values comprising the mean, none of which were derived using MDL values.

3.5.2 NOx (as NO_2 equivalent)

The mean value is recommended for estimating the NOx emissions from OB and OD activities for the same reasons mentioned for the carbon oxides. That is, the data sets are large and no MDL values are included in the means.

3.5.3 SO_2

The mean values should be used for estimating the SO_2 emissions from OB and OD activities. Since the mean for the OB portion of the UNDP - EDB was derived from nine values, its selection is rather obvious. Although the SO_2 mean for the OD portion was derived from only five values, it agrees very closely to the median value and this difference between the highest and lowest values in the data set is small relative to the mean.

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[17] *Procedures for Preparing Emissions Factor Documents,* US Environmental Protection Agency, Office of Air Quality Planning and Standards, Durham, NC. EPA Report - EPA 454/R-95-015 (Revised), September 1997.

[18] J K Taylor, *Statistical Techniques for Data Analysis.* pp 23-28, Lewis Publishers Inc., Boca Raton, FL. 1990.

3.5.4 Chlorides (as HCl)

Because of the small size of the data set, the median HCl values should be used for estimating the Cl emissions from OB and OD activities.

Table 2: Summary statistics for Open Burn portion of the UNDP - EDB

Emission Product	Reporting Units	N	N = 1/ 2MDL	Maximum	Minimum	Mean	Median
Particulate Matter (PM)	kg PM /kg NEQ	5	0	2.0E-02	6.9E-03	1.3E-02	1.1E-02
SO_2	kg SO_2 / kg NEQ	5	0	3.2E-03	1.2E-04	1.2E-03	1.1E-03
Energetic	kg Energetic X / kg Energetic X in EM	17	11	1.5E-05	6.9E-10	1.4E-06	3.4E-08
Metals- Casings	kg Metal X /kg Metal X in EM	0	0	NA	NA	NA	NA
Metals-Coatings	kg Metal-X /kg Metal-X in EM	0	0	NA	NA	NA	NA
Metals-Energetic	kg Metal-X/kg Metal-X in EM	6	0	1.4E+00	5.4E-02	4.9E-01	3.1E-01
CO	kg CO/ kg C in EM	17	0	4.1E-02	1.5E-04	7.4E-03	3.4E-03
NOx (as NO_2)	kg NO2 / kg N in EM	15	0	2.6E-01	6.3E-03	6.2E-02	3.2E-02
Chloride (As HCl)	kg HCl / kg Cl in EM	2	0	9.6E-01	8.8E-01	9.2E-01	9.2E-01
Aromatics (As Benzene)	kg Benzene / kg C in EM	15	0	5.3E-04	1.4E-06	6.1E-05	1.2E-05
Saturated HC (As Ethane)	kg Ethane / kg C in EM	12	0	1.6E-04	1.1E-06	1.9E-05	2.2E-06
Unsaturated HC (As Ethylene)	kg Ethylene / kg C in EM	12	0	3.2E-03	1.4E-06	3.8E-04	4.6E-05
Methane	kg Methane / kg C in EM	5	0	2.3E-02	1.5E-04	5.5E-03	5.5E-04
PAHs (As Naphthalene)	kg Naphthalene / kg C in EM	17	12	8.9E-06	3.0E-09	2.7E-06	2.4E-06
PCDD/PCDF (As TEQ)	kg TEQ / kg NEQ	4	4	2E-12	2E-12	2E-12	2E-12

Table 3: Summary statistics for Open Detonation portion of UNDP - EDB.

Emission Product	Units (mass in plume / mass Treated	N	N = 1/ 2MDL	Maximum	Minimum	Mean	Median
Particulate matter (PM)	kg PM /kg NEQ	4	0	1.1E+01	7.2E+00	9.2E+00	9.3E+00
SO_2	kg SO_2 / kg NEQ	9	0	1.4E-03	1.3E-04	5.0E-04	4.0E-04
Energetic	kg Energetic X/kg Energetic X in EM	49	25	3.5E-03	3.0E-10	2.8E-04	1.5E-06
Metals- Casings	kg Metal X /kg Metal X in EM	15	2	3.0E-02	2.6E-05	1.1E-02	6.9E-03
Metals -Coatings	kg Metal X/kg Metal X in EM	6	0	9.1E-01	1.6E-02	2.4E-01	1.0E-01
Metals -Energetic	kg Metal X/kg Metal X in EM	18	8	1.1E+00	8.1E-04	1.1E-01	4.9E-02
CO	kg CO/ kg C in EM	27	0	2.1E-01	8.5E-03	7.4E-02	4.5E-02
NOx (as NO_2)	kg NO2 / kg N in EM	23	0	3.2E-01	3.5E-05	4.8E-02	3.3E-02
Cl (as HCl)	kg HCl / kg Cl in EM	2	0	1.3E-01	1.2E-01	1.2E-01	1.2E-01
Aromatics (as Benzene)	kg Benzene / kg C in EM	27	0	2.7E-03	9.8E-06	3.1E-04	1.7EB04
Saturated HC (As Ethane)	kg Ethane / kg C in EM	21	0	1.1E-01	8.1E-07	1.5E-02	8.4E-03

Emission Product	Units (mass in plume / mass Treated	N	N = 1/ 2MDL	Maximum	Minimum	Mean	Median
Unsaturated HC (As Ethylene)	kg Ethylene / kg C in EM	23	0	1.0E-02	4.8E-05	1.4E-03	7.5E-04
Methane	kg Methane / kg C in EM	5	0	2.6E-02	3.1E-05	6.8E-03	2.3E-03
SVOCs (as Naphthalene)	kg Naphthalene / kg C in EM	28	22	8.3E-05	1.4E-08	2.0E-05	2.0E-05
PCDD/PCDF (as TEQ)	kg TEQ / kg NEQ	9	9	2.0E-12	2.0E-12	2.0E-12	2.0E-12

3.5.5 Particulate matter

Although the mean and median values agree very well, because of the small number of energetic materials used in calculating the mean, the median values are recommended for estimating the particulate matter (PM) emissions from OB and OD activities. Despite the large differences in the composition of the energetic materials burned, the mean and median PM values agree very well which is consistent with detonation theory and the fact that the energetic materials were burned in steel pans. On the other hand, at first glance, the close agreement between the OD mean and median values and the small difference between the maximum and minimum values seems unusual considering the differences in the average crater volumes produced by the four energetic materials. These average volumes were: TNT (20m^3), Comp B (26m^3), RDX (27m^3) and Explosive D (45m^3). Based on these volumes one might have expected that the Explosive D mean value would have been considerably larger than the others. However, based on detonation theory and the dynamics within detonation plumes, the agreement is not unexpected and supports the soundness of the OD EF values. That is, detonation theory predicts that the soil entrained in the plume would consist predominately of large particles and these particles would settle out of the plume fairly quickly thereby producing a plume containing mostly particles having small aerodynamic diameters.

Table 4: Recommended EF and EFF values for use in EIAs and HRAs

Emission Product	EF/EFF Units	OB	OD
Particulate matter (PM)	kg PM / kg NEQ	1.1E-02	9.3E+00
SO_2	kg SO_2 / kg NEQ	1.2E-03	5.0E-04
Energetics	kg Energetic X/kg Energetic X in EM	1.4E-06	2.8E-04
Metals- Casings	kg Metal X /kg Metal X in EM	1.1E-02 1	1.1E-02
Metals -Coatings	kg Metal X /kg Metal X in EM	1.0E-01 1	1.0E-01
Metals -Energetics	kg Metal X /kg Metal X in EM	3.1E-01	1.1E-01
CO	kg CO/ kg C in EM	7.4E-03	7.4E-02
NOx (as NO_2)	kg NO_2 / kg N in EM	6.2E-02	4.8E-02
Chloride (As HCl)	kg HCl / kg Cl in EM	9.2E-01	1.2E-01
Aromatics (As Benzene)	kg Benzene / kg C in EM	6.1E-05	3.1E-04
Saturated HC (As Ethane)	kg Ethane / kg C in EM	1.9E-05	1.5E-02
Unsaturated HC (As Ethylene)	kg Ethylene / kg C in EM	3.8E-04	1.4E-03
Methane	kg Methane / kg C in EM	5.5E-04	2.3E-03
PAHs (as Naphthalene)	kg Naphthalene / kg C in EM	2.7E-06	2.0E-5
PCDD/PCDF (as TEQ)	kg TEQ / kg NEQ	2.0E-12	2.0E-12

Note: 1. No emissions data available, OD value used as default.

3.5.6 Energetics

Because of the large number of values used to calculate them, the means would normally be selected for estimating the energetic compound emissions from OB and OD activities. However, the large differences between the mean and median values, the magnitude of the differences between the mean and the maximum and minimum values, and the large number of MDL-derived values comprising each mean caution against its selection. In fact, based on the points presented below, both means are probably biased high and a value halfway between the median and mean values might be more appropriate value for estimating the emissions from normal OB and OD activities.

The OB mean for energetics likely over estimates the mass of energetic that is entrained in the plume for the following reasons. Eleven of the 17 values are derived from MDL values, so the energetic compounds were not measured in the plumes of 11 of the 17 energetic materials characterised. In addition, 25% of the MDL values are from the Bang Box tests where the MDL for the measurement system was approximately 100 times larger than that of the method used in the DPG field tests. Further, the analysis of the ash and the splutter from the DPG burns detected only milligram quantities of the energetic and this was only for two of the five energetic materials open burned, which again indicates the efficiency of OB in destroying the energetic. Based on these considerations, one could argue that the much smaller median value would be a better estimate to use for real world OB processes. On the other hand, only bulk propellants and propellant wastes were used in the characterisation tests where an attempt was made to characterise the energetic content of the plumes. If one were attempting to burn small ammunition, it is possible that the percent of the energetic destroyed might be lower.

The OD energetic mean value also likely overestimates the mass of the energetic that is entrained in the plume for the same reasons given for the OB mean. For example, 22 of the 23 MDL - derived values used in calculating the mean came from the Bang Box where the MDL of the measurement system was 100 times larger than that used in the DPG field tests. In addition, the highest values were derived in the Bang Box tests where the ratio of donor mass to EM mass was 3 to 5 times higher than would normally be used for real world detonations and the majority of the high values produced in the Bang Box are associated with the donor material (PETN/RDX). (This high donor to EM ratio was required because of the restrictions on the total mass of energetic which could be detonated in the Bang Box.)

Unfortunately, there are no computational or statistical methods suitable for adjusting the energetic EFF values for the effect of these factors. Therefore, the simplest way to correct compensate would be to use a value halfway between the mean and the median values for estimating the energetic compound emissions from OB and OD activities and this is our recommendation.

3.5.7 Aromatics (as benzene equivalent)

Based on the large number of measured values used, the means are recommended for estimating the aromatic emissions from OB and OD activities. These means likely provide an excellent representation for the single ring compounds emitted by OB and OD processes. (NOTE – the small size of the EFF values shows that the benzene emissions from OB and OD events would never exceed the EU ambient air quality standard 5 ug benzene per cubic metre.)

3.5.8 PAHs

Because of the large number of values used to calculate the means for the OB and OD portions of the UNDP - EDB, the mean values would normally be selected for estimating the PAH emissions from OB and OD activities. However, the means are likely biased high for many of the same reasons discussed above for the energetics. First, a substantial percentage of the values used were derived from MDL values. Second, most of these MDL values are attributable to the Bang Box where the PAH measurement system had a MDL value much higher (e.g.: less sensitive) than that used for the DPG field tests. Third, the mean values for single-ring aromatic compounds are only four times larger than those for the PAH compounds whereas, based on detonation theory and other considerations, the difference should have been much greater. Therefore, the study recommends using the median value for estimating the emissions from OB and OD activities.

3.5.9 PCDD/PCDF (as TEQ)

As noted earlier, the 21 dioxin and furan target analytes were not detected in the 37 plumes (covering 13 energetic materials) analysed for these compounds even though the method had an extremely low MDL (4E-12) and the proper mix of reactant substances (chlorides, and plastics or other large carbon-containing molecules) was present in the energetic materials. The results are consistent with detonation theory, so common sense would suggest deleting the PCDD/PCDF values from the UNDP - EDB. Unfortunately, because of the concerns of the environmental community about these compounds, deletion is not practical at this time. Therefore, it our recommendation that the PCDD/PCDF mean EF value be applied only in situations where the EM being treated contains the substances required to form these compounds.

3.5.10 Metals in casings

Based on the large number of values comprising the OD mean, the mean is recommended for estimating the metals from casings, rotating bands, interior metal components and similar materials for OD activities. Since there are no data available for OB events, the OD mean should also be used for OB events, but caution should be exercised.

3.5.11 Metals in energetics

Based on the number of values comprising the means, the means are recommended for estimating the emissions from OB and OD activities. However, because of the large number of MDL values used to calculate the OB mean and the contamination of the detonation plumes by metals from the concrete floor of the Bang Box and the high donor-to-EM ratios used in the Bang Box detonations, the means likely overestimate the percentage of the metal released into the plume.

3.5.12 Metals in coatings

Because of the small number of values used in calculating the OD man, the median value is recommended for estimating the percentages of the metals in coatings and plated surfaces released into the plume. Although there are no data available for OB events, because of the similarities (at the molecular level) between OB and OD events, the median OD value should apply to OB events.

3.6 Some Examples of the Information Provided by EFF Values

Because the EFF term relates the mass of the emission product to the mass of a substance in the EM, it allows one to quickly estimate the percentage of a substance in the EM that will be released into the plume when the EM is detonated or open burned. It also allows one to do a quick reality test on the emissions data, for example if the EFF value indicates that 500% of the Pb in an EM was released into the plume, the EFF value is suspect and the original test report needs to be inspected to determine the cause for the obviously anomalous value.

Here are some examples of the types of information that can be obtained from the EFF values in Table 4.

- Detonation theory predicts that in a high order detonation about 98% of the carbon in the EM should be converted to CO_2, CO and CH_4 which is the case for the OB and OD portions of the UNDP - EDB. That is, the percentages of the original represented by these three species 98.3%, 0.3% and 0.5%, respectively for the OB portion of the database and 96.7%, 3.1% and 0.5%, respectively for the OD portion. This finding implies that the EFF values reflect real-world situations.

- Detonation theory predicts that the essentially all of the nitrogen in the energetic should be converted to N_2 with only a small percent converted to the nitrogen oxides which is indeed the case for both the OB and OD portions of the UNDP - EDB. That is, the percent of the nitrogen in the energetic compound(s) represented by the NOx EFF values are 1.5% and 1.9% for the OD and OB portions of the database, respectively.

- The median value for the OB portion of the UNDP - EDB is probably fairly accurate because it accounts for 90% of the original chloride. On the other hand, although the OD median accounts for only 12% of the Cl, the EFF values for the two Energetic materials detonated are similar. The difference in the percentage of the chloride found in OB and OD plumes is probably attributable to reaction of the HCl with the particles (from the concrete floor of the detonation chamber) in the detonation plume. However, the OD EFF value obviously should be used with caution until the reasons for the low recovery are determined.

- The OD EFF value for metals-in-casings indicates that approximately 1.1% of the metal in the casing and interior metal components of an EM will be released into the plume when the EM is detonated. (Similar data is not yet available for OB.)

- The OD EFF value for metals-in-coatings indicate that approximately 11% of the metal in coatings will be released into the plume when an EM is detonated. (Similar data is not yet available for OB.)

- The EFFs values indicate that when metal-containing energetic compounds are open burned, approximately 31% of the metal will end up in the plume and when these compounds are detonated, approximately 11% of the metal will end up in the plume.

- A comparison of the EFF values for the carbon-containing emission products supports the concept that CxHy- molecular fragments are the source of the saturated, unsaturated, aromatic and polycyclic aromatic hydrocarbon compounds. For example, in the detonation data, the relative concentrations of the hydrocarbons decrease by a factor of ten as you move from the structurally smallest and simplest group (saturated hydrocarbons) to the largest, most structurally complex group, i.e., PAHs. These results are consistent with detonation theory. They could also help the general public understand why three-ring and larger PAH compounds and dioxin and furan compounds are not produced when OB and OD events are conducted properly.

3.7 Using EFF and EF Values for Predicting Air Emissions from OB and OD Events

Using the EFF and EF values in Table 4 for predicting OB and OD emissions is a straightforward, easily understood process, as shown by the following example – detonation of 100, 81mm HE M374A2 mortars (fuze removed) using a 20-kg TNT donor charge. First, the chemical composition of the mortar was obtained from the US Army's - Army Munitions Inventory Disposal Action System (MIDAS) database. The MIDAS search determined that this mortar has a steel body, an aluminium tail fin and a number of internal components comprised of a copper–aluminium-zinc alloy. Approximately 0.95 kg of its 4.0 kg weight is comprised of NC, NG and cast Composition B (39% TNT, 60% RDX, and 1% wax). This information was used to calculate the total kgs of C, N, and each metal and energetic compound that would be present when these mortars were detonated using a 20-kg TNT donor charge. The resulting values (presented in the Footnote and in Column 2 of Table 5) were then multiplied by the appropriate EFF/EF factor (Column 3 in Table 5) to produce estimates for each emission product or emission product category (Column 4 of Table 5). (The calculations from Chlorides (As HCl) and TEQ (dioxin and furans) were not done because the mortars and donor charge did not contain chlorine.)

Although a U.S. Army mortar round was used in this example, the approach would be the same for any other munition. Because of the statistical robustness of the EF and EFF values, it should be possible to obtain an average chemical composition for all similar munitions of the same size and explosive configuration, for example, all 80/81mm HE mortars. In addition, in most cases, when the chemical composition data is not available for a munition in the SEE stockpiles, it should be possible to use the composition of a similar item in the class (even if its from another country) as a surrogate source for the missing compositional data without severely compromising the emission estimates.

Table 5. Using EF /EFF values to estimate emissions from detonating 100 x 81mm Mortar Bombs HE

Input Parameter / Emission Product	kg Detonated	EF / EFF Value	kg Released Into Plume
PM	-	9.3 kg / kg NEQ	1073.00000 kg
SO_2	-	5.0E-04 kg / kg NEQ	0.05800 kg
CO	-	7.4E-02 kg / kg C	2.50000 kg
NOx	-	4.8E-02 kg / kg N	1.60000 kg
Aromatics (As Benzene)	-	3.1E-04 kg / kg C	0.01000 kg
Saturated HC (As Ethane)	-	1.5E-02 kg / kg C	0.50000 kg
Unsaturated HC (As Ethylene)	-	1.4E-03 kg / kg C	0.04600 kg
PAHs (As Naphthalene)	-	2.0E-05 kg / kg C	0.00007 kg
METALS IN CASINGS			
Iron (Fe)	225.0 kg	1.0E-02 kg / kg	2.250 kg
Manganese (Mn)	4.0 kg	1.0E-02 kg / kg	0.040 kg
Aluminium (Al)	80.1 kg	1.0E-02 kg / kg	0.800 kg
Zinc (Zn)	1.2 kg	1.0E-02 kg / kg	0.012 kg
Copper (Cu)	3.6 kg	1.0E-02 kg / kg	0.036 kg
METALS IN COATINGS			
Zinc (Zn)	1.200 kg	1.1E-01 kg / kg	0.13000 kg
Cadmium (Cd)	0.012 kg	1.1E-01 kg / kg	0.00130 kg
Chromium (Cr)	0.006 kg	1.1E-01 kg / kg	0.00066 kg
METALS IN ENERGETICS			
Lead (Pb)	0.0010 kg	1.1E-01 kg / kg	0.00011 kg
ENERGETICS			
RDX	57.0 kg	2.8E-04 kg / kg	0.0160 kg
TNT	57.0 kg	2.8E-04 kg / kg	0.0160 kg
Nitrocellulose (NC)	6.0 kg	2.8E-04 kg / kg	0.0017 kg
Nitroglycerin (NG)	4.1 kg	2.8E-04 kg / kg	0.0011 kg

Note: For 100 x 81mm Mortar Bombs HE the NEQ = 115.4 kg, Total Carbon = 33.4 kg and Total Nitrogen = 33.7 kg.

4 Comparison of the emissions from OB and OD to EU and North American emission limits

The contract specified that at the completion of the UNDP- EDB, the database was to be used to compare the emissions from OB and OD processes to the most stringent emissions limits in Europe and North America applicable to the alternative technologies (to OB and OD). Consequently, the environmental regulations of the EU, its member countries, the UK, Canada and USA were examined to identify the emissions limits that should be used for the comparison. This review determined that a combination of the emissions limits for new sources specified in EU Directive 2000/76/EC on waste incineration [19] and the U.S. Standards for Hazardous Waste Incinerators [20] would be the most appropriate emissions limits for the comparison.

Directive 2000/76/EC, which became effective for new sources on December 28, 2002, has been accepted and implemented by Canada, the UK and the Members of the European Community. It places stringent operating conditions and emission limits (Table 6) on virtually all waste incineration processes, including processes that incinerate their off-gases. It replaces Directive 89/429/EC (Reduction of Air Pollution From Existing Municipal Waste Incinerators), Directive 89/369/EEC (Reduction of Air Pollution From New Municipal Waste Incinerators) and Directive 96/67/EC (Reduction of Air Pollution From Hazardous Waste Incinerators).

Table 6: EU and US Regulations for Hazardous Waste Incinerators

Emission Product or other Measure of Performance	EU / Canada Directive 2000/76/EC [1]	USA 40CFR63 [2]
% DRE	None	99.99%
Total PM	10 mg/m^3	34.0 mg/m^3
SO_2 (including SO_3)	50 mg/m^3	None
HCl	10 mg/m^3	31.3 mg/m^3
NOx (as NO_2 Equivalent)	400 mg/m^3	NA
CO	50 mg/m^3	115.0 mg/m^3
Dioxin/Furan as TEQ [3]	<0.1 ng/m^3	0.20 ng/m^3
Total Toxic Metals, as Metal (Sb, As, Co, Pb, Cu, Mn, Cr, V, Ni)	0.5 mg/m^3	None
Cd + Tl	50 ug/m^3	None
Hg (as metal)	50 ug/m^3	45 ug/m^3
LVM (As, Be, Cr)	None	97 ug/m^3
SVM (Pb, Cd)	None	120 ug/m^3

Note: 1. All limits are for reference conditions of one atmosphere and 7% O_2, except PM which is corrected to 11% O_2.

Note: 2. All limits are for reference conditions of one atmosphere and 7% O_2.

Note: 3. TEQ = Sum of all dioxin and furan compounds after conversion to their toxicity relative to TCDD, which is assigned a toxicity equal to 1.00. The next most toxic PCDD/PCDF has a toxicity value of 0.1.

The USA emission limits for hazardous waste incinerators (Table 6) are similar to the EU limits in many ways, but there are some meaningful differences. First, the USA emission limits specify that the incinerator must destroy at least 99.99% of the hazardous waste entering the kiln, whereas, the EU Directive has no such requirement. Second, although both place the heavy metals into three categories, the metals in the three categories differ.

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[19] *Directive 2000/76/EC of the European Parliament and of the Council on the Incineration of Hazardous Wastes,* Official Journal of the European Communities.

[20] Title 40, Code of Federal Regulations, Part 63, *Interim Standards for Hazardous Air Pollutants from Hazardous Waste Combustors,* February 13, 2002.

That is, the USA placed the metals into their three categories based on the vapour pressures (volatility) of the metal, whereas, the EU seems to have used other factors besides vapour pressure. Third, the EU specifies limits for NOx and SO_2 whereas, but the USA does not.

The emission limits selected for the comparison were adjusted to the equivalent concentration in air by multiplying the emission limit by the %O2 (7% or 11%) specified in the regulation and dividing the resulting value by 21%. These adjusted limits are shown in Column 3 in Tables 7 and 8.

For the following reasons, it was not possible to conduct a straightforward comparison.

- EWIs operate continuously, whereas, OB and OD are intermittent processes.
- EWIs have limits on the quantity of each energetic that it can process over a specified period of time, whereas OB and OD do not.
- EWI plumes disperse close to the ground, whereas, OB and OD plumes rise rapidly and disperse hundreds of metres above ground.
- The OB and OD EF and EFF values predict the mass of each emission product released into the plume in relation to the mass detonated or burned, whereas, the EWI emission limits are based on the concentration of the emission product in the plume.

Obviously, for the comparison to be realistic, it had to be designed and conducted in a manner that compensated for these differences. The compensation needs were met in the following manner.

- Copies of recent EWI emissions test reports were obtained to establish the maximum feed rate and stack gas flow at which EWIs can process energetic materials similar to those of concern to SEESAC (Annex G). Based on this search, the Trial Burn May 2001 test results for the APE-1236 EWI at Tooele UT were selected as the source of the energetic materials, EM feed rate and the stack volumetric flow rate to be used in the comparison [21]. The energetic materials were a cast double-base propellant waste (M-9) and the 20mm API MK-107 cartridge. (The 20mm cartridge was selected because its composition is similar to the 20mm cartridges in the stockpiles in SEE. Attempts to find EWI data and compositional data on detailed energetic materials in the stockpiles in SEE were unsuccessful.) The test report noted that the maximum feed rate of the Tooele EWI was 47 kg of M-9 per hour and 576 x 20mm cartridges per hour and that the average stack gas volumetric flow rate was 5,000 dry standard cubic metres per minute (dscm). These values were selected for the comparison.
- An 8-hour time period was selected for the comparison and the total kg of M-9 propellant and 20mm cartridges that could have been processed by the EWI in that time period was calculated.
- The US Army Munitions Inventory Disposal Action System (MIDAS) was consulted to obtain detailed information on the identities, masses and locations of the energetics and metals in the propellant and cartridge. This information was then used to calculate the total kgs of carbon, nitrogen and chloride and each metal (by matrix) and energetic compound that would have been fed into the EWI over the 8-hr period.
- These totals were then used along with the volumetric flow rate (5,000 dscm) and the emission limits (Column 3 in Tables 7 and 8) to estimate the quantity of each emission product that would have been emitted over an 8-hr period if the EWI's emissions were just below the emission limits (Column 4, Tables 7 and 8).
- The totals calculated in step three above were multiplied by the appropriate EF/EFF values (from Table 4) to estimate the quantity of each emission product /emission product category that would be released into the air (plume) when the M-9 and 20mm cartridges were open burned and open detonated (Columns 5 and 6 in Tables 7 and 8, respectively).

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[21] *Final Report, Air Pollution Management Study No- 43-EL-1476-01, APE 1236 Deactivation Furnace Metals Test, Building 1320, Tooele Army Depot, UT.* Prepared by the US Army Center for Health Promotion and Prevention, Aberdeen Proving Ground, MD. August 2001.

Note: NOTE: An amount of TNT equal to the NEQ of the cartridges (242 kg) was used as the donor material for the cartridge detonation and a 10kg TNT donor charge was used for the detonation of the M-9 propellant. The emissions that would have been produced by these donor charges have been included in Tables 7 and 8.)

The results presented in Tables 7 and 8 demonstrate pretty convincingly that OB and OD can be acceptable for destroying some of the EM in the stockpiles in SEE. For many of the emission products, the quantity emitted is considerably below the amount that the EWI would be permitted to emit. In fact, the PM emissions from the detonations are the only ones that noticeably exceed the corresponding emissions from the EWI.

However, there are some caveats and cautions associated with the results of this comparison that need to be discussed.

- EWI emissions occur from stacks located within a 100 metres of the ground, and they dilute slowly through simple dispersion pathways. On the other hand, OB and OD plumes rise hundreds of metres above ground and undergo massive dilution before any of the plume constituents (other than large soil particles) return to the ground. The only way to fully compare OB and OD emissions to those from EWI's and other alternative technologies is to input the emission estimates for each demilitarization process into a credible plume dispersion and deposition model, such as ADORA, OBODM or the one being developed and calibrated in Project CP-1159 of the Strategic Environmental Research and Development Program of the DOD.

- While the energetics and other organic materials in the cartridges would have been destroyed in the detonations, the metal that did not enter the plume would be dispersed in the vicinity of the detonation site. Depending on the materials detonated and a host of site-specific conditions, it may be necessary to remove these metals from the site either during or after the detonations are completed. If the toxic metals are in the casings or interior metal components, the data in Table 4 and in Reference 29 [22] suggest that they would not present a risk to HH&E. However, if they were in the energetic, they may present a risk because the detonation will release the metals from their matrix.

- Vegetation may provide a relatively inexpensive method to monitor the movement of metals and other OD emission products through the environment over time while simultaneously providing some site remediation. There is an extensive body of published, scientifically credible information documenting the ability of various plants, trees and other vegetation to selectively adsorb and/or neutralise organics, metals and energetic compounds from soils and water [23]. Specific plants have been identified that have high affinity for individual metals and energetic compounds. Thus, one could plant vegetation that adsorbs or metabolises the energetic and metal emission products of concern around the detonation site and could periodically harvest a portion of the vegetation to accomplish the following.

    - o To monitor the spatial and temporal distribution of the emission products around the detonation which would allow a robust assessment of the extent of contamination that has occurred.

    - o To remove energetics and metals from the soil surface and surface water before they can harm HH&E. Using plants to simultaneously prevent pollution, remediate the soil and provide information to the citizens living near the detonation site (on how the ordnance-related emissions are depositing in the environment) would be a relatively simple, inexpensive and easily explainable means to assure them that the emissions are not entering the environment at levels which could endanger their health on either a short term or long term basis.

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[22] *AtienzaMoore T M, Boggs T O, Heimdahl O E, Woolridge D, Gerber B, Zellmer L A and Mohn B M, Preliminary Report - Metals Emissions from the Open Detonation Treatment of Energetic Wastes,* Naval Air Warfare Center Weapons Division, China Lake, CA 93555. May 2002.

[23] *Introduction to Phytoremediation,* Report Number - EPA/600/R-99/107. US Environmental Protection Agency, Office of Research and Development, Washington, DC. February 2000. (http://www.clu-in.org);

Schnoor J L, Light L A, McCutcheon S C and Wolfe N L, *Phytoremediation of Organic and Nutrient Contaminants,* Environmental Science and Technology, 29, 318A-323A, 1995.

Table 7: Comparison of masses of emission products released air over an Eight Hour period from destruction of 378-kg of M-9 propellant

Emission Product or other Measure of Performance	Source	Emission Limit [1]	Kg Emitted Over 8-hr Period		
			EWI	OB	OD
%DRE (Energetics)	US	99.99%	0.038	0.0005	0.10
Total PM	EU	5.2 mg/m^3	13	4.2	3,520
SO$_2$ (including SO$_3$)	EU	16.7 mg/m^3	40	0.45	0.19
HCl	EU	3.3 mg/m^3	0	0	0
NOx (as NO$_2$ Equivalent)	EU	133 mg/m^3	320	3.5	2.7
CO	EU	16.7 mg/m^3	40	0.62	6.2
Dioxin/Furan as TEQ	EU	0.067 ng/m^3	1.6E-07	7.6E-10	7.6E-10
Total Toxic Metals, as Metal (Sb, As, Co, Pb, Cu, Mn, Cr, V, Ni)	EU	167 ug/m^3	NA	NA	NA
Cd + Tl	EU	16.7 ug/m^3	NA	NA	NA
Hg (as metal)	NA	16.7 ug/m^3	NA	NA	NA
LVM (As, Be, Cr)	US	32 ug/m^3	NA	NA	NA
SVM (Pb, Cd)	US	40 ug/m^3	NA	NA	NA

Note: 1. Corrected to 21% O$_2$.

Table 8: Comparison of masses of emission products released into air over an Eight Hour Period from destruction of 4,608 x 20mm API MK107 Cartridges

Emission Product or other Measure of Performance	Source	Emission Limit [1]	Kg Emitted Over 8-hr Period		
			EWI	OB	OD
%DRE (Energetics)	US	99.99%	0.024	0.0034	0.13
Total PM	EU	5.2 mg/m^3	1.3	2.7	4,530
SO$_2$ (including SO3)	EU	16.7 mg/m^3	4.0	0.29	0.24
HCl	EU	3.3 mg/m^3	7.9	0.12	1.3
NOx (as NO2 Equivalent)	EU	133 mg/m^3	320	0.05	1.2
CO	EU	16.7 mg/m^3	40	0.52	5.2
Dioxin/Furan (As TEQ)	EU	0.067 ng/m^3	1.6E-07	4.8E-10	9.2E-10
Total Toxic Metals, as Metal (Sb, As, Co, Pb, Cu, Mn, Cr, V, Ni)	EU	167 ug/m^3	0.41	0.79	0.57
Cd + Tl	EU	16.7 ug/m^3	0.040	0	0
Hg (as metal)	NA	16.7 ug/m^3	0.0	0	0
LVM (As, Be, Cr)	US	32 ug/m^3	0.08	0.0008	0.0008
SVM (Pb, Cd)	US	40 ug/m^3	0.10	0.03	0.12

Note: 1. Corrected to 21% O$_2$.

Annex A
(Informative)
Terms and Definitions

A.1.1
analyte
the substance being measured

A.1.2
ANFO
(Ammonium Nitrate and Fuel Oil)

A.1.3
BMA
Bill Mitchell and Associates, LLC, Durham, North Carolina, USA

A.1.4
CCS
Chemical Compliance Systems, Incorporated, Lake Hopatcong, New Jersey, USA

A.1.5
Comp B
a mixture of TNT and RDX

A.1.6
DOD
US Department of Defense

A.1.7
DPG
Dugway Proving Grounds, Utah, USA

A.1.8
EDB
(Emissions Database)

A.1.9
EF
(Emissions Factor)
the mass of emission product / mass of explosive compound detonated or burned.

A.1.10
EFF
(Environmental Fate Factor)
the mass of emission product / mass of related substance in items detonated or burned.

A.1.11
EIA
(Environmental Impact Assessment)

A.1.12
EWI
(Explosive Waste Incinerator)

A.1.13
EM
(Energetic Material)
the munition, ammunition, fuse, propellant waste, etc.

A.1.14
EPA
(US Environmental Protection Agency)

A.1.15
HH&E
(Human Health and the Environment)

A.1.16
HRA
(Health Risk Assessment)

A.1.17
MDL
(Minimum Detection Limit)
the concentration below which the analytical result is suspect or otherwise unreliable.

A.1.18
MIDAS
(Munitions Inventory Disposal Action System)

A.1.19
NC
(Nitrocellulose)

A.1.20
ND
(Not Detected)
analyte not detected in plume sample

A.1.21
NEQ
(Net Explosive Quantity)
the explosive mass detonated or burned, excluding the mass of all non-energetic materials.

A.1.22
NG
(Nitroglycerin)

A.1.23
NQ
(Nitroguanidine)

A.1.24
OB
(Open Burning)

A.1.25
OD
(Open Detonation)

A.1.26
PAH
(Polycyclic Aromatic Hydrocarbons)
substances containing two or more benzene (aromatic) rings with all atoms lying in the same plane and electron cloud above and below this plane.

A.1.27
SAA
(small arms ammunition)
ammunition of less than 20mm calibre

A.1.28
SALW
(small arms and light weapons)
all lethal conventional munitions that can be carried by an individual combatant or a light vehicle, that also do not require a substantial logistic and maintenance capability.[24]

A.1.29
SEESAC
(South Eastern Europe Clearinghouse for the Control of Small Arms and Light Weapons)

A.1.30
SPSEE
(Stability Pact for South East Europe)

A.1.31
SVOC
(Semi-Volatile Organic Compounds)
organic molecules which partition between the gaseous and solid state at normal temperatures and pressures.

A.1.32
TEQ
the total mass of chlorinated dioxin and furan compounds standardized to the mass of the most toxic dioxin compound (2, 3, 7, 8-tetrachlorodioxin).

A.1.33
TIC
(tentatively identified compound (analyte))

A.1.34
VOC
(Volatile Organic Compounds)
organic compounds which exist only in the gaseous state at normal temperatures and pressures.

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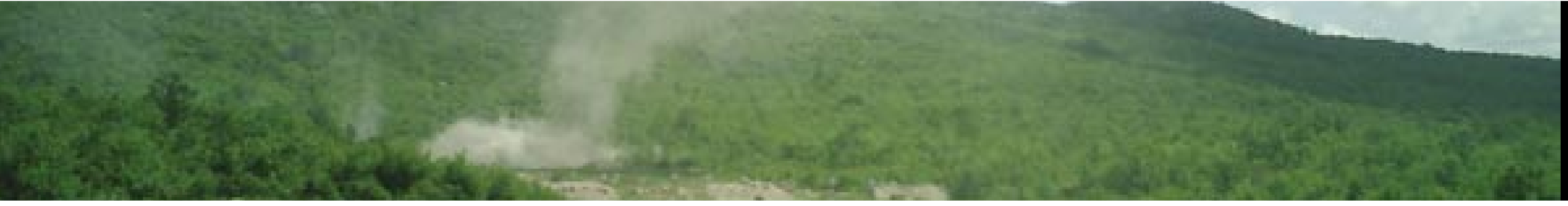
[24] **www.undp.org.yu/seesac** Draft RMDS 02.10 - SALW Standards/ SALW definitions.

Ammunition destruction - environmental releases

(2004 - 05 - 30)

Annex B
(Informative)
Open Burn Portion of the UNDP - EDB Database

TEST NUMBER		N	N =1 /2 MDL	Maximum	Minimum	Mean	Median	OB -1	OB-2	OB-3	OB-4	OB-5	OB-6	OB-7	OB-8	OB-9	OB-10	OB-11	OB-12	OB-13	OB-14	OB-15	OB-16	OB-17	OB-18	OB-19
EF VALUES																										
PM -2.5	kg PM / kg NEW	5	0	2.00E-02	6.90E-03	1.28E-02	1.10E-02	1.6E-02	1.0E-02	6.9E-03	1.1E-02	2.0E-02	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sulfur dioxide	kg SO2 / kg NEW	5	0	3.20E-03	1.20E-04	1.19E-03	1.10E-03	.	.	.	.	.	.	.	1.1E-03	.	3.2E-03	.	1.2E-04	.	1.2E-03	.	3.5E-04	.	.	.
TEQ	kg TCDD / kg NEW	4	4	2.00E-12	2.00E-12	2.00E-12	2.00E-12	.	.	.	.	.	2.0E-12	2.0E-12	2.0E-12	.	.	.	.	.	2.0E-12	.				
EFF VALUES																										
RDX	kg RDX / kg RDX	1	1	4.08E-08	4.08E-08	4.08E-08	4.08E-08	.	.	.	.	.	.	.	.	.	.	.	4.1E-08	.	.	.	.	.	.	.
HMX	kg HMX / kg HMX	1	1	3.42E-08	3.42E-08	3.42E-08	3.42E-08	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3.4E-08	.	.	.
Diphenylamine	kg DPA / kg DPA	6	2	1.51E-05	3.69E-08	3.87E-06	2.17E-06	1.2E-06	1.5E-05	6.3E-08	3.7E-08	.	.	.	.	.	.	3.1E-06	.	3.6E-06	.	.	.	.	.	.
2,6-Dinitrotoluene	kg 2,6 -DNT/ kg 2, 6 DNT	3	3	3.24E-07	1.01E-08	1.15E-07	1.14E-08	.	.	1.1E-08	1.0E-08	.	.	.	.	.	.	3.2E-07	.	.	.	.	.	.	.	.
2,4-Dinitrotoluene	kg 2,4 -DNT/ kg 2, 4-DNT	2	0	3.34E-09	3.15E-09	3.24E-09	3.24E-09	.	.	3.1E-09	3.3E-09	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NG	kg NG / kg NG	3	3	1.46E-09	8.74E-10	1.14E-09	1.07E-09	1.1E-09	8.7E-10	.	.	1.5E-09	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nitroguanidine (NQ)	kg NQ / kg NQ	1	1	6.93E-10	6.93E-10	6.93E-10	6.93E-10	.	.	.	.	6.9E-10	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	kg Energetic / kg energetic	17	11	1.51E-05	6.93E-10	1.39E-06	3.42E-08																			
CO2	kg CO2 / kg C	17	0	4.90E+00	2.27E+00	3.63E+00	3.65E+00	4.6E+00	3.4E+00	3.3E+00	3.5E+00	4.0E+00	3.0E+00	3.4E+00	4.1E+00	3.2E+00	4.9E+00	2.3E+00	3.9E+00	3.7E+00	4.0E+00	3.7E+00	3.7E+00	3.3E+00	.	.
CO	kg CO / kg C	17	0	4.11E-02	1.52E-04	7.38E-03	3.35E-03	2.9E-03	2.4E-03	7.4E-04	3.0E-04	1.5E-04	1.1E-02	1.3E-03	4.1E-02	7.3E-03	4.8E-03	2.6E-02	3.3E-03	1.1E-02	8.7E-04	1.8E-03	4.4E-03	6.1E-03	.	.
Chlorine	kg Cl2 / kg Cl	2	0	3.54E-02	2.06E-02	2.80E-02	2.80E-02	.	.	.	.	.	2.1E-02	3.5E-02	.	.	.	.	.	.	.	.	.	.	.	.
HCl	kg HCl / kg Cl	2	0	9.41E-01	8.46E-01	8.94E-01	8.94E-01	.	.	.	.	.	9.4E-01	8.5E-01	.	.	.	.	.	.	.	.	.	.	.	.
ALL Cl (As HCl)	kg Cl (As HCl) / kg Cl	2	0	9.61E-01	8.82E-01	9.22E-01	9.22E-01						9.6E-01	8.8E-01												
Nitrogen Oxides	kg NOx (as NO2) / kg N	15	0	2.62E-01	6.30E-03	6.20E-02	3.15E-02	7.1E-02	2.9E-02	2.0E-02	4.3E-02	2.9E-02	3.2E-02	8.6E-02	1.9E-02	9.5E-03	2.6E-01	.	3.1E-02	.	6.3E-03	.	1.2E-02	.	1.9E-01	9.4E-02
Al - Energetic	kg Al / kg Al	3	0	3.34E-01	5.45E-02	2.27E-01	2.93E-01	.	.	.	.	.	5.5E-02	.	2.9E-01	.	.	.	.	.	.	.	.	.	3.3E-01	.
Pb - Energetic	kg Pb / kg Pb	3	0	1.36E+00	2.79E-01	7.56E-01	6.31E-01	.	.	.	.	.	.	.	.	6.3E-01	1.4E+00	.	.	.	.	.	.	.	.	2.8E-01
All METALS IN ENERGETIC	kg Metal / kg Metal	6	0	1.36E+00	5.45E-02	4.92E-01	3.13E-01																			
ALL METALS IN CASINGS	kg Metal / kg Metal	0	0	0	0	0	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
ALL METALS IN COATINGS	kg Metal / kg Metal	0	0	0	0	0	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PAH (As Naphthalene)	kg Naphthalene / kg C	17	12	8.92E-06	3.03E-09	2.70E-06	2.42E-06	8.9E-06	1.8E-06	5.6E-08	2.4E-07	3.0E-09	4.6E-06	4.6E-06	4.9E-06	2.4E-06	2.5E-06	9.5E-07	2.5E-06	1.9E-06	3.4E-06	3.4E-06	1.8E-06	1.9E-06	.	.
Methane	kg CH4 / kg C	5	0	2.38E-02	1.47E-04	5.47E-03	5.50E-04	.	2.5E-03	2.4E-02	1.5E-04	.	.	.	.	.	.	.	.	.	.	.	.	.	3.6E-04	5.5E-04
AROMATICS (As Benzene)	kg benzene / kg C	15	0	5.35E-04	1.45E-06	6.09E-05	1.17E-05	.	5.4E-05	1.4E-05	5.4E-06	.	2.8E-06	2.7E-06	.	1.5E-06	.	2.2E-05	1.1E-05	1.2E-05	2.0E-06	2.0E-06	1.8E-05	1.5E-05	1.1E-04	5.4E-04
SATURATED HC (As Ethane)	kg ethane / kg C	12	0	1.59E-04	1.13E-06	1.88E-05	2.25E-06	.	.	.	.	.	2.8E-06	2.7E-06	.	1.5E-06	.	2.5E-06	1.5E-06	1.2E-06	2.0E-06	2.0E-06	3.7E-06	1.1E-06	4.7E-05	1.6E-04
UNSATURATED HC (As Ethylene)	kg ethylene / kg C	12	0	3.21E-03	1.45E-06	3.77E-04	4.59E-05	.	.	.	.	.	10.0E-05	2.7E-06	.	1.5E-06	.	4.4E-05	6.0E-05	6.3E-05	2.0E-06	4.8E-05	4.4E-05	4.9E-06	3.2E-03	9.5E-04
Energetic and Metal Constituents of Test Materials																										
ITEM DESCRIPTION								Manufacturing Propellant Residue	Manufacturing Propellant Residue	M-1 Propellant	M-6 Propellant	M-30 Propellant	Aluminized AP Propellant	AP Propellant	MK-6 Propellant	Double Base Propellant	Double Base Propellant	M-3 Propellant	M-43 Propellant	M-9 Propellant	M-31A1E1 Propellant	MK-23 CTBN Propellant	PBXN -110 Propellant	Smokeless Powder	Hawk Rocket Motor	Nike Rocket Motor
kg NEW				.	.	.	.	2.8E+03	2.1E+03	3.1E+03	3.1E+03	3.2E+03	1.1E+00	2.3E+00	4.5E-01	2.2E+00	4.7E-01	2.3E+00	1.1E+00	2.4E+00	2.3E+00	1.0E+00	1.1E+00	4.5E-01	5.9E+02	1.0E+03
Kg Carbon				.	.	.	.	4.7E+02	6.2E+02	1.0E+03	9.8E+02	5.2E+02	1.2E-01	2.5E-01	4.6E-02	4.6E-01	9.3E-02	1.2E+00	2.1E-01	6.2E-01	3.4E-01	1.5E-01	2.9E-01	1.2E-01	8.6E+01	3.4E+02
Kg RDX				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7.8E-01	.	.	.	.	.	9.0E-01	1.0E+00
Kg TNT				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Kg PETN				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Kg 2,4 DNT				.	.	.	.			3.2E+02	3.1E+02	.	.	.	.	.	.	2.1E-01	.	.	.	.	.	.	.	.
kg DPA				.	.	.	.	4.5E+01	4.3E+01	1.6E+01	2.8E+01	.	.	.	.	.	.	2.2E-02	.	2.0E-02	.	.	.	.	.	2.1E+01
kg Al				.	.	.	.	3.5E+01	.	.	.	.	2.3E-01	.	2.0E-03	.	.	.	.	.	.	.	.	.	4.4E+00	.
kg Cr				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	Trace	Trace
kg Fe				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
kg Cu				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	Trace	Trace
kg Zn				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	Trace	Trace
kg Pb				.	.	.	.	7.0E+01	.	.	.	.	.	.	.	2.0E-02	4.5E-03	.	.	.	.	.	.	.	Trace	5.1E+00
kg Cl				.	.	.	.	.	.	.	.	.	2.5E-01	5.9E-01	1.1E-01	.	.	.	.	.	.	.	.	.	1.2E+02	Trace
kg N				.	.	.	.	1.8E+02	2.8E+02	3.4E+02	2.9E+02	1.1E+03	1.0E-01	2.2E-01	9.5E-02	6.1E-01	6.8E-02	2.8E-01	3.3E-01	3.6E-01	6.7E-01	9.5E-02	3.5E-01	5.8E-02	7.1E+01	1.3E+02
kg HMX				.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9.3E-01	.	.	.
kg NG				.	.	.	.	8.7E+02	7.9E+02	.	.	7.2E+02	.	.	.	Unknown	1.8E-01	.	.	9.6E-01	4.1E-01	.	.	2.3E-02	.	.
kg NC				.	.	.	.	1.1E+03	1.1E+03	5.7E+03	2.8E+03	8.9E+02	.	.	.	Unknown	2.4E-01	1.8E+00	.	1.4E+00	4.9E-01	.	.	4.3E-01	.	.
kg NQ				.	.	.	.	.	.	.	.	1.5E+03	.	.	.	.	.	.	.	.	.	.	.	.	.	.
kg Am. Perchlorate				.	.	.	.	.	.	.	.	.	8.2E-01	1.9E+00	3.8E-01	.	.	.	.	.	.	8.0E-01	.	.	.	3.5E+02
kg Trinitrophenol								.	9.2E+02	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NOTE - A PERIOD (.) MEANS DATA POINT NOT AVAILABLE																										



Annex C
(Informative)
Open Detonation Portion of the UNDP - EDB Database

TEST NUMBER		N	N = 1/ 2MDL	Maximum	Minimum	Mean	Median	OD-1	OD-2	OD-3	OD-4	OD-5	OD-6	OD-7	OD-8	OD-9	OD-10	OD-11	OD-12	OD-13	OD-14	OD-15	OD-16	OD-17	OD-18	OD-19	OD-20	OD-21	OD-22	OD-23	OD-24	OD-25	OD-26	OD-27	OD-28
EF VALUES																																			
PM - 2.5	kg PM / kg NEW	4	0	1.1E+01	7.2E+00	9.2E+00	9.3E+00	9.0E+00	1.1E+01	9.6E+00	7.2E+00	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sulfur dioxide	kg SO2 / kg NEW	9	0	1.4E-03	1.3E-04	5.0E-04	4.0E-04	.	.	.	.	.	.	2.6E-04	2.4E-04	4.0E-04	2.6E-04	1.3E-04	1.0E-03	1.4E-03	4.1E-04	4.0E-04	.	.	.	.	.	.	.	.	.	.	.	.	.
2, 3, 7, 8-TCDD	kg TCDD / kg NEW	9	9	2.0E-12	2.0E-12	2.0E-12	2.0E-12	.	.	.	.	.	.	.	2.0E-12	2.0E-12	2.0E-12	.	2.0E-12	2.0E-12	2.0E-12	2.0E-12	.	.	2.0E-12	2.0E-12	.	.	.	.	.	.	.	.	.
EFF VALUES																																			
Diphenylamine	kg DPA / kg DPA	1	1	7.3E-06	7.3E-06	7.3E-06	7.3E-06	.	.	.	.	7.3E-06	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PETN	kg PETN / kg PETN	7	1	2.5E-03	3.4E-07	4.7E-04	1.1E-04	.	.	.	.	.	.	.	3.4E-07	2.5E-03	3.3E-04	.	.	1.7E-04	1.1E-04	.	.	.	9.8E-05	6.3E-05	.	.	.	.	.	.	.	.	.
RDX	kg RDX / kg RDX	22	6	3.5E-03	1.7E-09	4.7E-04	3.9E-05	1.7E-09	.	2.0E-06	.	4.1E-05	3.7E-05	1.5E-06	3.5E-03	1.3E-07	6.7E-04	8.8E-08	2.7E-04	2.1E-03	6.8E-04	7.5E-04	9.9E-08	9.9E-06	9.1E-04	2.4E-04	.	1.4E-04	1.1E-03	5.8E-06	1.5E-06	1.5E-06	.	.	.
TNT	kg TNT / kg TNT	10	8	6.3E-07	5.0E-08	1.4E-07	8.3E-08	6.3E-07	.	.	1.4E-07	.	.	1.0E-07	.	.	.	1.4E-07	.	.	.	.	1.5E-07	.	.	.	.	5.0E-08	5.0E-08	5.0E-08	6.6E-08	6.6E-08	.	.	.
Trinitrophenol	kg TNP / kg TNP	1	1	3.0E-10	3.0E-10	3.0E-10	3.0E-10	.	3.0E-10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HMX	kg HMX / kg HMX	0	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NQ	kg NQ / kg NQ	0	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NG	kg NG / kg NG	5	5	4.0E-06	4.2E-07	1.3E-06	6.9E-07	.	.	.	.	9.5E-07	4.0E-06	.	6.9E-07	5.8E-07	4.2E-07	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
TETRYL	kg Tetryl / kg Tetryl	3	3	6.0E-07	6.4E-08	2.5E-07	6.7E-08	.	.	.	.	.	.	.	.	.	.	.	.	6.7E-08	6.4E-08	.	.	.	.	.	6.0E-07	.	.	.	.	.	.	.	.
ALL ENERGETICS	kg Eneregetic / kg Eergetic	49	25	3.5E-03	3.0E-10	2.8E-04	1.50E-06																												
Carbon dioxide	kg CO2 / kg C	27	0	6.5E+00	6.1E-01	3.5E+00	3.7E+00	3.4E+00	3.4E+00	3.7E+00	3.5E+00	4.1E+00	3.7E+00	3.8E+00	6.1E-01	8.6E-01	2.0E+00	3.1E+00	3.7E+00	3.7E+00	3.2E+00	3.4E+00	4.1E+00	6.5E+00	3.5E+00	3.4E+00	.	4.1E+00	3.8E+00	3.5E+00	4.2E+00	4.1E+00	4.3E+00	4.7E+00	3.1E+00
Carbon monoxide	kg CO / kg C	27	0	2.1E-01	8.5E-03	7.4E-02	4.7E-02	1.2E-01	1.8E-01	2.0E-01	1.5E-01	2.1E-01	8.8E-02	5.3E-02	1.7E-02	1.5E-02	3.3E-02	1.2E-02	3.8E-02	6.0E-02	6.2E-02	2.1E-01	2.1E-02	3.9E-02	7.1E-02	8.0E-02	4.3E-02	2.7E-02	1.8E-02	.	1.0E-02	8.5E-03	4.7E-02	2.3E-02	1.6E-01
Nitrogen Oxides	kg NOx (as NO2) / kg N	23	0	3.2E-01	3.5E-05	4.9E-02	3.3E-02	6.4E-03	9.6E-03	1.7E-03	1.8E-02	.	.	1.6E-01	3.8E-02	3.8E-02	3.2E-01	1.9E-02	3.8E-02	3.2E-02	3.3E-02	3.4E-02	5.7E-02	.	3.1E-02	3.2E-02	.	.	6.6E-02	80.0E-	5.4E-02	6.3E-02	3.5E-05	5.8E-05	4.5E-05
Chlorine	kg Cl2 / kg Cl	2	0	1.6E-03	1.5E-03	1.6E-03	1.6E-03	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.5E-03	1.6E-03	.
Hydrogen Chloride	kg HCl / kg Cl	2	0	1.4E-01	1.4E-01	1.3E-01	1.3E-01	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.4E-01	1.2E-01	.
CHLORIDE (As HCl)	kg Cl (As HCl) / kg Cl	2	0	1.4E-01	1.4E-01	1.4E-01	1.3E-01																										1.4E-01	1.2E-01	
Cd - Coating	Kg Cd / kg Cd	1	0	1.0E-01	1.0E-01	1.0E-01	1.0E-01	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.0E-01	.	.	.	.	.	.	.	.
Cr - Coating	kg Cr / kg Cr	1	0	1.6E-02	1.6E-02	1.6E-02	1.6E-02	.	.	.	.	.	.	.	.	.	.	.	1.6E-02	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cu - Coating	kg Cu / kg Cu	2	0	9.1E-01	8.1E-02	5.0E-01	5.0E-01	.	.	.	.	.	9.1E-01	.	.	.	.	.	.	.	.	.	.	.	.	.	8.1E-02	.	.	.	.	.	.	.	.
Zn - Coating	kg Zn / kg Zn	2	0	2.5E-01	1.0E-01	1.8E-01	1.8E-01	.	.	.	.	.	2.5E-01	.	.	.	.	.	.	.	.	.	.	.	.	.	1.0E-01	.							
ALL METALS IN COATINGS	kg Metal / kg Metal	6	0	9.1E-01	1.6E-02	2.4E-01	1.0E-01																												
Al - Casings	kg Al / kg Al	5	0	2.1E-02	4.3E-03	1.1E-02	6.9E-03	.	.	.	.	.	1.6E-02	.	4.3E-03	6.9E-03	.		.	.	.	.	.	.	2.1E-02	.	.	.	.	.	.	.	.	.	6.9E-03
Cr -Casings	kg Cr / kg Cr	1	0	1.2E-03	1.2E-03	1.2E-03	1.2E-03	.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	1.2E-03	.	.	.	.	.	.	.	.
Cu - Casings	kg Cu / kg Cu	3	0	1.8E-02	1.5E-04	1.1E-02	1.3E-02	.	.	.	.	1.8E-02				1.3E-02																			1.5E-04
Mn - Casings	kg Mn / kg Mn	1	0	6.7E-05	6.7E-05	6.7E-05	6.7E-05	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6.7E-05
Fe - Casings	kg Fe / kg Fe	1	0	2.6E-05	2.6E-05	2.6E-05	2.6E-05	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2.6E-05
Zn - Casings	kg Zn / kg Zn	4	2	3.0E-02	6.1E-04	1.8E-02	2.0E-02	.	.	.	.	3.0E-02			1.1E-02	2.8E-02	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6.1E-04
ALL METALS IN CASINGS	kg Metal / kg Metal	15	2	3.0E-02	2.6E-05	1.1E-02	6.9E-03																												
Al - Energetic	kg Al / kg Al	7	0	1.6E-01	8.1E-04	7.6E-02	8.9E-02	.	.	.	.	1.5E-02	.	.	.	.	.	.	.	.	.	.	4.9E-02	.	.	.	8.1E-04	.	.	.	8.9E-02	9.5E-02	1.6E-01	1.3E-01	.
Ba - Energetic	kg Ba / Kg Ba	2	2	5.2E-02	2.3E-03	2.7E-02	2.7E-02	.	.	.	.	5.2E-02	.	.	.	.	2.3E-03	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pb - Energetic	kg Pb / kg Pb	9	6	1.1E+00	1.9E-03	1.6E-01	1.1E-02	.	.	.	.	4.9E-02	.	.	3.1E-03	2.0E-01	.	.	.	1.1E+00	1.1E-02	.	.	1.9E-03	6.1E-02	7.7E-03	.	.	.	.	.	.	.	.	5.8E-03
ALL METALS IN ENERGETICS	Kg Metal / kg Metal	18	8	1.1E+00	8.1E-04	1.1E-01	4.9E-02																												
PAH (As Naphthalene)	kg Naphthalene / kg C	28	22	8.3E-05	1.4E-08	2.0E-05	2.0E-05	1.6E-06	2.2E-06	1.3E-06	1.4E-08	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	6.1E-05	8.3E-05	1.3E-05
Methane	kg CH4 / kg C	5	0	2.6E-02	3.1E-05	6.8E-03	2.3E-03	2.3E-03	2.6E-02	1.3E-03	4.1E-03	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3.1E-05
AROMATIC HC (as Benzene)	kg benzene / kg C	27	0	2.7E-03	9.8E-06	3.1E-04	1.7E-04	2.4E-05	3.8E-04	4.4E-04	1.7E-04	3.0E-04	1.6E-04	1.6E-04	1.1E-04	5.3E-05	1.8E-04	2.5E-05	3.3E-04	4.1E-04	4.9E-04	1.1E-03	4.1E-05	2.7E-03	2.0E-04	3.5E-04	3.4E-04	2.3E-05	1.7E-05	.	1.6E-05	9.8E-06	9.3E-05	6.3E-05	2.6E-04
SATURATED HC (as Ethane)	kg ethane / kg C	21	0	1.1E-01	8.1E-07	1.5E-02	8.4E-03	.	.	.	.	2.1E-04	1.4E-04	9.8E-03	1.3E-02	1.1E-02	6.0E-03	5.1E-06	1.1E-02	1.8E-02	9.3E-03	1.1E-01	6.4E-03	8.4E-03	1.5E-02	5.8E-02	1.8E-03	8.1E-07	1.8E-03	.	2.9E-06	2.1E-03	.	.	2.7E-02
UNSATURATED HC (As Ethylene)	kg ethylene / kg C	23	0	1.0E-02	4.8E-05	1.4E-03	7.5E-04	.	.	.	.	9.5E-04	5.4E-04	7.5E-04	7.7E-04	8.0E-04	1.1E-03	8.3E-05	2.0E-03	2.7E-03	2.5E-03	1.0E-02	2.8E-04	1.7E-03	1.9E-03	3.7E-03	4.8E-05	1.2E-04	9.7E-05	.	2.4E-04	1.6E-04	6.0E-04	5.2E-04	5.1E-04
Energetic and Metal Constituents of the Test Materials																																			
ITEM DESCRIPTION								Composition B	Explosive D	RDX	TNT	20mm HEI Cartridge	40mm HEI Cartridge	Amatol	Impulse cartridge	Impulse cartridge	Impulse cartridge	Composition B	Flare	Tail Fuse	Tail Fuse	Gas Generator	HBX	Claymore Mine	Flare	Flare	Adapter Booster	TNT	TNT	TNT	Tritonal	Tritonal	C3 propellant	C4 Propellant	155mm Projectile
kg NEW				.	.	.		8.9E+02	9.2E+02	8.4E+02	9.0E+02	1.9E-01	1.6E-01	2.4E-01	2.2E-01	1.4E-01	2.1E-01	2.4E-01	2.4E-01	1.7E-01	2.1E-01	1.4E-01	2.2E-01	2.3E-01	2.6E-01	2.4E-01	8.3E-02	2.3E-01	2.3E-01	2.3E-01	2.4E-01	2.4E-01	2.4E-01	2.4E-01	2.9E+02
kg Carbon				.	.	.		2.3E+02	2.7E+02	1.3E+02	3.3E+02	9.8E-02	3.8E-02	4.4E-02	1.7E-01	8.1E-02	8.9E-02	8.5E-02	5.3E-02	6.5E-02	6.1E-02	1.8E-02	5.4E-02	1.8E-01	8.1E-02	3.6E-02	2.4E-02	8.5E-02	8.5E-02	8.5E-02	6.8E-02	7.6E-02	3.7E-02	3.7E-02	7.1E+01
kg RDX				.	.	.		5.3E+02	.	8.4E+02	.	5.5E-02	1.6E-01	8.0E-03	5.3E-02	5.3E-02	5.3E-02	1.4E-01	5.4E-02	2.8E-02	2.8E-02	2.6E-02	1.1E-01	2.3E-01	5.4E-02	5.4E-02	9.0E-03	2.0E-03	2.0E-03	2.0E-03	8.0E-03	8.0E-03	.	.	1.7E+02
kg TNT				.	.	.		3.5E+02	.	.	9.0E+02	.	.	1.2E-01	.	.	.	8.6E-02	.	.	.	.	7.2E-02	.	.	.	.	2.3E-01	2.3E-01	2.3E-01	1.8E-01	1.8E-01	.	.	1.1E+02
kg PETN				.	.	.		.	.	.	.	.	.	.	3.2E-02	3.2E-02	3.2E-02	.	.	1.7E-02	1.8E-02	.	.	.	3.2E-02	3.2E-02	.	.	.	.	.	.	.	.	9.0E-03
kg TETRYL												.	.	.	.	.	.	.	.	1.3E-01	1.6E-01					.	8.3E-02	.	.	.	.	.	.	.	.
Kg 2,4 DNT				.	.	.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
kg DPA				.	.	.		.	.	.	.	1.3E-03	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
kg NC				.	.	.		.	.	.	.	9.9E-02	7.0E-03	.	5.6E-02	4.2E-02	8.6E-02	.	5.0E-03	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
kg NG				.	.	.		.	.	.	.	1.0E-02	2.0E-03	.	1.6E-02	1.2E-02	2.5E-02	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
kg Al				.	.	.		.	.	.	.	1.2E-02	1.5E-01	.	Trace	2.2E-01	Trace	.	Casing	Trace	Trace	Trace	3.9E-02	Trace	2.3E-01	Casing	3.9E-01	.	.	.	4.3E-02	4.3E-02	4.3E-02	4.4E-02	2.1E+00
kg Cr				.	.	.		.	.	.	.	1.6E-03	Trace	.	Trace	6.0E-02	Trace	.	2.4E-03	Trace	Trace	Trace	.	Trace	.	.	2.9E-03	.	.	.	.	.	.	.	5.8E-02
kg Fe				.	.	.		.	.	.	.	2.0E-01		.	Trace	Trace	Trace	.	Trace	Trace	Trace	Trace	.	.	trace	.	1.4E+00	.	.	.	.	.	.	.	1.2E+03
kg Cu				.	.	.		.	.	.	.	2.7E-01	1.6E-03	.	6.3E-03	1.3E-02	Trace	.	Trace	Trace	Trace	.	.	.	Trace	Trace	1.2E-03	.	.	.	.	.	.	.	2.1E+01
kg Mn				.	.	.		.	.	.	.	.	1.6E-03	.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2.6E+00
kg Zn				.	.	.		.	.	.	.	10.0E-02	7.0E-04	.	2.9E-03	.	Trace	.	Trace	.	Trace	.	.	.	Trace	Trace	1.0E-03	.	.	.	.	.	.	.	2.2E+00
kg Pb				.	.	.		.	.	.	.	2.7E-03	Trace	.	2.1E-03	9.2E-04	.	.	Trace	4.1E-04	5.9E-04	.	.	3.6E-03	3.0E-04	9.3E-04	.	.	.	.	.	.	.	.	1.1E-02
kg Cl				.	.	.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6.6E-03	5.7E-03	.
kg N				.	.	.		3.0E+02	2.3E+02	9.4E+02	2.0E+02	2.2E-02	6.1E-02	4.1E-02	6.5E-02	2.7E-02	1.5E-02	1.8E-01	6.7E-02	1.7E-01	8.2E-02	2.0E-02	5.7E-02	8.7E-02	1.7E-01	4.0E-02	1.8E-01	4.2E-02	4.8E-02	4.3E-02	4.1E-02	3.7E-02	4.2E-02	5.1E-02	9.0E+01
kg Ba				.	.	.		.	.	.	.	2.0E-04	Trace	.	.	Trace	5.0E-03	.	Trace	.	.	.	.	.	2.0E-04	.	.	.	.	.	.	.	.	.	Trace
kg Cd				.	.	.		.	.	.	.	Trace	Trace	.	Trace	Trace	Trace	.	Trace	Trace	Trace	Trace	.	.	Trace	Trace	2.0E-03	.	.	.	.	.	.	.	Trace
kg TNP				.	.	.		.	9.2E+02	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

NOTE - A PERIOD (.) MEANS DATA POINT NOT AVAILABLE

Annex D

(Informative)

Descriptions of the environmental conditions and materials used in the open burning emissions characterisations contained in the UNDP - EDB

1 Test numbers OB -1 through OB-5

These open burn tests were conducted on the West Desert Test Range at Dugway Proving Grounds, Utah in 1989 - 1990 [25]. Three steel pans approximately 1.2 m wide, 11.0 m long and 0.25 m high placed side by side were used in each burn. The propellant materials were placed in the pans to a depth of 6 - 9 cm and the burns initiated using black powder trains placed at both ends of each pan. Between 2,000 to 3,200 kg quantities of propellants were burned in each test.

Test OB - 1 (Propellant Manufacturing Residue A Burn)

This material, which was comprised of four, double-base propellants and one ammonium perchlorate (AP) or composite propellant, was burned during the Phase B test series. Some of the propellants were in pellet form, others were in sheet form and one was in the form of chunks, but the form of each propellant was not given in the report. The AP propellant was placed in the centre pan and the double base propellants were placed in the outer pans. This propellant mixture served as a surrogate for the residues, which result from propellant manufacturing processes when the final product does not meet the product performance/quality specifications and is destroyed by open burning in steel pans. The material burned contained 1135 kg NC, 865 kg NG, 45 kg diphenylamine (DPA), 606 kg AP, 85 kg triacetin, 70 kg of Pb, and 35 kg Al. A single trial comprised of two 3,000kg burns spaced approximately 11 minutes apart, was conducted. One burn required 180 seconds to complete and the other required 240 seconds. The average mass of ash recovered from the burn pan for the two burns was 5.4 kg, which is equal to 0.2% of the energetic mass burned. The ash contained 2.9 mg of phenol; no other SVOC or energetic target analytes were found.

Test OB - 2 (Propellant Manufacturing Residue B Burn)

This material was comprised of two, double base propellants in sheet form. The propellants were open burned while rolled out flat in the burn pans during the Phase C test series. The two propellants together contained 1115 kg NC, 793 kg NG, 43 kg DPA, 13 kg triacetin, 55 kg Pb and 184 kg dibutylphthalate. Two x 2-burn trials were conducted. The first trial consisted of one open burn with an NEQ of 2,253kg and a second burn with an NEQ of 2,184kg. In the second trial, two 2,218kg quantities of the propellant were burned. The two burns in the first trial were initiated approximately 12 minutes apart and the two burns in the second trial were initiated approximately 15 minutes apart. The burn times for the four burns ranged from 63 to 68 seconds. The average mass of ash recovered from the burn pan for the four burns was 0.6 kg, which is equal to 0.1% of the energetic mass burned. The ash contained low nanogram quantities of 2,4-DNT; no other SVOC or energetic target analytes were found.

Test OB - 3 (M-1 Propellant Burn)

This single base propellant was burned as multi-perforated propellants approximately 1 cm long and 0.4 cm in diameter during the Phase C test series. The material burned contained 2,729 kg NC, 16 kg DPA, 321 kg 2.4-DNT, and 160 kg dibutylphthalate. Two, three-burn trials were conducted. Each trial involved the open burning of three 3,159kg quantities of propellant. In the first trial, the second burn was initiated approximately 14 minutes after the first and the third burn was initiated approximately 21 minutes after the second. In the second trial, the three burns were initiated approximately 13 minutes apart. The burn times for the six burns ranged from 16 to 19 seconds. The average mass of ash recovered from the burn pan for the six burns was 4.0 kg, which is equal to 0.1% of the energetic mass burned. The ash contained 76 mg of 2,4-DNT and 3 mg of 2,6-DNT; no other SVOC or energetic analytes were found.

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[25] M Johnson, *Development of Methodology and Techniques for Identifying and Quantifying Products from Open Burning and Open Detonation Thermal Treatment Methods - Field Test Series A, B and C, Volume 1 (Test Summary),* US Army, AMMCOM, Rock Island, IL 61299-6000, January 1992.

Test OB - 4 (M-6 Propellant Burn)

This single base propellant was burned as multi-perforated pellets approximately 1.7 cm long and 0.8 cm in diameter during the Phase C test series. The material burned contained 2,793 kg NC, 28 kg DPA, 309 kg 2,4-dinitrotoluene (2,4-DNT), and 80 kg dibutylphthalate. Four, three-burn trials were conducted. In the first three trials, the burns were initiated approximately 12 minutes apart and in the fourth they were initiated approximately 15 minutes apart. The NEQ in each of the first nine burns was 3,184kg and in the last three burns the NEQ was 3,320kg. The burn times for the 12 burns ranged from 12 to 21 seconds. The average mass of ash recovered from the burn pan for the four trials was 2.6 kg, which is equal to 0.026% of the energetic mass burned. The ash contained 30 mg of 2,4-DNT and 91mg of dibenzofuran; no other SVOC or energetic target analytes were found.

Test OB - 5 (M-30 Propellant Burn)

This triple base propellant was burned as perforated pellets during the Phase A test series. The material burned contained approximately 890 kg nitrocellulose (NC), 715 kg of nitroglycerine (NG), 1510 kg nitroguanidine (NQ), and 50 kg of ethyl centralite (N,N-diethyl-N,N-diphenylurea). Two, three-burn trials were conducted. The NEQ of the first burn was 3,144kg and the NEQ of the second burn was 3,193kg. The two burns were initiated 14 minutes apart. The burn time for each burn was approximately 20 seconds. The ash left in the burn pan contained milligram quantities of phenol, ethyl centralite, NC, NG and 2,4 DNT. The total mass of the ash was not determined.

2 Test numbers OB - 6 through OB-17

These tests were conducted in an inflatable, 930 m^3, 16.5 m diameter hemispherical test chamber (Bang Box) made from a flexible polyvinyl-coated polyester fabric. Energetic materials were burned in stainless steel burn pans placed on a steel pad located in the centre of the test chamber [26]. A description of each test material used in these tests is presented below.

Test OB - 6 (Aluminised Ammonium Perchlorate (AP) Propellant Burn)

The AP propellant used in this test was delivered to the Bang Box as kg blocks where it was divided into pieces weighing approximately 1.2 kg each for the testing. One 1.2 kg block was burned in each trial. The block was prepared for the test as follows. First, the block was placed in a 30.5 by 50.8 by 15.2 cm deep burn pan. Then a flap was cut in the top of the block and an 81-mm propellant bag containing 4g of Hercules unique smokeless powder was placed in the hole along with two electric squibs. The flap was then placed back over the hole and the burn was initiated on the command of the test coordinator. Other than the following elemental composition, no information is available for this propellant: 19% Al, 20.8% Cl, 10.09% C, 3.7% H, 8.3% N, 38.1% O and 0.008% P. This formulation implies that the propellant contained 69% AP by weight. Two, single-burn trials were conducted. The NEQs (including 4g of smokeless powder) for the first and second trials were 1,216g and 1,159g, respectively for an average NEQ of 1192g. This average mass would contain: 3.8g NC, 0.2g NG, 821g AP, 226g Al, and 141g of a material or materials with an elemental composition of $C_{20}H_{34}O$).

Test OB - 7 (Ammonium Perchlorate (AP) Propellant Burn)

The AP propellant used in this test was delivered to the Bang Box as kg blocks where it was divided into pieces weighing approximately 2.2 kg each for the testing. One 2.2 kg block was burned in each trial. The block was prepared for the test as follows. First, the block was placed in a 30.5 by 50.8 by 15.2 cm deep burn pan. Then a flap was cut in the top of the block and a 81-mm propellant bag containing 4 g of Hercules unique smokeless powder was placed in the hole along with two electric squibs. The flap was then placed back over the hole and the burn was initiated on the command of the test coordinator. Other than the following elemental composition, no information is available for this propellant: 25.87% Cl, 11.32% C, 4.31% H, 10.35% N, 47.31%O, and 0.89% Zr. This formulation implies that the propellant was 85% AP. Two, single-burn trials were conducted. The NEQ burned in each of the two trials was 2,270g, including the 4g of smokeless powder used to initiate each burn.

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[26] Mitchell W J and Suggs J C, *Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD),* EPA Report Number EPA/600/R-98/103, August 1998.

Based on the above elemental composition, the 2,270g of propellant burned contained: 1946g AP, 300g of a material or materials with the elemental formula of $C_{21}H_{32}$, 3.8g NC, 0.2g NG and 20g Zr.

Test OB - 8 (Composite Propellant MK-6, 88 P-217 Burn)

448g of MK-6 propellant chips were placed in a stainless steel burn pan and the burn was initiated using two electric matches, which had been inserted into the mix. The NEQ burned was 448g. The major energetic constituents of the propellant were: 381g AP, 35.9g hydroxy-terminated polybutadiene, 20.2g dioctyl sebacate and 4.5g aluminium. One, single-burn trial was conducted

Test OB - 9 (Double-Based Propellant Burn)

2,223g of pelletised propellant was placed in a stainless steel burn pan along with a 81-mm propellant bag containing 4 g of smokeless powder and the burn was initiated using an electric squib that had been inserted into the smokeless powder. Two, single-burn trials were conducted. The propellant contained NC, NG and diphenylamine. Its elemental composition was 20.36% C, 2.97% H, 28.73% N, 46.14% O, 0.89% Pb, 0.89% Zr and 0.02% Sn which corresponds to 454.4g C, 66.1g H, 639.8g N, 1027.5g O, 19.8g Pb, 19.8g Zr and 0.5g Sn.

Test OB - 10 (Double-base Propellant-NOSIH-AA2 Burn)

454 g of propellant chips and 26.6 g of ethyl cellulose were placed in as stainless steel burn pan and the burn was initiated using an electric match that had been inserted into the mix. One, single-burn trial was conducted. The major constituents of the propellant were: 240g NC, 184g NG, 26.6g ethyl cellulose, 12.3g triacetin, 9.1g of di-n-propyl adipate and 4.5g lead.

Test OB - 11 (M-1 Propellant In M-3 Propellant Bags Burn)

Three, single-burn trials were conducted. The NEQ burned in each trial was 2,273g, including 4g of smokeless powder and 113g of reducer charge. The M-1 propellant was contained in Number 4 and Number 5 M-3 propellant bags; the composition is not given in the final report. The Number 4 bag weighed 15g and the Number 5 bag weighed 19.5g. Two Number 4 bags and two Number 5 bags were burned during each trial. Each Number 4 bag contained 428g of M-1 propellant and 29g of reducer charge and each Number 5 bag contained 650g of M-1 propellant and 27.5g of reducer charge. The composition of the reducer charge was not given in the final report. The major energetic constituents of the 2,156g of M-1 propellant burned were: 1,815g NC, 213g dinitrotoluene, 106g dibutylphthalate and 22g diphenylamine. Each burn was conducted under different temperature and humidity conditions. These conditions were generated using electric heaters and pans containing water. The first trial was conducted at low humidity and at a temperature above ambient temperature; the second trial burn was conducted under conditions of cool temperature and high relative humidity, and the third trial was conducted at ambient temperature. Unfortunately, the specific temperatures and humidities used are not given in the final report. Because the three trials gave emission factors which were essentially the same, the emission factors are identified in the CRD as M-1 propellant burn without referencing the environmental conditions under which each burn was done.

Test OB - 12 (MK-43 LOVA Propellant, MIL-P-70818 Burn)

One, single-burn trial was conducted. The NEQ of the material burned was 1060g, including 40g Hercules smokeless powder. The energetic composition of the MK-43 propellant burned was: 775g RDX, 41g NC, 122g cellulose acetate butyrate (CAB) and 78g of a mix of bis(2,2-dinitropropyl)acetal and bis(2,2-dinitropropyl)formal.

Test OB - 13 (M-9 Propellant Burn)

Three, single-burn trials were conducted. Two hundred and thirty two (232) unopened bags of M-9 propellant were placed in the burn pans and the propellant ignited using 4g of smokeless powder and two electric squibs. Each bag weighed 11.5g and contained approximately 10.4g of M-9 propellant. The NEQ used in each burn was 2405g, including 4g of smokeless powder. The energetic composition of the 2,401g of M-9 propellant burned

was: 1,387g NC, 960g NG, 36g potassium nitrate and 18g diphenylamine. The propellant bags were identical to those used to fire the 181 mm mortar, but their chemical composition was not given in the final report. Based on 1.1g per bag, the total mass of the 232 bags was 255g.

Test OB-14 (M31A1E1, Triple Based Propellant Burn)

Three, single-burn trials were conducted. During the first trial, the stick propellant was burned in an upright position, which resulted in extensive propellant kick-out. To reduce propellant kick-out, for the second and third trial burns, the propellant sticks were placed horizontally in the pan. For these latter burns, four propellant sticks were broken into fourths (18.4 cm) and placed in the pan. Then additional propellant sticks were broken in half (36.8 cm) and placed crosswise on top of the other propellant sticks. The NEQ (including the 4g of smokeless powder) used in the three trials conducted were 2,284g, 2,280g and 2,264g, for the first, second and third burns, respectively. The major energetic constituents of the M31A1E1 propellant burned were: 492g NC, 410g NG, 1,245g NQ, 34g ethyl centralite and 1g of charcoal.

Test OB - 15 (MK-23 CTBN Propellant Burn)

One, single-burn trial was conducted. The NEQ of energetic material burned was 1030g, including 30g Hercules smokeless powder. The major energetic components of the 1000g of MK-23 propellant burned were 800g AP, 142g carboxyl-terminated polybutadiene and 20 g Al.

Test OB - 16 (PBXN-110 Propellant Burn)

One, single-burn trial was conducted. The NEQ burned was 1064g, which included 14g of smokeless powder. The major energetic components of the 1050g of PBXN-110 burned were: 924.1g HMX, 53g hydroxyl-terminated polybutadiene, and 53g isodecyl pelargonate.

Test OB - 17 (Hercules Unique Smokeless Powder Burn)

One, single-burn trial was conducted. The NEQ burned was 454g; it was comprised only of smokeless powder (431.3g NC and 22.7g NG).

3 Test numbers OB - 18 and OB - 19

These tests were done in the X-tunnel chamber at the Nevada Test Site [27].

Test OB - 18 (Improved HAWK Rocket Motor Burn

Two rocket motors (605 kg propellant total mass) were burned simultaneously in the single trial conducted. The mass of propellant would contain approximately 352kg AP, 74kg NG, 44kg Al and 118kg polyurethane foam. Copper linear-shaped charges and explosive cutting tape were used to split the steel rocket motor cases longitudinally and at both ends and to initiate the burn. These explosive charges added 1.1 kg of RDX to the total energetic mass burned. The exact composition of the propellant is classified, however, from the Executive Summary and the test report it was possible to determine that the total masses of C, N and Cl in the material burned were 85.6 kg, 71.1 kg and 116.2 kg, respectively. The rocket motors burned for approximately 20 seconds, but elevated temperatures and pressures and severe plume stratification existed in the chamber over most of the plume sampling effort. The peak temperature was reached about 50 sec after the burn was initiated, but the average peak temperature is uncertain because the temperatures measured by the five thermocouples in the chamber ranged from 330 to 540 °C at the time. This substantial temperature difference continued for quite some time after the burn ended. For example, the approximate temperature range measured in the chamber at 2, 3, 4 and 5 minutes after the burn was initiated were: 250 - 450 °C, 180 - 350 °C, 120 - 280 °C and 90 - 220 °C. The maximum pressure measured in the chamber during the burn was 40 psia. These elevated temperatures and pressure are obviously not representative of an open burn situation where the hot plume is quickly cooled by dilution with ambient air.

Test OB - 19 (NIKE Rocket Motor Burn)

Two, single-burn trials were conducted. The first trial involved the simultaneous burn of two NIKE rocket motors and the second trial involved the simultaneous burn of four NIKE rocket motors. Each NIKE rocket motor contained approximately 341 kg of a double base propellant comprised primarily of nitrocellulose (203 kg) and nitroglycerin (88 kg). The propellant also contained 36kg of glycerol triacetate (triacetin); 7kg of 2-nitrodiphenylamine; 1.7 kg of lead (as lead stearate); 9 kg of dimethylphthalate; 9 kg of diethylphthalate; and a chlorinated rubber liner. The total masses of energetic material burned in the first and second trials were 683 kg and 1365 kg, respectively. Copper linear-shaped charges and explosive cutting tape were used in each burn to split the steel rocket motor case longitudinally and at both ends and to initiate the burn. These explosive charges added approximately 0.6 to 1.01 kg of RDX to the total energetic mass burned. Each burn lasted approximately 20 seconds, but elevated temperatures and pressures and severe plume stratification existed in the chamber over most of the plume sampling effort. For both burns the peak temperature (800 °C) was reached about 1-minute after the burn was initiated and the differences between the thermocouples was approximately 50 - 90 °C. The approximate temperatures in the chamber at 2, 3, 4 and 5 minutes after the burns were initiated were: 550 °C, 425 °C, 350 °C and 280 °C, respectively. The maximum pressures measured in the chamber during the two and four rocket motor burns were 56 and 85 psia, respectively. These elevated temperatures and pressure are obviously not representative of an open burn situation where the hot plume is quickly cooled by dilution with ambient air.

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[27] *Individual Test Reports, Appendix B, Draft Rocket Motor Summary Report for the Nevada Test Site*, report prepared by Radian International LLC for Lockheed Martin Energy Systems, October 1997.

Ammunition destruction - environmental releases

(2004 - 05 - 30)

Annex E
(Informative)
Descriptions of the environmental conditions and materials used in the open detonation emissions characterisations contained in the UNDP - EDB

1 Tests OD - 1 through OD - 4

These detonation tests were conducted on the West Desert Test Range at Dugway Proving Ground (DPG), Utah in 1989-1990 [28]. These tests involved detonating 900-kg quantities of four explosives. The four explosives were detonated in topless, steel barrels approximately 1.2 m high and 1.1 m in diameter. The detonations were initiated using 0.5 kg of C-4 and an electric blasting cap. All four explosives were detonated with the barrel sitting on the ground (surface OD). Some TNT was detonated with the barrel suspended approximately 12 m above the ground. The data from this latter test, which was conducted to determine if the efficiency of the detonation could be substantially improved by increasing the ease with which air could enter the detonation fireball, was not included in the UNDP -EFD because it was not representative of real world detonations.

Test OD - 1 (Bulk Composition B Detonation)

The composition B was reclaimed material in flake form. The material detonated contained approximately 360 kg TNT, 525 kg RDX and 10 kg wax. The three detonation trials were conducted during Phase C of the test series. The first trial involved two 907-kg detonations spaced approximately 15 minutes apart. The second and third trials each involved three detonations spaced approximately 15 minutes apart. In the second trial, the first and third detonations were 907-kg detonations and the second was a 916-kg detonation. The third trial involved three, 907-kg detonations.

Test OD - 2 (Bulk Explosive D Detonation)

The Explosive D was in granular form and may have been recycled material. The material contained 915 kg of picric acid. Two, three detonation trials were conducted during Phase C of the test series. The NEQ of each of the six detonations was 916kg. During the first trial, the second detonation was initiated approximately 10 minutes after the first and the third was initiated approximately 21 minutes after the second detonation. In the second trial, the three detonations were spaced approximately 20 minutes apart.

Test OD - 3 (Bulk RDX Detonation)

The RDX was received in pasteboard boxes and was detonated without removing it from the boxes. The two, three-detonation trials were conducted during the Phase C test series. The material detonated contained 835 kg of RDX and 45 kg of Viton A rubber. The NEQ for the first, second and third detonations in the first trial were 871kg, 875kg and 880kg, respectively. The NEQ for the same detonations in the second trials were 899kg, 880kg and 880kg, respectively. The three detonations in the first trial and the first two in the second trial were spaced approximately 15 minutes apart. The third detonation in the second trial was initiated approximately 20 minutes after the second detonation.

Test OD - 4 (Bulk Reclaimed TNT)

The TNT detonated was reclaimed material. TNT detonations were conducted during all three phases of the test series. The emissions data from Phase A (one trial comprised of five, 898kg detonations) and Phase C (two trials comprised of three, 900-kg detonations each) were averaged to produce the emissions factors in the CRD. The Phase A detonations were initiated 10 - 20 minutes apart. During the first trial in Phase C, the second detonation was initiated approximately 20 minutes after the first and the third was initiated approximately 28 minutes after

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[28] Mitchell W J and Suggs J C, *Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD),* EPA Report Number EPA/600/R-98/103, August 1998.

the second detonation. During the second Phase C trial, the second detonation was initiated approximately 18 minutes after the first and the third was initiated approximately 15 minutes after the second detonation. (The Phase B TNT detonations were excluded because the TNT was severely contaminated with asphaltum and gum residues, was not homogeneous in physical properties and suffered from other defects, which caused it not to meet the test specifications.)

2 Tests OD - 5 through OD - 27

These tests were conducted in an inflatable, 930 m3, 16.5 m diameter hemispherical test chamber (Bang Box) made from a flexible polyvinyl-coated polyester fabric [29]. The test chamber was kept inflated by two high-capacity blowers; six fans spaced 600 apart circulate the air in the test chamber to produce a homogeneous pollutant mix that is sampled with instruments in the chamber and the attached air lock. Energetic materials were detonated in a one-metre3 steel-lined pit after the steel cover is removed. The test chamber was purged with air for at least 60 minutes (two air volume exchanges) between trials. A description of each test material used in these tests is presented below.

Test OD - 5 (20mm HEI Cartridge, M56A4 Detonation)

Three, single-detonation trials were conducted. The NEQ detonated in each trial was 189g, including 60g of C-4 with an EBC. Three, 20mm brass cartridges were placed on the C-4 strip and tied in place with 16 gauge iron wire for each detonation. Each cartridge contained 8.8 g RDX (explosive charge), 39.2g of WC870 propellant (major energetic constituents: 33g NC and 3.3g NG), 0.9 g of lead, 0.53 g chromium, 89.4 g copper, 33.3 g zinc, 4.1 g aluminium, 67.3 g iron, and 0.07 g of barium. The cartridge also contained unknown quantities of the following carbon-based materials: dibutylphthalate, graphite and some adhesives and sealants.

Test OD - 6 (40mm HEI Cartridge, M384 Detonation)

Three, single-detonation trials were conducted. The NEQ detonated in each trial was 158g, including 40g of C-4 with an EBC. Two 40mm aluminium alloy cartridges were placed on the C-4 strip and tied in place with 16-gauge iron wire for each detonation. Each cartridge contained 54.4g of composition A5 explosive (comprised of 53.3g RDX, and 1.1g stearic acid); 4.6g of M-2 propellant (major energetic constituents: 3.5g NC, 0.9g NG), 74 g aluminium, 0.8 g copper, 0.8 g manganese, 0.35 g zinc and small, but uncertain, quantities of barium, lead and tin. The cartridge also contained unknown quantities of the following carbon-based materials: dibutylphthalate, graphite and some adhesives and sealants.

Test OD - 7 (Amatol Surrogate Detonation)

Amatol is a secondary explosive comprised of TNT and ammonium nitrate (AN). It is used in a wide variety of munitions. Three, single-detonation trials were conducted using an amatol surrogate containing 113.5g of TNT and 113.5g AN. The amatol was prepared by mixing crushed TNT block with AN powder in a manner similar to that used to prepare the tritonal surrogate. The amatol surrogate was placed in the polyethylene bags and detonated in the same manner as the tritonal surrogate. The NEQ of the material detonated in each of the three trials was 235g, including 8g from the C-4/EBC.

Test OD - 8 (Cartridge, Impulse, Mod 0, ARD446-1 Detonation)

This item has a NEQ of 12.5g. Three, single-detonation trials were conducted For each trial, ten aluminium alloy cartridges were tied to a 57g C-4 brick using detonation cord and the suspended assembly was detonated using an EBC. The NEQ of the assembly was 216g, including 91g from the detonation train. Each cartridge was stated to contain 20g of aluminium, 0.63g of copper, 0.29g of zinc, 0.214g lead and approximately 8g of smokeless powder.

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[29] Johnson M, Development of Methodology and Techniques for Identifying and Quantifying Products from Open Burning and Open Detonation Thermal Treatment Methods - Field Test Series A, B and C, Volume 1 (Test Summary), US Army, AMMCOM, Rock Island, IL 61299-6000, January 1992;

Radian Corporation, Sampling results for C3 and C4 Propellant Emission Characterisation, test report prepared for Hill Air Force Base, Utah by Radian International (now URS Corporation), June 1998.

Test OD - 9 (Cartridge, Impulse, BBU 36B Detonation)

This item deploys chaff from aircraft and contains a pyrotechnic filler which readily burns when initiated. Each aluminium alloy cartridge has a NEQ of 875mg. Three, single-detonation trials were conducted. Sixty cartridges were used in each of the three detonations. In each detonation, 42 cartridges were clustered around a 57g block of C-4 and 18 cartridges were placed on the sides of a 0.5 m length of detonation cord that had been folded into a 0.25 m length. In trial 1, the two assemblies were hung separately with one end of the detonation cord inserted in the block of C-4. An EBC was used to detonate the C-4. In trials 2 and 3, the C-4 and detonation cord assemblies were bound together using 16-gauge iron wire. The NEQ of the assemblies detonated was 144g, including 91g from the detonation train. The energetic composition of the cartridge is not fully known; it did contain approximately 1g of smokeless powder. Each cartridge also contained 3.7g aluminium, 1.0g chromium, 0.21g copper, 0.015g lead and 0.012g zinc.

Test OD - 10 (Cartridge, Impulse, MK107, Mod 01 Detonation)

This cartridge has a NEQ of 24.5g. Three, single-detonation trials were conducted. For each detonation, five steel cartridges were placed around a 57g block of C-4. They were parallel to each other, but alternated tip to base. This assembly was wrapped with 3 m of detonation cord and detonated over the detonation pit using an EBC. The NEQ of each assembly was 208g, including 91g for the detonation train. The energetic composition of the MK107 cartridge was 17.4g NC, 5.0g NG, 1g barium nitrate and 1.2g of potassium nitrate. The item also contained some aluminium pellets and a small quantity of lead, but the amounts are not known. In addition, the steel casing contained small quantities of chromium, nickel, zinc, and aluminium.

Test OD - 11 (Low-Density Composition B Surrogate Detonation)

Composition B, a secondary explosive found in a wide variety of bombs and artillery projectiles, is a combination of RDX and TNT. Three, single-detonation trials were conducted using 227g quantities of the surrogate Composition B material contained in a thin plastic bag. (The surrogate material was prepared by mixing crushed block TNT with C-4. The energetic composition of this composition B was 128g RDX, 86.3g TNT and 12.7g of mineral oil/polyisobutylene (from the C-4). The total NEQ detonated was 235g, including 8g from the C-4/EBC.

Test OD - 12 (Flare, Countermeasure, Aircraft, M206 Detonation)

This flare is used to decoy heat-seeking missiles away from aircraft. Each flare has a NEQ of 150.2g and contains 102g powered magnesium, 1g potassium nitrate, 5g NC, 13g rubber, 2.4 g chromium and small, but uncertain, amounts of barium, copper, lead and zinc. Three, single detonation, single flare trials were conducted. The flare, which had an aluminium casing (weight not specified in MIDAS), was prepared for detonation as follows. A 57g block of C-4 was cut in half lengthwise and the two halves placed on the long axis of the flare such that two halves remained in contact. This assembly was wrapped in polyethylene sheeting and then 3 m of detonating cord was wrapped around the assembly starting at the end opposite the C-4. The plastic plug in the forward end of the flare was left in place and the final assembly suspended 0.5 m above the floor of the detonation pit. The pit cover was partially extended over the pit when the flare was detonated using an EBC to initiate the detonation. The total NEQ of the final assembly was 241g, including 91g from the detonation train.

Test OD - 13 (Fuze, Tail Bomb, Fuze Mechanical Unit, 139B Detonation)

This fuze which has a stainless steel housing, contains 126g of TETRYL. It is used to initiate the longitudinal detonation cast into GP air-dropped bombs. Three, single detonation, single fuze trials were conducted. Each fuze was prepared for detonation as follows. A 28.5g block of C-4 was taped to the side of the fuze near its main explosive charge and the assembly wrapped in polyethylene sheeting. 1.5 m of detonation cord was then wrapped around the fuze and the fuze was screwed onto a threaded shaft. (The opposite end of the shaft was attached to a 1.9 cm thick by 30.5 cm diameter steel plate. The purpose of the steel plate was to break up any focused blast effect resulting from the detonation.) The fuze was detonated 0.5 m above the floor of the detonation pit using an EBC. The NEQ of the fuze is 126g. The total NEQ of the each assembly detonated was 172g, including 46g from the detonation train. Each fuze also contained 0.4 g lead and small, but uncertain, quantities of aluminium, copper, chromium and tin.

Test OD - 14 (Fuze, Tail Bomb, Fuze Mechanical Unit FMU-54A/B Detonation)

This fuze, which contains 163g of TETRYL, initiates the longitudinal detonator cast into general purpose (GP) air-dropped bombs such as the M117 and MK82. The NEQ of the fuze is 163.3g. Three, single detonation, single fuze trials were conducted. Each fuze was prepared for detonation as follows. A 28.5g block of C-4 was taped to the side of the fuze near its main explosive charge and the assembly wrapped in polyethylene sheeting. 1.5 m of detonation cord was then wrapped around the fuze and the fuze was screwed onto a threaded shaft. (The opposite end of the shaft was attached to a 1.9 cm thick by 30.5 cm diameter steel plate. The purpose of the steel plate was to break up any focused blast effect resulting from the detonation.) The fuze was detonated 0.5 m above the floor of the detonation pit using an EBC. The NEQ was 209g, including 46g from the detonation train. Each fuze also contained 0.6 g lead and small, but uncertain, quantities of aluminium, chromium, copper, iron and zinc.

Test OD - 15 (Generator, Gas Pressure, Propellant Actuated, GCU-2/A Detonation)

This item, which is used in the LGM30 minuteman missile, has a NEQ of 95.3g; its energetic composition is classified. Three, single detonation, single gas generator trials were conducted. The gas generator was prepared for detonation by removing the outer metal jacket to expose the solid propellant which is cast as a short hollow cylinder. Twenty-eight and a half grams of C-4 was packed into the hollow cylinder and the cylinder wrapped in polyethylene sheeting. This assembly was then wrapped with 1.5 m of detonation cord and the gas generator's plastic shipping plug was taped on top of the detonation cord. The gas generator was then oriented with its steel plug facing into the detonation pit and detonated with an EBC. The NEQ of each assembly detonated was 139g.

Test OD - 16 (HBX Surrogate Detonation)

HBX is an aluminized form of Composition B; it is used in a variety of bombs, depth charges and torpedoes. Three, single-detonation trials were conducted using 227g quantities of the surrogate HBX material contained in a thin plastic bag. The HBX surrogate was prepared by mixing aluminium powder with Composition B surrogate. The energetic composition of the HBX surrogate detonated was: 109g RDX, 72g TNT, 7.8g mineral oil/polyisobutylene and 38.5g Al. The NEQ of the material detonated was 235g, including 8g from the C-4/EBC.

Test OD - 17 (M18A1 Antipersonnel Mine (Claymore) Detonation)

Three, single-detonation, single-mine trials were conducted. The NEQ detonated in each trial was 227g. Because the mine contained 681g of C-4, it was necessary to remove 454 g of the C-4 before detonating it in the Bang Box, which has a detonation NEQ limit of approximately 230g. The mine was opened and the 700, 22-caliber steel balls and 454g of C-4 were removed from the 360g of fiberglass resin casing. The case was a 50:50 composite of fiberglass and a polystyrene/polybutadiene resin. The mine was suspended in the detonation pit, an EBC inserted in the 227g of C-4 remaining and the mine was detonated. The mine also contained 0.36 g of lead and small, but uncertain, quantities of aluminium, copper, chromium, and zinc.

Test OD -18 (Signal, Illumination, Aircraft, Red Star M43A2 Detonation)

This aluminium alloy-encased flare has a NEQ of 56.8g with 56.6g of this NEQ in the illuminating charge. The illuminating charge contains 10.2g magnesium powder, 13.6g potassium perchlorate, 24.9g strontium nitrate, 3.4g hexachlorobenzene, 4g asphaltum, 0.02 g barium, 0.1 g lead, and small, but uncertain, quantities of cadmium, copper and zinc and the aluminium tube contains 78g of Al. Three, single detonation trials using three flares (and there bandoliers) per detonation were conducted. The three flares were tied to a 57g block of C-4 and detonated employing a procedure similar to that used for the M158 flares detonated. The NEQ of each assembly detonated was 260g, including 91g from the detonation train.

Test OD -19 (Signal, Illumination, Ground, Red Star, M158 NSN Detonation)

This flare is housed in an cylindrical, aluminium alloy casing (weight not specified in MIDAS) with a steel liner. It has a NEQ of 36.8g. Three, single detonation trials using four flares (and there bandoliers) per detonation were conducted. Two flares were placed on one side of a 57g block of C-4 and two were placed on the opposite side.

This assembly was wrapped in polyethylene sheeting; 3 m of detonation cord was then wrapped around the assembly and secured with 16-gauge iron wire. This final assembly was detonated with the flare-releasing end pointed down into the pit. An EBC was used to initiate each detonation. The NEQ of each assembly was 239g, including 91g from the detonation train. The complete energetic composition of the item is unknown. It did contain 2.5g of black powder, 5.2g of strontium nitrate, 2.5g magnesium, 11g potassium nitrate, 2.5g charcoal, 0.23 g lead and small but uncertain quantities of cadmium and zinc.

Test OD - 20 (Adapter-booster, T45E7 Detonation)

The NEQ detonated was 83g, which included 10g of C4 with an EBC. (NOTE- the 1995 test report indicated that this item had a NEQ of 183 g, but the latest MIDAS data indicate that the NEQ is 73g. Some small changes in the masses of Al and Pb were also found between the test report and MIDAS. Therefore, the originally reported EFs were adjusted to reflect the current MIDAS data on this item.) Three, single-detonation, single-adapter-booster trials were conducted. The adapter-booster contained 73g of TETRYL, a booster pellet and a hollow bursted well which was closed with a 980g steel plug and housed in a 440g steel cylinder 17.3 cm long and 7.2 cm in diameter. It also contained two 7.5g pressed wool wafers (to protect the booster casing), 2.9 g chromium, 1.2 g copper, 412 g aluminium, 2.0 g cadmium, 1.1 g zinc, and approximately 2g of lead (in lead chromate). To reduce the chance for the blast pulse to become focused, a steel wool plug was placed in the large end of the bursted well and the end was closed with a 31g plastic plug. A 1.6 cm diameter x 25 cm long steel rod was screwed into the fuze well and a 2.5 cm thick x 23 cm diameter steel disk was fastened to the other end of the rod. This assembly was suspended horizontally in the detonation pit. A 10g charge of C-4 with an EBC initiated the detonation. However, significant focusing of the blast still occurred because: (1) a hole was punched through the 1.25 cm steel plate lining of the pit; and (2) the paper on the fiberglass insulation behind the steel plate and the top of the wood witness shield approximately 3 meters above the pit were charred.

Note: This charring could explain the higher than theoretical result for carbon when the carbon oxide values are converted to kg carbon.

Test OD - 21 (Flake TNT Detonation)

Three, single-detonation trials each using 221g of flaked TNT were conducted. The total NEQ detonated was 227g, including 6g for the electric blasting cap (EBC).

Test OD - 22 (TNT Block Detonation)

One, single-detonation trial using three small blocks of TNT was conducted. The purpose of the test was to confirm that the test equipment was operating properly. The three TNT blocks (total NEQ of 221g) were tied together with 16-gauge iron wire, wrapped with 1.9g of polyethylene sheeting and detonated (using an EBC inserted in the bottom of the assembly). The total NEQ detonated was 227g, including 6g for the electric blasting cap (EBC).

Test OD - 23 (TNT Block Detonation)

Three, single-detonation trials were conducted. A 221g block of TNT was used in each detonation. The TNT was obtained by removing the Mylar film from TNT demolition block and cutting the TNT into the shape and weight desired. The TNT block was made from pressed TNT grains ranging in size from 35 to 65 mesh; graphite (used to facilitate the pressing process) was the only other component in the block. An RP-83 initiator, which consisted of PETN and RDX encased in an aluminium alloy casing, was used as the initiator.

Test OD -24 (Tritonal Surrogate Detonation)

Low density tritonal is used in 750 lb. air-dropped bombs. It is comprised of 80% TNT and 20% finely powdered aluminium by weight. A tritonal surrogate was prepared using crushed TNT block and aluminium powder. These components were placed in a jar and mixed until the mixture appeared to be homogeneous. This mix

contained 1274g TNT and 431g Al. Three, 227g portions of this mix were placed in thin polyethylene bags and the bags closed with cotton string. One bag was used in each detonation; the detonations were done with the bags suspended approximately 1 m above the concrete floor of the Bang Box. Three, single-detonation trials were done. In the first two trials, a single M-6 EBC was used to initiate the detonation. It was apparent from the noise of the blast and the residues on the floor that the two detonations did not go high order. To ensure that the third detonation went high order, the EBC was inserted into a 6.5g block of C-4 for this detonation. The NEQ of the material detonated in the three detonations was 229g for the first two detonations and 235g for the last detonation. Because they were not high order detonations, the results from the first two detonations are not included in the database.

Test OD - 25 (Tritonal Surrogate with 2.5% Calcium Stearate Detonation)

The calcium stearate served as a surrogate for the organic materials associated with tritonal when it is steamed out of 750 lb. bombs. Three, single-detonation trials were done. A 6.4g block of C-4 and an EBC were used to initiate each detonation. The tritonal/calcium stearate mixes detonated were contained in thin polyethylene bags in a manner identical to the tritonal surrogate detonations. Each bag contained 216g of the tritonal surrogate mix prepared earlier and 11g of calcium stearate. The NEQ of the material detonated was 226g, including 8g from the C-4/EBC.

Test OD - 26 (C3 Propellant Detonation)

C3 is a rocket propellant comprised of aluminium, ammonium perchlorate, nitroglycerin and nitrocellulose. Four, single-detonation trials were conducted using 225g cube of the propellant. A M130 EBC inserted into the cube was used to detonate it. When the cubes detonated, the shock cut a hole in the 12 mm thick steel plate on the floor of the pit in which the propellant cube was suspended. The energetic composition of the propellant is classified. The only information available as to its composition is, as follows: 17.9% Al, 2.7% Cl, 12.6% NC and unknown quantities of NG and HMX. The C, H, N and O content was: 15.0% C, 2.5% H, 17.4% N and 44.4% O. The NEQ of the material detonated was 235g, including 8g from the C-4/EBC.

Test OD - 27 (C3 Propellant Detonation)

C4 is a rocket propellant comprised of aluminium, ammonium perchlorate, nitroglycerin and nitrocellulose. Three, single-detonation trials were conducted using a 225g cube of the propellant. A M130 EBC inserted into the cube was used to detonate it. When the cubes detonated, the shock cut a hole in the 12 mm thick steel plate on the floor of the pit in which the propellant cube was suspended The energetic composition of the propellant is classified. The only information available as to its composition is, as follows: 18.3% Al, 2.4% Cl, 12.6% NC and unknown quantities of NG and HMX. The C, H, NB and O content was: 15.4% C, 2.8% H, 21.2% N and 39.8% O. The NEQ of the material detonated was 235g, including 8g from the C-4/EBC

Test OD - 28 (155 mm Projectile HEI, M-107)

This test was conducted in the X-tunnel at the Nevada Test site [30]. Each projectile contained 6.98 kg of Composition B (60% RDX, 39% TNT and 1% wax by weight) and 0.13 kg of a supplementary charge (98.5% Composition B, 1.5% barium stearate by weight). The projectile has a steel casing and weighs approximately 34.5 kg, approximately 0.61 kg of this is attributable to a 90% copper/10% zinc rotating ring on the exterior of the projectile. Each projectile is also coated with 2.4 g of zinc phosphate and 5.6 g of zinc chromate (0.067 kg zinc/projectile). Four, single-detonation trials were done. The results from the first trial were excluded from the emission factor database because it was an operational readiness test (ORI). The second and third trials involved the detonation of 24 projectiles and the fourth involved the detonation of 60 projectiles. The second trial was done with the projectiles lying on top of a steel plate, and the third and fourth trials were done with the projectiles lying on gravel.

For the 24 projectile trials, the projectiles were placed in two rows of twelve projectiles each with the lifting plugs in one row pointing in the opposite direction from those in the other row. For the 60-projectile detonation trial,

they were placed in rows containing 15 projectiles each; two of the rows were stacked on top of the other two rows. The rows were oriented in the same manners as the 24 projectile detonation trials. The donor charge was Composition C4 (91% RDX, 5.3% di(2-ethylhexyl)sebacate, 2.1% polyisobutylene, and 1.6% motor oil by weight) initiated with PETN-based slip on boosters (one per projectile) and 10- m of primacord. Approximately, 27.2 kg of C-4 was used in the 24-projectile detonations and 38.5 kg were used in the 60-projectile detonation. Including the PETN boosters and primacord cord, the net mass of energetic material (NEQ) detonated in each of the 24-projectile trials was 199 kg and in the 60-projectile trial was 468 kg. The results from the second, third and fourth trials were averaged for inclusion in the CRD which results in the following masses: 288.7 kg NEQ, 173.3 kg RDX, 112.5 kg TNT, 1221 kg iron, 21.1 kg copper, 2.23 kg zinc, 1.1E-02 kg lead, 90 kg nitrogen, 71 kg carbon and 2.1 kg aluminium.

The peak chamber temperature reached in these detonations ranged from 75 to 115 °C. The chamber temperature remained above the ambient temperature over the duration of the sampling for each test.

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[30] *Executive Summary of Phase I Demonstrations - Detonation of Conventional Weapons: 155-mm High Explosive M107 Projectiles,* Lawrence Livermore National Laboratory Report Number UCRL-ID-131252 prepared for US Army Defense Ammunition Center, July 1998

Individual Test Reports, Appendix B, Draft Detonation Summary Report for the Nevada Test Site, report prepared by Radian International LLC for Lockheed Martin Energy Systems, August 1997.

Ammunition destruction - environmental releases

(2004 - 05 - 30)

Annex F

(Informative)

Descriptions of the sampling and analysis methodology used in the OB and OD emissions characterisations contained in the UNDP - EDB

1 Overview of the sample collection methodology

Six sample collection procedures and ten analytical procedures were used across all the detonation and burn tests comprising the CRD. The six sampling procedures were: gas transfer line (leading to continuous emissions monitor), filter, particle sizing inlet followed by filter, filter followed by impinger, filter followed by a cartridge containing an adsorbent (either XAD-2 or a polyurethane foam (PUF) plug), and evacuated canister. The nine analytical procedures were: continuous emissions monitor (CEM), GC with Thermal Conductivity Detector (GC/TCD), GC with Flame Photometric Detector (GC/FPD), GC/ Mass Spectrograph (GC/MS), GC/with Selective Ion Mode Mass Spectrometry (GC/SIM-MS), High Pressure Liquid Chromatography with Selective Ion Mode MS (HPLC/SIM-MS), HPLC with UV detection (HPLC/UV), Supercritical Fluid Chromatography with Selective Ion Mode MS (SFC/SIM-MS), Inductively Coupled Argon Plasma Emission Spectroscopy (ICP) and x-ray fluorescence spectroscopy (XRF). These six sampling and ten analytical procedures were combined to produce 17 measurement systems. Ten of these are described in Table E-1 (Inorganic and Metal Measurement Systems) and the remaining seven are described in Table E-2 (VOC, SVOC, Energetic and PCDD/PCDF Measurement Systems).

In some studies more than one measurement system was used for the same analyte. When this occurred the results from the technically superior method were used for the database, or, if the two methods were equal in their capabilities, the average value was used.

In many of the tests the energetic, SVOC and PAH target analytes had been selected based on the composition of the starting materials and the possible emission products. For example, if the materials detonated did not contain NG or NQ, these two energetic materials were not target analytes. This variation in target analytes is reflected in the database. That is, if a compound was not a target analyte in an emission test, a lower case ‘a’ was placed in the database for that analyte/emission test combination.

2 Target analytes

There were more than 275 target analytes (substances) across all of the tests, but the individual target analytes varied from test to test, depending on the funds available, the expected emission products, and the test schedule. Most of the target analytes were never detected in the plumes at concentrations, emissions plume at concentrations above either the background level or the minimum detection limits (MDL) of the measurement systems used. The target analytes used in the studies are listed below.

2.1 Inorganic and filterable particulate matter target analytes

CO, CO_2, NO, NO_2, NOx, N_2, O_2, SO_2, HCl, Cl_2, HCN, Total Particulate Matter (PM), PM-10 and PM-2.5

2.2 Metal target analytes

Aluminium, Iron, Copper, Chromium, Zinc, Nickel, Cadmium, Manganese, Lead, Vanadium, Cobalt and Barium.

2.3 Volatile Organic Compound target analytes (VOC)

Organic compounds with saturation vapour pressures greater than 1E-02 kilopascals at 25º C were placed in this category. Using this definition, the target VOC analytes are:

- acetylene;
- acrolein;
- acetonitrile;
- benzene;
- bromomethane;
- 1,3-butadiene; n-butane;
- 1-butene;
- cis-2-butene;
- trans-2-butene;
- n-butylbenzene;
- tert-butylbenzene;
- chlorobenzene;
- cyclohexane;
- cyclohexene;
- cyclopentane;
- cyclopentene;
- n-decane;
- 1-decene;
- 1,1-dichloroethane;
- 1,2-dichloroethane;
- 1,2-dichloropropane;
- (m, p)-diethylbenzene;
- 2,3-dimethylbutane;
- 2,2-dimethylheptane;
- 2,3-dimethylhexane;
- 2,5-dimethylhexane;
- 2,3-dimethylpentane;
- 2,4-dimethylpentane;
- 1,4-dioxane;
- cyanogen;
- ethane;
- ethylbenzene;
- 2-ethyl-1-butene;
- 3-ethylhexane;
- ethylene;
- (o,m,p)-ethyltoluene;
- n-heptane;
- 1-heptene;
- nBhexane;
- 1-hexene;
- cis-2-hexene;
- isobutane;
- isobutene;
- isobutylbenzene;
- isoheptane;
- isohexane;
- isopentane;
- isopropylbenzene;
- methane;
- 2-methylpentane;
- 2-methyl-1-butene;
- 2-methyl-2-butene;
- 3-methyl-1-butene;
- 2-methyl-1-pentene;
- 4-methyl-1-pentene;
- 2-methyl-2-pentene;
- cis-3-methyl-2-pentene;
- methylcyclohexane cis-4-methyl-2-pentene;
- methylcyclohexane;
- 1-methylcyclohexene;
- methylcyclopentane;
- methylcyclopentene;
- methylene chloride;
- 2-methylheptane;
- 3-methylheptane;
- 3-methylhexane;
- 3-methylpentane;
- naphthalene;
- neohexane;
- neopentane;
- n-nonane;
- 1-nonene;
- 4-nonene;
- nBoctane;
- 1-octene;
- cis-2-octene;
- n-pentane;
- 1-pentene;
- cis-2-pentene;
- trans-2-pentene;
- propane;
- n-propylbenzene;
- propylene;
- styrene;
- tetrachloroethene;
- 1,1,2,2-tetrachloroethane;
- toluene;
- 1,2,4-trichlorobenzene;
- 1,1,1-trichloroethane;
- 1,1,2-trichloroethane;
- trichloroethene;
- trichloroethylene;
- 1,2,3-trimethylbenzene;
- 1,2,4-trimethylbenzene;
- 1,3,5-trimethylbenzene;
- 2,2,4-trimethylhexane;

- 2,2,4-trimethylpentane;
- 2,3,4-trimethylpentane;
- 2,2,5-trimethylhexane 2,4,4-trimethyl-l-pentene;
- 2,4,4-trimethyl-2-pentene;
- 2,2,3-trimethylpentane;
- n-undecane;
- 1-undecene;
- (o,m,p)-xylene;
- vinylidine chloride;
- vinyl chloride; and
- total non-methane hydrocarbons.

2.4 Semi-Volatile Organic Compounds (SVOCs) and Polycyclic Aromatic Hydrocarbons (PAHs)

Organic compounds which were not energetic materials and which had saturation vapour pressures between 1E-02 and 1E-08 kilopascals at 25^{0} C were placed in the SVOC and PAH categories depending on the number of aromatic rings. The target analytes in this category are:

- acenaphthylene;
- acetophenone;
- 2-acetylmninofluorene;
- 4-aminobiphenyl;
- aniline;
- anthracene;
- benz(a)anthracene;
- benz(a)pyrene;
- benzidine;
- benzo(b)fluoranthene;
- benzo(g,h,i)perylene;
- benzoic acid;
- benzo(k)fluoranthene;
- benzyl alcohol;
- biphenyl;
- bromophenylphenylether;
- butylbenzylphthalate;
- p-chloroaniline;
- chlorobenzilate;
- chloroethene,
- bis(2-chloroethoxy)methane;
- bis(2-chloroethyl)ether;
- bis(2-chloroisopropylether;
- 4-chloro-3-methylphenol;
- 2-chloronaphthalene;
- 2-chlorophenol;
- 4-chlorophenylphenyl ether;
- chrysene;
- cyanogen,
- diallate;
- dibenz(a,h)anthracene;
- dibenzofuran;
- 1,2-dichlorobenzene;
- 1,3-dichlorobenzene;
- 1,4-dichlorobenzene;
- 3,3'-dichlorobenzidine;
- 2,4-dichlorophenol;
- 2,6-dichlorophenol;
- diethylphthalate;
- p-dimethylaminoazobenzene;
- dimethylbenz(a)anthracene;
- 3,3'-dimethylbenzidine;
- dimethylphenethylamine;
- 2,4-dimethylphenol;
- dimethylphthalate;
- di-n-butylphthalate;
- 1,3-dinitrobenzene;
- 4,6-dinitro-2-methylphenol;
- 2,4-dinitrophenol;
- 2,4-dinitrotoluene;
- 2,6-dinitrotoluene;
- di-n-octylphthalate;
- 1,4-diphenylamine;
- 1,2 diphenylhydrazine;
- bis(2-ethylhexyl)phthalate;
- N-nitrosodiphenylamine;
- ethyl methanesulfonate;
- fluoranthene;
- fluorene;
- hexachlorobenzene;
- hexachlorobutadiene;
- hexachlorocyclopentadiene;
- hexachloroethane;
- hexachloropropene;
- indeno(1,2,3-cd)pyrene;
- isophoron;
- isosafrole;
- kepone;
- methapyrilene;
- 3-methylcholanthrene;

- methyl methanesulfonate;
- 2-methylnaphthalene;
- 2-methylphenol;
- 4-methylphenol;
- 3-methylphenol;
- naphthalene;
- 1,4-naphthoquinone;
- 1-naphthylamine;
- 2-naphthylamine;
- 2-nitroaniline;
- 3-nitroaniline;
- 4-nitroaniline;
- nitrobenzene;
- 5-nitro-o-toluidine;
- 2-nitrophenol;
- 4-nitrophenol;
- 4-nitroquinoline-1-oxide;
- N-nitrosodiethylamine;
- N-nitrosodimethylamine;
- N-nitroso-di-n-butylamine;
- NBnitroso-di-n-propylamine;
- N-nitrosomethylethylamine;
- N-nitrosomorpholine;
- NBnitrosopiperidine;
- N-nitrosopyrrolidine;
- pentachlorobenzene;
- pentachloroethane;
- pentachloronitrobenzene;
- pentachlorophenol;
- perylene;
- phenacetin;
- phenanthrene;
- phenol;
- 2-picoline;
- pronamide;
- pyrene;
- pyridine;
- safrole;
- 1,2,4,5-tetrachlorobenzene;
- 2,3,4,6-tetrachlorophenol;
- o-toluidine;
- 1,2,4-trichlorobenzene;
- 2,4,5-trichlorophenol;
- 2,4,6-trichlorophenol; triethylphosphorothioate; and
- 1,3,5-trinitrobenzene.

2.5 Energetic target analytes

The compounds in this category have saturation vapour pressures similar to the SVOC target analytes, but are also explosives. The compounds in this category are:

- octahydro-1,3,5,7-tetranitro - 1,3,5,7 - tetrazocine (HMX);
- hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX);
- 2,6-dichlorophenol;
- methyl-2,4,5-trinitrophenylnitramine (TETRYL);
- 1,3,5-trinitrobenzene;
- 2,6 dichlorphenol;
- 1,3-dinitrobenzene;
- nitrobenzene;
- 2-nitrodiphenylamine;
- 2,4,6-trinitrotoluene (TNT);
- 4-amino-2,6-dinitrotoluene;
- 2-amino-4,6-dinitrotoluene;
- 2,6-dinitrotoluene;
- 2,4-dinitrotoluene;
- 2-methylnaphthalene;
- 2-nitronaphthalene;
- naphthalene;
- 1-nitropyrene;
- 2-nitrotoluene;
- 4-nitrotoluene ;
- 3-nitrotoluene; and
- pentaerythritol tetranitrate (PETN).

Note: Nitrocellulose (NC) was not a target analyte in any study because it is not possible to measure at the low concentrations expected in the detonation plumes.

2.6 PCDD/PCDF target analytes

- Total chlorinated dibenz-p-dioxin (TCDD);
- Total pentachlorinated dibenzo-p-dioxin (PeCDD);
- Total hexachlorinated dibenzo-p-dioxin (HxCDD);
- Total heptachlorinated dibenzo-p-dioxin (HpCDD);
- Octachlorinated dibenzo-p-dioxin (OCDD);
- 2378-TCDD;
- 1234678-HpCDD;
- 12378-PeCDD;
- 23478-PeCDD,
- 123678-HxCDD;
- 123789-HxCDD;
- Total tetrachlorinated dibenzofurans (TCDF);
- Total pentachlorinated dibenzofurans (PeCDF);
- Total hexachlorinated dibenzofurans (HxCDF);
- Total heptachlorinated dibenzofurans (HpCDF);
- Octachlorinated dibenzofuran (OCDF);
- 2378-TCDF;
- 12378-PeCDF;
- 23478-PeCDF;
- 123478-HxCDF;
- 123678-HxCDF;
- 234678-HxCDF;
- 1234678-HpCDF; and
- 1234789-HpCDF.

Table E-1: Inorganic and metals measurement systems used in the studies

Analyte	Sample Collection and Analysis Methodology
NO, NO_2, CO, CO_2, HCl, SO_2, N_2, O_2	Samples from the plume were analyzed by continuous emissions monitors(CEM).
CO, CO_2	Samples were collected in an evacuated stainless steel canister and analyzed for CO and CO_2 using GC/TCD.
HCl, Cl_2	A set of Midget impingers connected in series and preceded by a filter was used to collect HCl and Cl_2. Two of the impingers contained 0.1N H_2S04 (to collect HCl) and another contained 0.1 N NaOH (to collect Cl2). Impinger contents were analyzed for Cl by ion chromatography (EPA Method 26).
HCN	A set of Midget impingers connected in series and preceded by a filter was used to collect the HCN. The impingers containing 2.0 N zinc acetate solution. The impinger solutions were analyzed for the cyanide ion using EPA SW-846 Test Method 9012.
Filterable Particulate Matter	Samples were collected by pulling a sample of the plume through a filter and determining the mass collected on the filter.
Filterable Particulate Matter 10 Micron	Samples were collected by pulling the air sample through a PM-10 particle sizing inlet and then through a filter.
Filterable Particulate Matter M-2.5 Micron	Samples were collected by pulling the air sample through a PM-2.5 particle sizing inlet and then through a filter.
Metal Target Analytes	Samples were collected by pulling the plume sample through a heated quartz fibre filter and six impingers connected in series, (EPA Method 29). The first two impingers contained 5% nitric acid/10% hydrogen peroxide solutions (to collect gaseous lead compounds), the third impinger was empty (to collect any liquid carryover from the first two impingers), the next two impingers contained 4% potassium permanganate/10% sulphuric acid solutions (to collect gaseous mercury compounds), and the last impinger contained silica gel (to remove moisture. The filter was acid extracted and the extract analyzed for metals by EPA SW-846 Method 6010A (inductively coupled argon plasma emission spectroscopy, ICP). The solutions from the impingers were analyzed separately for lead and mercury by ICP (Method 6010A) and CVAAS (Method 7471A), respectively.
	Samples collected on Teflon-coated quartz fibre filter and analyzed by XRF
	Samples were collected using the sampler in Procedure E and analyzed using EPA SW-846 Method 6010A (ICP).

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