Treatment of Energetic Hazardous Waste by Open Detonation at the Naval Air Weapons Station, China Lake, California

Lauren A. Zellmer, Thomas L. Boggs, Eric D. Erickson, and Andrew P. Chafin

The Naval Air Weapons Station, China Lake, California, is the Navy's largest research, development, test, and evaluation (RDT&E) facility, encompassing more than 1.1 million acres. The State of California has a long tradition of strong enforcement of strict environmental standards. The treatment of energetic wastes by open burn/open detonation (OB/OD) has been a matter of considerable controversy in some of parts of the state, as well as areas around the country. With a science-based, data-driven approach, a team of China Lake environmental specialists and technical experts in the research and energetics area establishes the validity of OD as a preferred treatment method.

The anticipated outcome of China Lake's efforts is the approval by state regulatory agencies of a revised human health risk assessment (HRA). The purpose of the HRA is to address potential health effects (both cancer and non-cancer) from exposure to emissions from OB/OD activities on human receptors. In order to ensure that the revised HRA is based on valid scientifically backed data that can withstand public and regulatory scrutiny, China

***Lauren A. Zellmer** is the RCRA program manager for the Environmental Department at the Naval Air Weapons Station, China Lake. Ms. Zellmer has 15 years of environmental experience, mainly in hazardous waste management. She can be reached via e-mail at lauren.zellmer@navy.mil. **Thomas L. Boggs** is the chief scientist for energetics at the Naval Air Warfare Center Weapons Division, China Lake. He has over 35 years of experience in the combustion and detonation of propellants and explosives and has published over 260 papers. **Dr. Eric D. Erickson** is the mass spectrometrist and chromatographer in the Research Department at the Naval Air Warfare Center Weapons Division, China Lake. His research interests include environmental monitoring and cleanup, environmentally benign technologies for ordnance demilitarization, ordnance aging phenomena, and the analysis of new materials. **Andrew P. Chafin** has over 20 years of experience working for the U.S. Navy at China Lake as an energetic materials chemist. He has been involved in the synthesis of new energetic materials and nonlinear optical polymers. He has 17 patents and over 50 published articles.*

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Lake has focused efforts on three areas: (1) development of a validated emission factor database from actual test data; (2) fate of metal casings associated with the OD of munitions; and (3) OD simulation tests for energetic-contaminated wastes. This article discusses all three efforts.

INTRODUCTION

Background

China Lake is the Navy's largest Research, Development, Test, & Evaluation (RDT&E) facility for weapons development and testing. It consists of 1.1 million acres of land surrounded by 12.5 million acres of airspace in California's remote and sparsely populated Mojave Desert (**Exhibit 1**). Much of the surrounding land is either owned or controlled by the U.S. government. This fact, coupled with little population growth, makes the area an ideal location for China Lake's activities.

A diverse energetic wastestream is generated from activities associated with China Lake's RDT&E mission. Department of Transportation, Department of Defense (DOD), and Navy regulations prohibit the transport of most of this RDT&E energetic wastestream on public roadways, either because the wastes are research and development materials that have not been fully classified with respect to explosive safety, or because the wastes have been altered or damaged. Therefore, most of this RDT&E energetic wastestream must be treated at China Lake.

Exhibit 1. China Lake's Land and Airspace

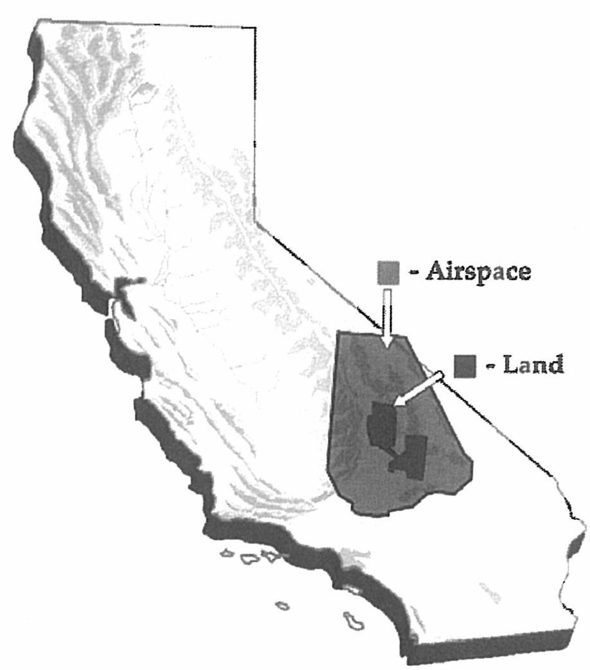
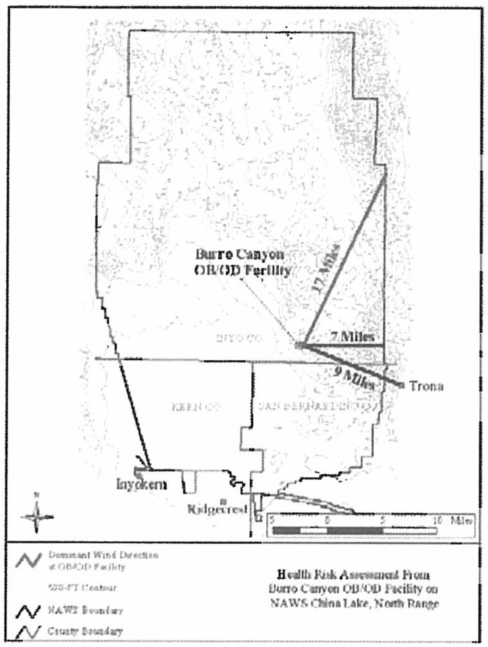


Exhibit 2. Location of Open Detonation Unit on China Lake's North Range

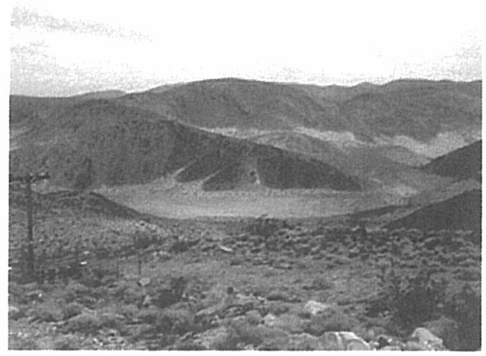


For simplicity, the energetic wastestreams can be broken into two categories: (1) a munitions wastestream that consists of both standard munitions (those that are either excessed or expired) and nonstandard munitions (standard munitions altered from some RDT&E process—e.g., heating, dropping); and (2) a laboratory wastestream that consists of leftovers from mixes and castings of experimental explosives and propellants, energetic-contaminated "trash" (e.g., rags, gloves), samples from the mixes, and energetic-contaminated solvents.

Currently, open detonation (OD) is the primary and preferred method of treating energetic hazardous wastes at China Lake. Open burn (OB) can be conducted in an elevated burn pan but is rarely used (the last OB was August 1998) for several reasons. Energetic wastes generated at other installations are not treated at China Lake. Additionally, China Lake is not a designated demilitarization facility.

China Lake operates one site to conduct OD events. The site is considered to be an environmentally friendly location for several reasons. China Lake is located in an arid climate. The OD unit is seven miles from the nearest base boundary to the east. The nearest base boundary in the dominant wind direction is 17 miles to the northeast, while the nearest town (Trona) is located nine miles to the southeast (**Exhibit 2**). A monitoring well at the site indicates that groundwater is more than 400 feet below the surface. The nearest surfacewater is on the base and is four miles to the west. Mountains surround the OD site, 1,400 feet

Exhibit 3. View of OD Unit from a Distance of One Mile



higher than the site to the north and 700 feet higher to the south, creating a natural amphitheater. The mountainous terrain mitigates the noise and blast from the OD. Additionally, the site is located in rocky terrain outside of the designated Desert Tortoise Management Area. A view of the OD unit from a one-mile distance is shown in **Exhibit 3**.

Rather than burying the waste items, the items are placed directly on the ground at the OD unit (**Exhibit 4**). This practice allows for maximum air entrainment, which in turn optimizes the important afterburning of the OD reaction to produce stable nontoxic compounds. **Exhibit 5** further explains the breakdown of an OD reaction. Because the range limit for the OD unit is 15,000 pounds of explosive weight, large amounts of donor explosive can be used to treat all types of energetic wastes. The use of donor explosives also ensures that all waste items are completely reacted to nontoxic products.

An open detonation is actually several reactions. The first reaction is the *detonation* itself. The detonation is over in microseconds. The temperatures associated are 3000°C and greater, sometimes up to 5000°C. Immediately after the detonation, *afterburning* is promoted by

Exhibit 4. Waste Items with Donor Ready for Treatment

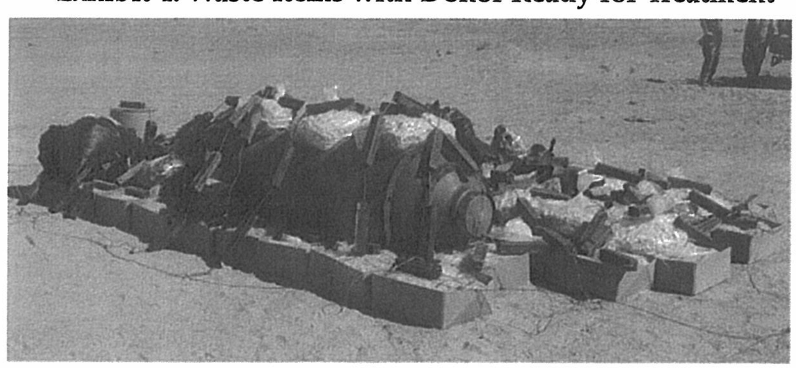
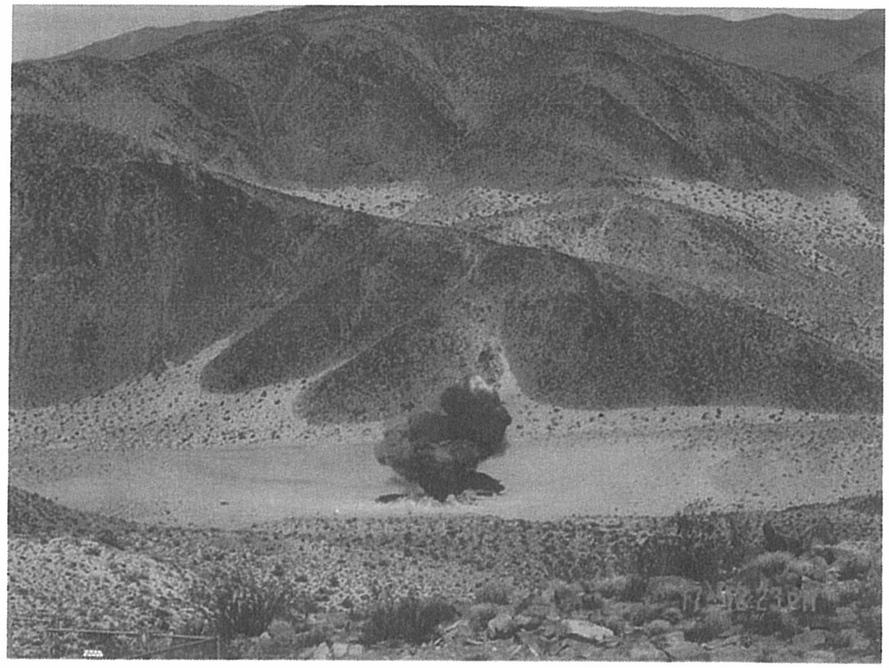


Exhibit 5. An OD Event at China Lake Treatment Unit



air that is entrained as the fireball rises. These afterburning reactions are very important because they convert the carbon monoxide to carbon dioxide, the hydrogen to water, and any other incomplete combustion/detonation products to stable nontoxic products. These afterburning reactions last for seconds and are characterized by 700–1700°C temperature flames. The *plume* is formed next. This takes seconds to several minutes. The visible plume is primarily dirt—dirt from the crater formed by the detonation and dirt entrained from the desert floor by the air entrained by the rising fireball.

PERMITTING AND THE HRA

The China Lake OD unit currently operates under a Resource Conservation and Recovery Act (RCRA) Part A (interim status) permit and a Clean Air Act Title V permit. The requirements for a RCRA Part B (final) permit are numerous. Perhaps the most significant of these requirements is a human health risk assessment (HRA). The HRA addresses health risks to people from the exposure from OD emissions at receptor locations (i.e., China Lake fenceline) over a 70-year period. It addresses cancer, acute non-cancer, and chronic non-cancer toxicities. Preparation of the HRA began in the early 1990s with direction from the state regulatory agencies. To compensate for the lack of validated data and the lack of standardized guidance available in the early 1990s, conservative assumptions were used. These conservative assumptions inaccurately inflated the health risks associated with OD emissions. This ultimately led to a conflict between safety standards and environmental regulations.

Since preparation of this original HRA in 1996, additional research and development has provided new data and improved methodologies for analyzing the emissions of OD. Based on these new data and findings, the original HRA was evaluated by a team of environmental specialists and technical experts in the research and energetics area at China Lake. This technical evaluation determined that newly available data refutes many of the assumptions used in the 1996 HRA and should be used in place of those assumptions to provide a more realistic analysis of actual health risks.

The first step in the HRA process (determining emissions at the treatment unit) is the most difficult.

Evaluation of the original HRA assumptions by the China Lake team prompted China Lake to focus their OD permitting efforts on three areas. The new approach is science-based, technically accurate, data-driven, and, perhaps most importantly, supported by the state regulatory agencies.

CHINA LAKE EFFORTS TO REVISE THE HRA

Effort #1—Emission Factor Database

The first step in the HRA process (determining emissions at the treatment unit) is the most difficult. The detonation event is extremely violent, so it is almost impossible to monitor emissions at the source itself. In addition, the detonation event results in a large amount of dirt being entrained in the detonation plume. Because of this entrained dirt, remote detection of the emissions using optical methods is almost impossible until the dust has dissipated. This usually takes 15 to 30 minutes after the detonation. By this time, the emissions have also dissipated and the resulting concentrations are below the method detection limits, except for species that are abundantly produced but typically do not pose a health concern (e.g., carbon dioxide, water, nitrogen). Other monitoring systems such as remote collection points or catch pans provide questionable results, if any, because of plume inhomogeneities.

Because of these difficulties, investigators conduct detonation tests in controlled environments, where they can collect and analyze the emissions. Validation of the emission factor database and incorporation of new data as it is obtained is continuing under the auspices of Chemical Compliance Systems, Inc., under contract to the Army Defense Ammunition Center, McAlester, Oklahoma. Data in the validated database originated from bang box–type tests, field tests at Dugway Proving Ground, and the "X Tunnel" at the Nevada Test Site.

Elimination Steps

The emission factor database consists of a matrix of data from tests. On the x-axis of the database is emission factor data from over 100 tests. On the y-axis is a list of over 1,000 compounds. The list of compounds originates from:

1) CA Assembly Bill (AB) 2588, Air Toxic Hot Spots Information and Assessment Act;
2) EPA Region IX Preliminary Remediation Goals (PRGs);
3) Compounds from the original China Lake HRA; and
4) Any leftover compounds from the tests not included on the above lists.

The first step at simplifying this massive database was to eliminate duplicates. For example, RDX was in the database as sym-cyclotrinitramine trinitramine, trimethylene trinitramine, hexahydro-1,3,5-trinitro-1,3,5-triazine, and as RDX. Also, many pesticides, herbicides, and pharmaceuticals that are neither treated by OD at China Lake nor likely to form as part of the detonation reaction, were deleted. After this step, 697 compounds remained. About 467 of these compounds are of health-risk concern (i.e., on the AB2588 and/or PRG lists).

As stated previously, OD treatment events at China Lake are conducted on the surface of the soil, which maximizes the afterburning of the OD reaction to turn incomplete reaction products into nontoxic compounds. Therefore, data from tests were also eliminated where the samples were buried or water quench was used, because they are irrelevant to China Lake's method of OD treatment.

Energetic Families

In order to assist with both the interpretation of the database for use in the HRA and the tracking of wastes treated for compliance purposes, it was decided to group the individual tests into families of energetic materials that are likely to give similar emissions. A review of energetic items treated at the China Lake OD unit resulted in the families listed in **Exhibit 6**.

Exhibit 6. Energetic Families

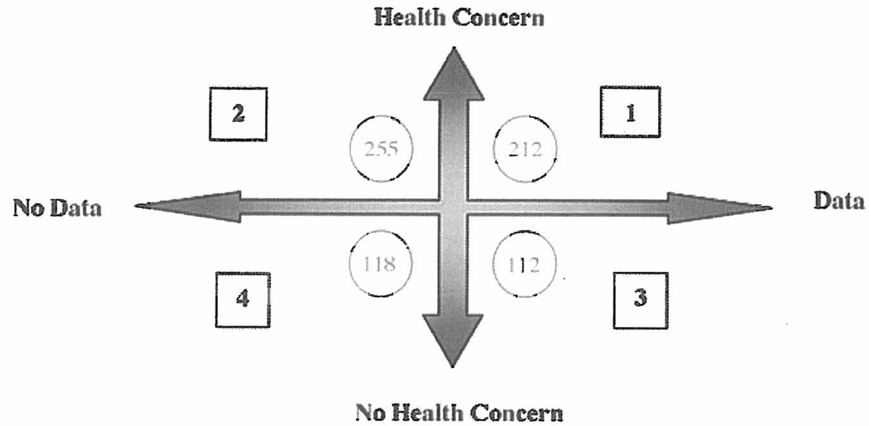
EXPLOSIVES

	Melt Cast Explosives
A1	TNT-Based (Comp-B, Octol)
A2	TNT/Aluminum (H-6)
	Plastic-Bonded Explosives (PBXs)
B1	Nitramine/Binder
B2	Nitramine/Binder/Aluminum
B3	Nitramine/Binder/Aluminum/AP
	Other Explosives
C1	e.g., PbN_3, ammonium picrate
	MISCELLANEOUS
P	Pyrotechnics
W	Energetic-Contaminated Wastes

PROPELLANTS

	Gun Propellant
IA	Single Base (NC)
IA	Double Base (NC/NG)
IA	Triple Base (NC/NG/NQ)
	Rocket/Missile Propellant
IIA	Double base with Lead
IIB	Double base without Lead
IIC	AP/Binder/Aluminum
IID	AP/Binder/Aluminum/Nitramines (> 50% AP)
IIE	AP/Binder Reduced Smoke
IIF	Nitramine/Energetic Binder/Al/ < 20% AP

Exhibit 7. Illustration of Quadrant Approach



Quadrant Definition

To assist with management of the emission factor database, the matrix of emission factors is broken into four quadrants based on the following:

> Is the compound of concern from a regulatory health-risk standpoint (i.e., is it included on the AB2588 and/or PRG lists)?
> Is test data for that compound available?

Based on the answers to both questions, each compound is placed into a quadrant, shown schematically in **Exhibit 7**. For example, there are 212 Quadrant 1 compounds with both a regulatory health-risk concern and data in the emission factor database. There are 255 Quadrant 2 compounds of health-risk concern, but without data in the database.

A quadrant is identified for each compound on a global basis. However, identification of emission factors is done on both a quadrant and a family basis. In each of the four quadrants, a different systematic approach was developed to identify the appropriate emission factor to be used in the HRA. The approach for each quadrant is outlined in the following paragraphs.

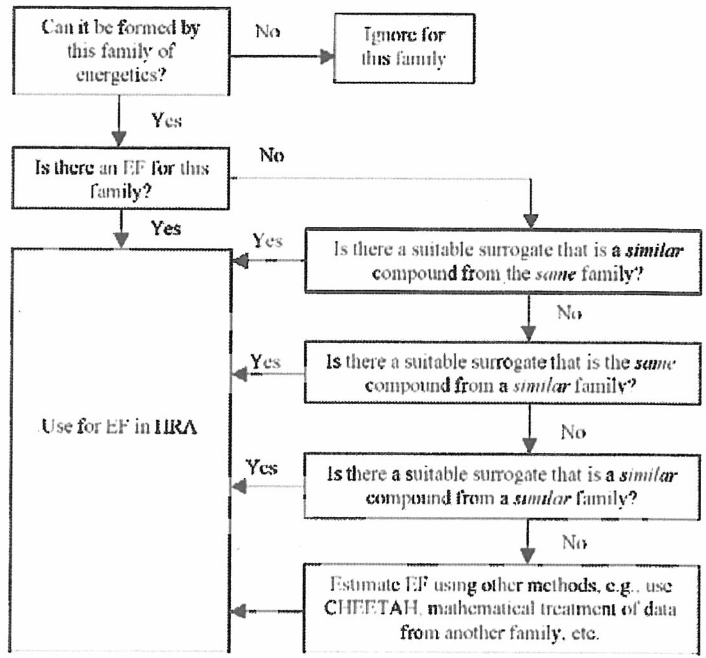
Quadrant 4

Quadrant 4 is the simplest to address. There is no regulatory health-risk concern and no data in the emission factor database. Species in this quadrant are simply ignored.

Quadrant 3

Quadrant 3 compounds have no regulatory health-risk concern but do have emission factor data. Because of the lack of a health-risk concern, they are not needed for the HRA. However, emission factor data for Quadrant 3 compounds are retained for potential use as surrogates for Quadrant 1 and 2 compounds.

Exhibit 8. Flowchart for Identification of Emission Factors for Quadrant 1 Compounds



Quadrant 1

Quadrant 1 compounds have emission factor data and are of health-risk concern. As stated previously, global approach is used to determine if a species should be placed into Quadrant 1. Therefore, emission factor data exists for that compound in at least one family but not necessarily for all. The overall approach to Quadrant 1 data is shown schematically in the flowchart in **Exhibit 8**.

For application of the flowchart to Quadrant 1 compounds, consider family A1 or the TNT family of explosives. Emission factor data for this family come from detonations of bulk TNT. TNT does not contain chloride, so no chloride compounds can be formed from the detonation of TNT. Hence, as an example, the Quadrant 1 compound, methyl chloride, cannot be formed. Methyl chloride is ignored for family A1.

As another example, benzene is also a Quadrant 1 compound. It can be formed from the detonation of TNT, because it is not very different from the starting TNT molecule. Continuing down the flowchart, the next question is: "Is there emission factor data for benzene in the TNT family?" Yes, a lot of emission factor data is available for benzene in this family. In order to provide an additional degree of conservatism in the revised HRA, the high emission factor value is used for compounds with more than one emission factor in a particular family of energetics.

Exhibit 9. Quadrant 2 Concentration Estimate

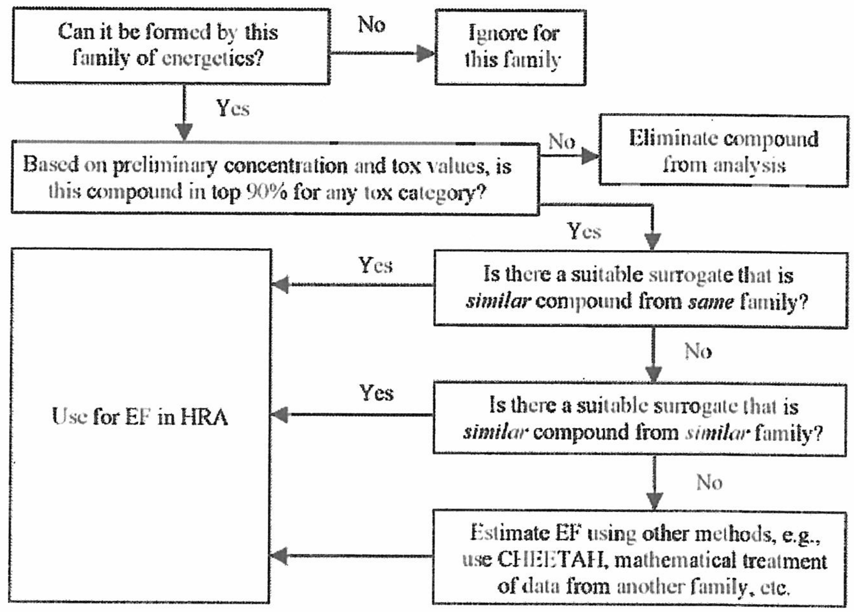
Present in Treated Ordnance?	Likelihood	Estimated Concentration (ppm)
Yes	Likely to withstand detonation intact	1
Yes	Likely to form (small molecules)	1
Yes	Unlikely to form	0.1
No	Likely to form (small molecules or similar to species present in treated ordnance)	0.1
No	Unlikely to form	0.001

One final example of a Quadrant 1 compound is azobenzene. It is conceivable that this compound could be formed from the detonation of TNT, but data are lacking for this compound in family A1. Continuing down the flowchart in Exhibit 8, a similar compound among those Quadrant 1 and 3 species with data in family A1 is sought. Nitrobenzene meets this requirement, so the high emission factor for nitrobenzene in family A1 will be used in the HRA as the emission factor for azobenzene for family A1. This surrogate approach ensures that a value will be used in the HRA for every Quadrant 1 compound independent of the existence of data within a family.

Quadrant 2

Quadrant 2 is the most problematic quadrant to address. Quadrant 2 compounds have regulatory health-risk concern but are without emission factor data. Options to address these compounds ranged from completely ignoring the compounds to conducting detonation tests on energetic materials. Ultimately, it was decided to use an operational risk management (ORM) approach. This approach allows China Lake to concentrate on those compounds that present the highest potential for a health-risk concern. First, a team of chemists with substantial experience in both synthesis and monitoring detonation products used the definitions in **Exhibit 9** to estimate expected concentrations of Quadrant 2 compounds (if these Quadrant 2 compounds were formed from a detonation). Next, the literature was reviewed for cancer, acute non-cancer, and chronic non-cancer respirable toxicity data. The estimated concentrations and toxicity data were mathematically combined to produce a health-risk screening. China Lake has decided to focus on those species that produce at least 90 percent of the cumulative health risk for each of the three toxicity categories. If a compound falls into this high-risk listing, a surrogate emission factor is chosen. Otherwise, the compound is ignored. This approach concentrates efforts on those species with the

Exhibit 10. Flowchart for Identification of Emission Factors for Quadrant 2 Compounds



highest potential health risk, while at the same time reducing the potential for significantly overestimating the health risk.

As with Quadrant 1, a systematic approach was developed for Quadrant 2 compounds, shown schematically in **Exhibit 10**.

As inferred from Exhibit 10, the Quadrant 2 approach to identifying emission factors is heavily dependent on identification of surrogate emission compounds from those Quadrant 1 and 3 species with emission factor data. Surrogate selection is based on chemical structural similarity, chemical formation mechanism similarity, and the likelihood that the surrogate compound will be present in a higher concentration than the compound needing a surrogate.

An example of a Quadrant 2 compound is 2-chloropropane. Using family A1 again, chloride compounds are not formed from the detonation of TNT, so this compound cannot be formed from family A1. The compound is ignored for this family.

Another Quadrant 2 compound, m-xylene, can conceivably form from the detonation of TNT. As with benzene, it is similar in structure to the original energetic material. However, m-xylene does not have a high cumulative health risk so it is ignored for family A1.

Methanol can conceivably form from the reaction products found in TNT detonations. This compound has a high health risk index for acute toxicity in family A1. Continuing down the flowchart in Exhibit 10, a similar compound is looked for from Quadrant 1 and 3 compounds with data in family A1. Ethanol serves as a good surrogate for methanol in this case. The highest emission factor for ethanol in family A1 will be used in the HRA as the emission factor for methanol in this family.

Effort #1—Summary

A systematic, data-driven approach to identifying emission factors for use in the revised HRA for OD events was developed by the China Lake team. This approach includes identification of emission factors for compounds without corresponding test data. Data gaps have been identified in the database, and new data or surrogates were used to fill the gaps. Where overlap exists, new emission factors are two to four orders of magnitude lower than those that were used in the original HRA, where inaccurate assumptions drove the risk.

Metal powders are typically incorporated in energetics to enhance performance or to increase burn rates.

The regulatory agencies have approved the approach described in this document and its application to family A1. Emission factors for all 17 families have been tabulated and are awaiting final regulatory approval.

Effort #2—Fate of Metals in Munitions

The primary concern addressed in this effort is the fate of metals in munitions treated by OD. The original HRA assumed that 1.1 pounds of metal casing were treated for every pound of energetic material treated, assumed compositions for these metals, and assumed that all of the metal was vaporized. When the original HRA was run "backwards" to determine which emissions were responsible for the apparent health risks, metals were determined to be the major cause for acute and chronic non-cancer risks. This is largely because the casing metal was assumed to vaporize upon detonation and persist in the atmosphere as a vapor.

Metals in Munitions

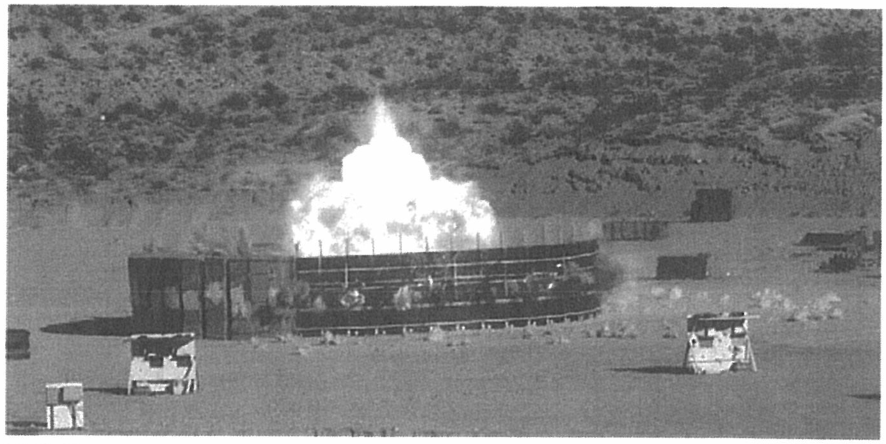
For clarification, metals may be present in munitions as:

- Ingredients in explosives, propellants, and pyrotechnics;
- Metal casings; and
- Platings, paints, and coatings

Metal powders are typically incorporated in energetics to enhance performance or to increase burn rates. These metals may be present in milligram quantities (e.g., lead azide) in primary explosives to several thousand pounds (e.g., aluminum) in propellants of large rocket motors. These metal additives are mainly oxidized in combustion and detonation reactions.

Rocket motor and warhead casings are typically steel. Aluminum is sometimes used for rocket motor casings. Casings range in weight from tens to hundreds of pounds. In addition, the casings of special design warheads may include titanium, tungsten, zirconium, or copper. The casing metal of a rocket motor or warhead does not participate in the detonation reaction; rather, it fractures and forms fragments. Warheads and bombs are designed to produce fragments.

Exhibit 11. Typical Arena Test for Lethality Analysis of Munitions



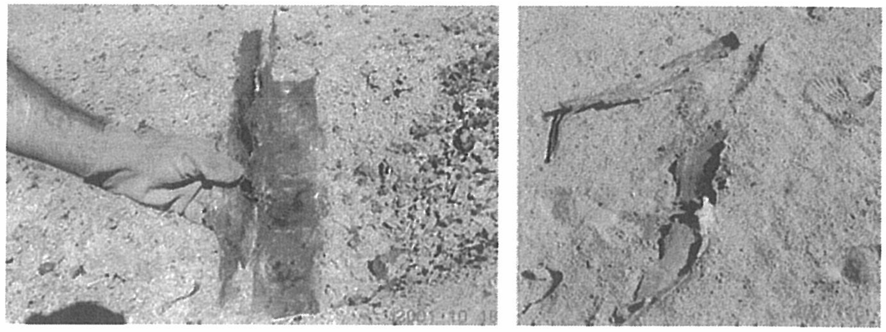
Examples of munition paints and coatings include protective paints and paints to designate (e.g., ordnance type and explosive fill), anodization, and zinc plating. Paints and coatings are very thin and in very small quantities. Therefore, these metals may vaporize and oxidize.

Proof That Metal Casings Fragment

Because the results of the original HRA were heavily biased from the assumption that metal casings vaporize rather than fragment, most of China Lake's effort focused on gathering evidence that this assumption was incorrect. China Lake compiled evidence that includes, but is not limited to, the following (a technical paper outlining this effort in detail is available from the lead author of this article):

1) Lethality studies of munitions (**Exhibit 11**). Test results indicate that 95–99 percent of the metal casings are recovered as fragments. The remaining fine fragments are difficult to recover and are not considered in lethality analysis. So no effort was made to recover these.
2) Fragments from the OD unit (**Exhibit 12**). Many fragments are found throughout the OD site, with many found several hundred yards from the impact area. Examination of these fragments indicates no evidence of melting (e.g., rounded edges). Fragments reveal sharp edges or edges that may be blunted as a result of impact. Melting occurs at lower temperatures than vaporization. Therefore, any appreciable vaporization of casing metals is not possible without evidence of melting.
3) Ultra-high-speed photos. **Exhibit 13** provides stop-action photos taken at a million frames per second. The example photographs show metal casing expansion at one, four, and

Exhibit 12. Fragments from OD Unit



six microseconds. Most significantly, frames 2 and 3 show the casing breaking into a pattern of small diamond shapes.

4) Thermal analysis calculations. China Lake scientists conducted thermal analysis calculations using conductive heat transfer into metals, detonation temperature and pressures, jump temperature caused by the shock wave, metal melting and vaporizing points, and exposure time versus time to casing breakup. Even with conservative parameters, such as the detonation temperatures applied for unrealistically long duration and at surrounding pressures much lower than the pressures of the detonation, the calculated amount of melting and, hence, vaporization is virtually nil.
5) Metallurgical analysis of an OD fragment. A 19-inch long metal casing fragment from an OD test was offered by the Army Defense Ammunition Center, McAlester, Oklahoma to China Lake for evaluation. The fragment was of interest because of a bronze smear on the steel sample. The smear could be evidence that the bronze rotating band melted or vaporized. Based on visual observations, metallographic examinations, chemical analysis, microhardness measurements, and scanning electron

Exhibit 13. Submunition Casing Fragmentation

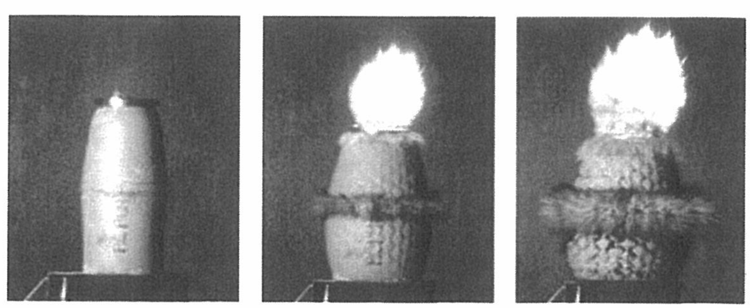
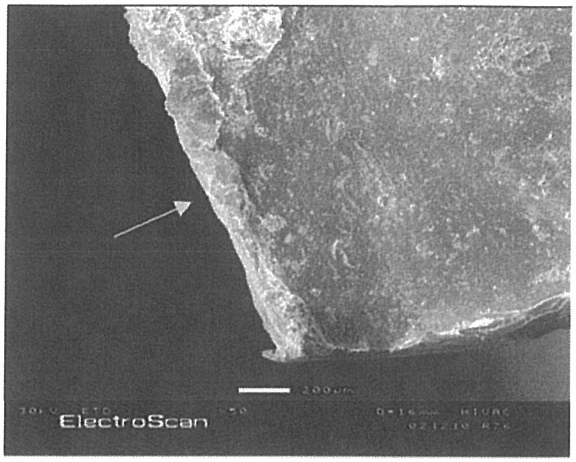
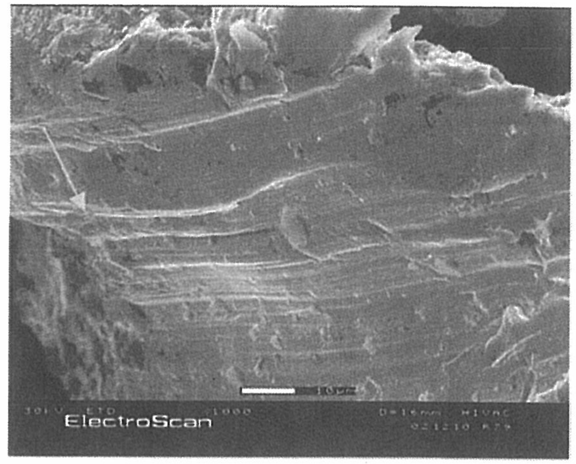


Exhibit 14. SEM Photographs of the OD Fragment





The left photograph shows a thin feathery edge that is most susceptible to melting. The edge is not featureless and therefore does not provide evidence of melting. The right photograph shows a rolled edge that is evidence of mechanical deformation, but not intense heat.

microscopy (SEM) (**Exhibit 14**), no melting of the bronze rotating band or steel casing was observed.

Effort #2—Summary

Even though the data that metal casings fragment and do not melt or vaporize are overwhelmingly convincing, China Lake has agreed to refine that analysis to account for casing particulates. Emissions test data from the emission factor database was combined with the amount of metal in a specific type of casing (e.g., warhead, missile motor, bomb) to calculate the emission factor of a specific metal resulting from a metal casing. This same methodology is applied for metal emissions from the energetic and from paint/coatings.

Calculations indicate that the emission factors for metal casings are four orders of magnitude lower than those in the original HRA. In addition, chromium, nickel, and molybdenum were not considered in the original HRA, but are in the revised methodology.

Effort #3—OD Tests for Energetic-Contaminated Wastes

One area where data is completely lacking in the emission factor database involves energetic-contaminated wastes (ECW). Due to this lack of data, the original HRA used emissions data from a medical waste incinerator. This data resulted in high levels of dioxins and mercury—both unrealistic emissions from OD of energetic waste. Unlike medical waste, very little mercury, if any at all, is present in the China Lake wastestream. The formation of dioxins is discussed below.

Exhibit 15. Test Items

Species	Donor Tests	ECW Tests
RP-501 Detonator	1 ea	1 ea
A3 Donor	225 g	225 g
Energetic	–	140 g
Plastic	–	11 g
Aluminum Foil	–	1.2 g
Rags and Paper	–	32.5 g
Glass	–	0.4 g
Acetone	–	5 g

ECW include items such as rags, velostat bags, aluminum foil, and cardboard used in preparing and packaging energetic materials. These materials are of concern because they tend to be fuel-rich unlike the energetics, which tend to be a stoichiometric mixture of fuel and oxidizer. Fuel-rich combustion processes are notorious for producing large quantities of toxic byproducts. In order to determine emission factors for ECW, a series of small-scale detonation experiments was performed at China Lake to monitor product species.

Description of Tests

Two series of tests were performed in triplicate as indicated in **Exhibit 15**. The first series consisted of only a donor charge. Composition A3 was chosen for the donor charge because it is a donor typically used for OD events at China Lake. These tests provided an indication of the emission products from the donor charge.

The second series of tests involved detonation of a donor charge along with an energetic containing the ECW component. Quantities of materials used to represent the ECW component were obtained through an historical evaluation of items treated by OD at China Lake. These quantities are also presented in Exhibit 15. A high ammonium perchlorate (AP) content aluminized energetic was intimately mixed with the ECW components and cast into a cylindrical cardboard tube (**Exhibit 16**). This ECW was mixed and cured in place on the donor charge prior to each test.

Dioxin/Furan Results

Sampling and analysis was conducted for a full suite of emission products. However, because dioxins/furans were responsible for the bulk of the cancer risk in the original HRA, dioxin/furan results are the most significant for the revised HRA. Therefore, only dioxins/furans results are presented in this article. It should be noted that the mechanisms for dioxin and furan formation require significant residence times in a limited temperature range, conditions that are not likely in a

Exhibit 16. As-Cast Energetic with ECW

detonation but are common in incinerators. To test this hypothesis, the ECW experiments were designed as a worst-case scenario in which the AP energetic contained large quantities of chlorine that could result in the production of high concentrations of dioxins and furans. Dioxins/furans results from these experiments are listed in **Exhibit 17**.

Test results using the A3 donor charge, which does not contain chlorine, show very low levels of dioxin formation. Concentrations of dioxin produced in the ECW tests are roughly two orders of magnitude higher than those formed by the donor alone, showing that dioxins can be formed in a chlorine-rich detonation. However, as predicted, concentrations of dioxins formed by OD are significantly lower than those found in the medical waste incinerator—by three orders of magnitude.

Effort #3—Summary

The primary drivers for non-cancer and cancer risks (mercury and dioxins, respectively) have proven to be much less of a factor

Exhibit 17. Dioxin and Furan Emission Factors from ECW Testing

	Average Emission Factor (g/g)		Original HRA Emission Factor
Compound	**Donor**	**ECW**	
TEQ (as 2,3,7,8-TCDD)	1.64e-13	2.03e-11	2.22e-8

than originally thought. In fact, dioxin emission factors are three orders of magnitude lower than values obtained from the medical waste incinerator.

For a fuel-rich source, remarkably little organic products were detected. Within experimental error, all of the carbon can be accounted for as carbon dioxide and carbon monoxide, indicating that afterburning for these experiments is almost complete. Additionally, detonations with ECW appear to be cleaner than those with just the A3 donor. In fact, many of the species detected in the donor tests were absent in the ECW test results. This cleaner detonation is likely an artifact of higher initial temperatures obtained through involvement of the aluminum and AP of the energetic sample.

CONCLUSION

China Lake has developed an innovative, science-based approach to address potential impacts on human health from OD activities. The approach is approved by the state regulatory agencies and is designed to withstand public scrutiny. By incorporating this approach in development of the HRA, health risks are lowered by several orders of magnitude. China Lake plans to finalize the HRA calculations in the next several months. The results of the HRA will then be available for distribution. In addition to the three efforts described in this article, China Lake has also prepared a detailed study of alternative technologies to OD for treatment of energetic wastes. Overall, OD is not only a cost-effective, simple, and safe treatment method, but also has proven to be an environmentally clean means of treating energetic hazardous wastes at China Lake. ❖