2016

Best Practices: Emergency Medical Management to Hydrazine Exposure

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Cleared, 88PA, Case # 2016-3680, 26 Jul 2016.

Acknowledgements

Many people greatly assisted me in this project and I would personally like to thank each of them. First, thanks to Nikki Rogers, Ph.D. and Lori Metivier for reviewing and answering all my questions regarding my culminating experience and especially for correcting all my APA format errors. Thanks to Naila Khalil, M.B.B.S, M.P.H., Ph.D. who provided a great review of my Methods, Analysis, and Results section. A special thanks to Mark Gebhart, M.D. for being a fantastic M.P.H. program advisor who solidified my understanding of emergency public health preparedness and reviewed my project for appropriate content. Though half a world away, a personal thanks to Talib Ali, M.D, M.P.H., for his review, inputs, and assistance in providing a solid occupational health framework for this project. Finally, I would like to thank my family for all the support they provided while I was banging my head against the wall trying to finish this.

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Abbreviations

ACGIH® – American Conference of Governmental Industrial Hygienists

ATSDR – Agency for Toxic Substances and Disease Registry

CDC – Centers for Disease Control and Prevention

EMS – Emergency Medical Services

EPU – Emergency Power Unit

IDLH – Immediately Dangerous to Life or Health

MDGI – Medical Group Instruction

NASA – National Aeronautics and Space Administration

NIOSH – National Institute for Occupational Safety and Health

OSHA – Occupational Safety and Health Administration

PEL – Permissible Exposure Limit

PPE – Personal Protective Equipment

REL – Recommended Exposure Limit

SPEGL – Short-Term Public Emergency Guidance Level

TWA – Time-Weighted Average

USAF – United States Air Force

Abstract

Objective: Hydrazine is a toxic industrial chemical with significant health risk. It is commonly used in aerospace technologies as a propellant fuel source for rockets and aircraft. The purpose of this project was to perform a comparative analysis of the emergency algorithms at United States Air Force installations where occupational hydrazine exposure may occur and then create a best practices approach for medical responders.

Methods: After review of current Occupational Safety and Health Administration standards and requirements for hydrazine, six United States Air Force Medical Group installation response protocols were analyzed and compared to each other and to current medical treatment recommendations.

Results: Analysis permitted creation of a best practices medical approach to a hydrazine exposure incident. Three specific areas of medical response focus were identified: initial fire department and emergency medical services requirements, medical evaluation and testing requirements, and immediate medical treatment requirements. Additionally, to facilitate emergency medical responders during a hydrazine incident, a protocol driven flow-sheet was created.

Conclusion: Though a rare event, occupational hydrazine exposure may lead to significant health consequences. Ensuring medical providers are able to both quickly and appropriately evaluate and treat exposure is of critical importance. As hydrazine is commonly encountered at United States Air Force bases, these findings could be utilized to standardize response protocols across all installations. As future studies and case reports clarify risk hazards, monitoring and updating of this protocol will be required.

Keywords: emergency management, EMS, first responders, occupational health

Cleared, 88PA, Case # 2016-3680, 26 Jul 2016.

Best Practices: Emergency medical management to hydrazine exposure

Hydrazine is a clear, colorless liquid at room temperature with an ammonia-like odor that is highly flammable, toxic, and potentially carcinogenic (National Institute for Occupational Safety and Health [NIOSH], 2007). It is a powerful reducing agent and readily absorbed through the skin, gastrointestinal, and respiratory tracts. Acute skin exposure may cause irritation, corrosion, and burns (Davis, Johnson, Stepanek, & Fogarty, 2008). Respiratory symptoms consist of irritation, shortness of breath, pneumonitis, and potential pulmonary edema (NIOSH, 2007). If swallowed, hydrazine may cause nausea, vomiting, and possible intestinal hemorrhage (NIOSH, 1988). Hydrazine is also a central nervous system depressant causing lethargy, seizure, neuritis, and coma (NIOSH, 1988). Chronic exposure presents as hepatic, renal, or blood disorders (Agency for Toxic Substances & Disease Registry [ATSDR], 1997). The anticipated individual health effects of hydrazine are contingent upon the duration, route of entry, and exposure concentration.

Hydrazine is used by multiple international Air Forces as well as international Space Agencies (including the National Aeronautics and Space Administration [NASA]), as a propellant fuel source for rockets, missiles, space vehicles, and as a primary energy source for the emergency power unit (EPU) in various military aircraft (Davis et al., 2008). Additionally, hydrazine is used as a reactant in chemical manufacturing, boiler water treatments, pharmaceuticals, and cancer research (ATSDR, 1997). The United States Air Force (USAF) has implemented engineering, administrative, and personal protective equipment (PPE) control measures to ensure workers receive minimal exposure risk consistent with National Institute for Occupational Safety and Health (NIOSH) guidance (United States Air Force [USAF], 2008).

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However, potential for hydrazine exposure still exists for maintenance personnel, a mechanical failure of equipment, an emergency or inadvertent activation of the system, or human error.

USAF installations where potential hydrazine exposure may occur have developed emergency response plans to be implemented by first responders (fire department and emergency medical services [EMS]) upon potential hydrazine exposure. Each medical facility separately develops its own Medical Group Instruction (MDGI) to be implemented by their medical response team. Because of hydrazine’s high toxicity, no human studies have been completed limiting published toxicological literature to animal studies and a few case reports. This lack of data creates difficulties in establishing a best emergency medical management response plan. Though each Air Force installation likely follows a similar response pattern, given individualized MDGI’s, there is potential for installations to have varying medical response plans. In this paper, I review current Occupational Health and Safety Administration (OSHA) and NIOSH hydrazine guidelines and analyze six United States Air Force hydrazine response MDGI’s from installations around the world. Using this data, I develop a best practices approach for emergency medical response to hydrazine given current published guidelines and review of medical response protocols from facilities actively engaged in hydrazine incidents. Additionally, a protocol driven flow-sheet was created to assist medical responders in achieving a best practice response. These recommendations may be beneficial to all entities involved in a potential hydrazine exposure in improving their site specific emergency medical response and treatment plans.

Hydrazine Review

Chemical Toxicity

Hydrazine, also known as diamine or anhydrous hydrazine, is an inorganic chemical compound with the chemical formula N_2H_4 (NIOSH, 2007). It is highly toxic, flammable, corrosive, and very unstable unless handled in solution (NIOSH, 2007). Table 1 depicts several physical properties of hydrazine.

Table 1

Physical Properties of Hydrazine

PHYSICAL PROPERTIES
Odor Threshold: 3.7 parts per million (ppm)
Flash Point: 100^o F (38^o C)
Boiling Point: 236^o F (113^o C)
Freezing Point: 36^o F (2.2^o C)
Vapor Pressure: 10 mm Hg at 68^o F (20^o C)
Water Solubility: Soluble
Specific Gravity: 1.01 (water = 1.00)

Source: New Jersey Department of Health, 2009

Hydrazine is mainly used as a reagent in creating chemical foaming agents, as a building block for agricultural pesticide products and pharmaceuticals, and in cancer research (World Health Organization [WHO], 1991). It is also found in low concentrations in tobacco smoke (National Research Council [NRC], 2007). Hydrazine's highly reactive and combustible properties led to its first use as a rocket fuel by the German Aeronautical Institute in their ME-163 fighter plane and their V-2 missiles during World War II (Simpson, 1986). Today's aerospace industry uses hydrazine for the maneuvering thrusters of spacecraft, as a propellant fuel source for rockets and missiles, and as the EPU fuel supply for various military aircraft (Davis et al., 2008).

Several modern day aircraft use 'fly-by-wire' systems which indicates that flight controls are powered electronically. When a 'fly-by-wire' aircraft control stick is operated, the movement on the control stick is converted to an electrical signal (USAF, 2000). This signal is then transferred to the onboard computer where determination of how to move the aircraft in the requested direction is controlled. These 'fly-by-wire' flight control systems operate on electrical power and hydraulic pressure provided by the main engine(s) (Suggs, Luskus, Kilian, & Mokry, 1979). In the case of aircraft engine failure, the EPU activates a small, secondary engine that propels an electrical generator and hydraulic pump system to provide the aircraft emergency flight controls (USAF 31 Medical Group, 2015). The EPU can be activated manually by the pilot or automatically with loss of electrical power or hydraulic pressure (USAF, 2000). When activated, hydrazine enters the EPU combustion chamber where it interacts with a catalyst to create a forceful reaction generating gases that then drive the small, turbine engine from 0 to 75,000 revolutions per minute in milliseconds (USAF, 2000). Though aircraft specific, in theory the hydrazine fueled EPU generates enough power to the aircraft flight control systems to afford the pilot enough time to perform emergency landing procedures (USAF, 2000).

Hydrazine used in military aircraft is an aqueous solution composed of 70% hydrazine and 30% water, commonly referred to as ‘H-70’ (USAF, 1997). When burned as an EPU fuel, it is converted to 99.6 to 99.98% ammonia and water with only trace amounts of hydrazine in the exhaust (Suggs et al., 1979). However, EPU exhaust studies performed by Suggs, Luskus, Killian, and Mokry found higher traces of unburned hydrazine in the first 30 seconds of EPU firing (1979). Thus, with an inadvertent ground EPU activation, the exhaust most likely provides an ammonia rather than hydrazine exposure except upon initial firing which presents a potential hydrazine exposure risk to maintenance personnel (USAF, 2000). Other risks of exposure to hydrazine are most likely to occur to individuals who service the aircraft and related EPU equipment via liquid spills and to first responders during a leak or crash recovery response (USAF 35 Medical Group, 2012). Pilots may encounter hydrazine during an emergency activation of the EPU system if the pilot is not breathing 100% oxygen (USAF 71 Flying Training Wing, 2011).

A more recent concern for individual exposure occurred in 2008 after the United States (U.S.) Navy shot down an aging government satellite dispersing its contents into space. The reason for the missile deployment was to stop the deteriorating satellite from crashing to earth exposing a half a ton of hydrazine from the satellite's unused propellant fuel tank to an unknowing population (Oberg, 2008). Similarly, because of its explosive quality, hydrazine was initially considered as an explosive agent in the 1995 Oklahoma City bombing but because the chemical was too expensive for purchase, ammonium nitrate and nitromethane were instead employed (Giordano, 2003).

Because of its toxicity, hydrazine has been listed on the Special Health Hazard Substance List with Workplace Exposure Limits recommended by OSHA, NIOSH, and other federal agencies (New Jersey Department of Health, 2009). Table 2 depicts current exposure limit recommendations as determined by the listed governmental agency. Current OSHA permissible exposure limits (PEL) for hydrazine is 1.0 parts of hydrazine per million parts of air (ppm) (NIOSH, 1988). NIOSH (1988) further recommends that hydrazine be controlled and treated as a potential carcinogen and that exposures be minimized to the lowest feasible limit. Interestingly, when NIOSH first established their recommended exposure limit (REL) in 1988 of 0.03 ppm in a 120-minute time frame, 0.03 ppm was the lowest concentration reliably detectable by existing NIOSH analytical methods (NIOSH, 1988). Because of continued toxicity concern, NIOSH opted to retain 0.03 ppm as their established REL when hydrazine was reviewed in 2007 (NIOSH, 2007). Thus, any exposure to hydrazine via skin, gastrointestinal, or respiratory tracts should be considered a significant exposure risk and appropriate management is warranted.

Table 2

Workplace Hydrazine Exposure Limits

EXPOSURE LIMITS
OSHA: 1.0 parts per million (ppm), 8-hr TWA NIOSH: 0.03 ppm, 2-hr ceiling ACGIH: 0.01 ppm, 8-hr TWA SPEGL: 2 ppm, 1-hr period NIOSH IDLH: 50 ppm The Protective Action Criteria values are: PAC-1 = 0.1 ppm PAC-2 = 13 ppm PAC-3 = 35 ppm
OSHA – Occupational Safety and Health Administration TWA – Time-Weighted Average NIOSH – National Institute for Occupational Safety and Health ACGIH – American Conference of Governmental Industrial Hygienists SPEGL – Short-Term Public Emergency Guidance Level IDLH – Immediately Dangerous to Life or Health

Source: New Jersey Department of Health, 2009

Because of its ammonia-like odor, hydrazine workers may develop a false sense of security with regards to potential exposure risk (Suggs et al., 1979). As Table 1 indicates, the odor threshold for hydrazine is estimated to be between 3 to 4 ppm, well above both the American Conference of Governmental Industrial Hygienists (ACGIH®) recommended exposure level and the Short-Term Public Emergency Guidance Level (SPEGL) as noted in Table 2 (Amoore & Hautala, 1983). Thus, a misperception occasionally circulated by occupational workers that ammonia smell equates to exposure is false and odor cannot be relied upon to warn workers of overexposure (Suggs et al., 1979).

The National Research Council's (NRC) Committee on Toxicology, established the SPEGL for hydrazine in 1985. SPEGL indicates the risk of acute illness or injury to individuals who are exposed. The SPEGL recommended for hydrazine is 2 ppm in a one-hour period (NRC, 1985). The United States Air Force follows both the ACGIH® threshold exposure limit of 0.01

ppm over an eight-hour time-weighted average (TWA) and the NRC's SPEGL recommendations (USAF, 1997).

Because of hydrazine's toxicity, NIOSH (1988) recommends both a pre-placement physical examination and, if hired, employee enrollment in an occupational health medical surveillance program. The pre-placement and periodic medical surveillance exams should focus on organ systems where exposure will likely cause harm. Additionally, providers should obtain a baseline complete blood count (CBC) and lung function evaluation via pulmonary function testing (PFT) prior to employment (NIOSH, 1988).

Many common operational control measures are recommended when working with hydrazine. Specifically, attempts to enclose the process, use of local exhaust ventilation, and PPE are recommended (NIOSH, 1988). Current PPE guidelines for occupational use of hydrazine include chemical protective clothing, gloves, goggles, and a self-contained breathing apparatus (SCBA) respirator operated in either a pressure-demand or positive-pressure mode if hydrazine is not enclosed (NIOSH, 1988).

During an emergency response, first responders are instructed to isolate the spill or leak area at least 150 feet away from the incident, stay upwind, keep out of low areas, and ventilate any closed spaces (Emergency Response Guidebook [ERG], 2012). Prior to entering the contaminated area, emergency responders are instructed to wear positive-pressure SCBA respirators and an under layer of chemical protective clothing (ERG, 2012).

Literature Review

There are minimal human epidemiological studies on hydrazine. In 1984, Wald *et al*. evaluated 427 English males who had variable amounts of occupational hydrazine exposure. The cohort examined was from a British industrial company that specialized in manufacturing

Cleared, 88PA, Case # 2016-3680, 26 Jul 2016.

hydrazine, with 1.4 million pounds generated annually. Employees were classified by their exposure amount (there was no evaluation of exposure duration). Individuals exposed to concentrations between 1-10 ppm were considered high exposures. Individuals with amounts <1 ppm were considered low exposures. Wald, Boreham, Doll, and Bonsall's (1984) study failed to reveal any relationship between exposure levels and cause of death. In a follow-up study 10 years later, Morris, Densem, Wald, and Doll (1995) re-evaluated 406 of the original 427 English workers and again noted no increase in mortality from all causes.

However, in 1999, Ritz, Morgenstern, Froines, and Moncau studied a group of over 6,000 males who worked with rocket-engine fuels, all of whom had greater than two years of potential hydrazine exposure. Individuals in the high-exposure group were found to have an 68% to 110% increased lung cancer rate ratio (rate ratio: 1.68 to 2.10) compared to unexposed workers (ratio dependent upon the duration of exposure). Additionally, rates for kidney, bladder, and lymphocytic cancers were higher than the baseline group (Ritz, Morgenstern, Froines, & Moncau, 1999). However, the author points out the study was technically flawed in that the occupational workers were also potentially exposed to asbestos, chlorine, beryllium, fluorine, and other chemical compounds known to increase cancer risk.

A few case reports have been published documenting unprotected individual exposure to hydrazine. Multiple case reports note skin and eye irritation upon contact exposure though no further health complication occurred after appropriate treatment. A few others, reviewed below, describe damage to the central nervous system, heart, and lungs.

One of the first case reports documenting adverse health effects of hydrazine was noted in a British sailor in 1965 after an accidental ingestion of a cup of hydrazine. He began to vomit, became weak with dilated pupils (though pupils were reactive to light), and went in and out of consciousness. Twelve hours after ingestion, his vomiting resolved but there were reports of behavior change with sporadic violence towards nursing staff. Within 48 hours, he was described as comatose, convulsive, and was receiving mechanical ventilation via endotracheal intubation. The patient became ataxic and lost all sensory vibration, though electroencephalogram (EEG) results were deemed normal. Fortunately, the individual's symptoms resolved over time and he eventually returned to work (Clayton & Clayton, 1982).

Another accidental ingestion case report documented a lab technician who drank 20-30 mL of a 6% aqueous hydrazine solution and vomited immediately after intake. Four hours later, he developed weakness, somnolence, and a cardiac arrhythmia. After five days of exposure, the worker had complete recovery (WHO, 2004).

Inhalation of hydrazine vapors has produced severe health effects in multiple cases. One such case report involved an individual who handled hydrazine weekly without appropriate PPE. Within six months he began showing signs of fatigue, eye redness and irritation, and tremors. His final day of occupational exposure led to fever, vomiting, and severe abdominal pain. He was hospitalized after becoming incoherent and found to have hepatomegaly, tracheitis, bronchitis, pleural effusions, and elevated creatinine levels. He died 20 days after his last exposure (Clayton & Clayton, 1982).

There is some debate on the appropriate medical management of hydrazine exposure. It is hypothesized that hydrazine forms oxygen free radicals which interferes with gluconeogenesis (Hussain & Frazier, 2002) and likely alters vitamin B6 (Pyridoxine) preventing the functioning of multiple co-factors (Harati & Niakan, 1986). Pyridoxine as a possible treatment for central nervous system effects is controversial given the limited number of case reports. Between 1965 and 1985, only four case reports of accidental hydrazine poisoning were found where Pyridoxine was administered. The first case study was reported by Kirklin, Watson, Bondoc, and Burke (1976) who successfully treated a hydrazine-induced coma with Pyridoxine. In total, three of the four case reports showed complete recovery leading Makarovsky, Markel, Dushnitsky, and Eisenkraft (2008) to recommend Pyridoxine 25 mg/kg intravenously for hydrazine treatment. However, previous experimental studies in rats showed mixed results. Azar, Thomas, and Shilliton (1970), in their review of hydrazine, cited three studies pointing to the ineffectiveness of Pyridoxine. Conversely, Cornish (1969) reported an 83% survival rate among rats given 15 mg/kg of Pyridoxine intravenously. In a hydrazine review by Zelnick, Mattie, and Stepaniak (2003) the issue is succinctly stated that with the limited knowledge of hydrazine treatment, future research is required.

Methods

To determine the best emergency medical management practices to a hydrazine exposure incident, primary analysis was conducted by researching current hydrazine treatment recommendations from the medical literature and analyzing recommendations from USAF installations actively engaged in operational use of hydrazine. Review of USAF active duty installations reveals approximately 65 worldwide locations (deployed sites were not considered) where active flying operations occur on a nearly daily basis (USAF, 2016). It was determined that evaluation of 10% of all active duty flying USAF installation medical response hydrazine protocols (six or seven installations) should provide a suitable baseline for analysis of hydrazine emergency management practices. MDGIs from seven locations around the world were requested for analysis and six responses were received (86% response rate).

Each USAF installation's MDGI was first analyzed individually and then compared to the other installations. This comparative analysis permitted evaluation for strengths and weaknesses of each installation's specific medical response plan. After comparative analysis of the content in all six MDGI's, three specific themes emerged from among each installation's emergency medical response. These three themes were then chosen to become the primary subject areas for development of a best practices approach. These three main focus areas for emergency medical response to a hydrazine exposure are: 1) initial fire department and emergency medical system (EMS) response requirements, 2) medical evaluation and testing requirements, and 3) immediate medical treatment considerations and recommendations.

After further MDGI comparative analysis and review of current literature, subcomponents were identified for each individual area of focus which thus allowed for creation of a best practice approach. Once this best practices reference criterion was established, the ability to analyze and compare various existing approaches to emergency medical management of hydrazine could successfully be accomplished. Appendix A shows the suggested best medical practices approach to a hydrazine incident.

The first best practices area of focus is the immediate tasks expected of first responders. There are multiple organizations which have established various algorithms for both fire departments and EMS to follow during a hazardous material (hazmat) response. As the purpose of this paper is not to review these protocols but to determine a best practices approach, it is assumed each EMS agency already follows established national guidelines as discussed previously and documented in the U.S. Department of Transportation's 2012 Emergency Response Guide. For specific first responder hazmat requirements, detailed guidance protocols have been developed by the following agencies, OSHA's "Best Practices for Protecting EMS Providers," (Occupational Safety and Health Administration [OSHA], 2009), Agency for Toxic Substances and Disease Registry's (ATSDR), "Emergency Medical Services Response to

Hazardous Material Incidents (ATSDR, 2001)," and the U.S. Department of Energy's "Hazardous Materials Incident Response Procedure" (U.S. Department of Energy, 2007).

During analysis of the six USAF installation MDGI response protocols, ten frequently performed emergency response tasks were identified. These ten tasks are the first domain of best practices and would be expected to occur during a best practice emergency hydrazine response by first responders and thus were used to create a best practices recommendation for emergency response to a suspected hydrazine exposure. These ten tasks identified are shown in Table 3.

Table 3

Ten Emergency Response Tasks for a Suspected Hydrazine Exposure

Emergency Response Tasks for a Suspected Hydrazine Exposure
Fire Services respond with appropriate Personal Protective Equipment (PPE)?
If hydrazine suspected, gross water decontamination performed by Fire Services?
Emergency Medical Services required to respond to suspected hydrazine exposure?
Physician evaluation required for suspected hydrazine exposure?
Hydrazine Response Team responds if hydrazine confirmed?
With moderate to severe exposure, immediate transfer to Emergency Department/hospital?
Is there a medical response protocol/flow sheet?
Requirement stated to document exposure to Public Health or Bioenvironmental Engineering?
Is there a discussion to treat EPU exhaust as ammonia and not as hydrazine?
Are permissible exposure limits documented?

The second best practices domain was medical evaluation and testing requirements. Medical evaluation establishes a baseline of examination and medical tests recommended based on potential health outcomes associated with hydrazine exposure. A complete history and physical exam focused on specific organ systems with disease potential from hydrazine is always recommended for medical responders (Lawrence, Bell, Merrill, & Hebert, 2013). For hydrazine, initial medical management of potentially affected organ systems includes a detailed exam of the dermatological, respiratory, cardiovascular, hepatic, renal, ophthalmological, oropharynx, and central nervous systems (NIOSH, 1988). The recommended laboratory and radiological tests are conducted following similar rationale. Given the potential length of time required from acute exposure to possible disease onset (i.e. pulmonary edema may occur four to eight hours after exposure), all laboratory and radiological testing recommendations are proposed to attain a baseline level which will be needed to trend potential worsening health status in exposed individuals. Because of the possibility for delayed symptom development, follow-up examinations are recommended at both 24 hours and seven days after exposure.

After review of current NIOSH recommendations and analysis of the six USAF MDGIs, 15 recommendations were identified which should be completed during a medical evaluation of a suspected hydrazine exposure. Given the toxicity of hydrazine, completion of these 15 recommendations would constitute a best practices approach for medical evaluation. Table 4 lists the organ systems and laboratory recommendations for medical evaluation of a hydrazine exposure.

Table 4

Medical Evaluation Tasks for a Hydrazine Exposure

Medical Evaluation Tasks for a Suspected Hydrazine Exposure
Vital Signs: blood pressure, pulse, respiratory rate, temperature, and oxygen saturation
Head and neck exam (with focus on pupillary reflex and conjunctiva)
Cardiovascular physical exam
Pulmonary exam
Abdominal exam
Neurological exam
Dermatological exam
Initial Pulmonary Function Test (PFT)
Complete Blood Count with differential (CBC)
Complete Metabolic Profile (CMP)
Urinalysis
Chest X-ray (discussion of delayed pulmonary edema risk?)
24-hour follow-up examination required?
7-day follow-up examination required?
Return to work discussion?

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The third best practices domain was the immediate medical management of exposed individuals. If hydrazine exposure is confirmed or individuals are symptomatic, appropriate medical treatment is critical. As with many chemical exposures, flushing with water to the exposed area (skin or eyes) should occur immediately and be performed for a minimum of 15 minutes (New Jersey Department of Health, 2009).

Previously discussed in the literature review, there is controversy regarding the use of Pyridoxine in the medical management of hydrazine exposure. This said, in a case with central nervous system effects or potential loss of life via a moderate to severe exposure, intravenous Pyridoxine should be highly considered as a potential treatment option. Benzodiazepines are considered first line treatment for managing seizures per current recommendations (Brophy et al., 2012). Hospitalization for observation of potential delayed effects should be considered in moderate to significant exposures (i.e. pulmonary edema may take up to eight hours before manifestation). Table 5 lists recommended best practices for immediate medical treatment for a hydrazine exposure given current published medical literature and NIOSH guidelines.

Table 5

Immediate Medical Treatments to be considered for a Hydrazine Exposure

Immediate Medical Treatments to be Considered for an Acute Hydrazine Exposure
Immediate flushing with water of exposed area for 15 minutes?
Use of anticonvulsant medication for seizures (benzodiazepine)?
Consideration of Vitamin B6 (Pyridoxine) administration?
Consider hospitalization for 24-hour observation due to pulmonary edema concern?

In summary, these three best practices domains, initial fire department and EMS response requirements, medical evaluation requirements, and immediate medical treatment considerations and recommendations, with their specific subcomponents, constitute the current recommended best practices for acute hydrazine exposure.

Data Collection

Six USAF installation hydrazine response MDGI's were obtained for review. Each MDGI was verified to ensure there were no release restrictions on the publication. Each MDGI at each installation was then reviewed to compare with the best practices. This quantitative data was placed into a Microsoft Excel spreadsheet with each installation receiving a "Y" (colored green) to indicate if a guideline was recommended and a "N" (colored red) to indicate if a guideline was not recommended. Subcomponents colored yellow are tests recommended by USAF installations that are not considered a best practice approach. Once completed, analysis and comparison of USAF MDG emergency response protocols could be assessed. Appendix B shows the comparative analysis results.

Analysis and Results

Initial Fire Department and EMS Response Requirements

Ten subcomponents were analyzed to determine the best approach for fire department and EMS response. All six USAF installations recommend that 1) medics should respond with fire services to the initial dispatch call, 2) fire services should respond with appropriate PPE, 3) gross decontamination should occur by fire services prior to initial EMS medical examination, 4) a specially trained hydrazine response team is required to respond if hydrazine confirmed, 5) hydrazine exposure requires medical evaluation by a trained physician, and 6) severe exposures should be immediately transferred to an emergency room where appropriate definitive care can be delivered.

The remaining four best practices' implementation varied among the six USAF installations. Given the rarity of hydrazine exposures, fifty-percent (50%) of installations included a worksheet for ease of documentation and to assist medical personnel in ensuring a full and complete examination is completed. Though mandatory by OSHA, only sixty-six percent (66%) of locations included the requirement to document the exposure to either public health or bioenvironmental engineering to ensure appropriate regulations are met. Permissible exposure limit was documented in sixty-six percent (66%) of MDGI's. Eighty-three percent (83%) of installations discussed the difference between ammonia and hydrazine exposure via jet exhaust as well as the appropriate treatment of exhaust.

Medical Evaluation Requirements

Analysis demonstrated that only sixty-six percent (66%) of installations specifically outlined the importance of assessing vital signs, cardiovascular, respiratory, abdominal, neurological (to include ophthalmological), and dermatological examinations, except for pupillary reflex which was discussed in only thirty-three percent (33%) of installation MDGIs. All installations agreed on obtaining the following baseline laboratories: CBC, urinalysis, and the liver function tests aspartate aminotransferase (AST) and alanine aminotransferase (ALT).

Fifty percent (50%) of locations recommended obtaining a complete metabolic profile (CMP) which in addition to assessing liver function (AST/ALT), also assesses kidney function and immediate glucose levels (hydrazine may inhibit gluconeogenesis). Since AST/ALT levels are included in a CMP, best practices would be to obtain a CMP and not repeat the same testing by also ordering AST/ALT. Chest X-ray and pulmonary function testing was recommended by only sixty-six percent (66%) of installations even though respiratory symptoms and disease may occur given inhalation risk.

The importance of follow-up in occupational health owing to possible delayed effects of toxic chemicals is noted by all six installations recommending both a 24-hour and seven-day follow-up examination. If labs were abnormal, then they should be repeated until return to baseline achieved (facilities differed on the frequency of repeat lab testing). Sixty-six percent (66%) of installations also discussed a return to work policy which is important for risk stratification since exposure only occurs at an individual's employment location.

Immediate Medical Treatment Considerations and Recommendations

Providing immediate medical treatment, specifically decontamination via flushing with water and removal of contaminated clothing, is critical in limiting and decreasing length of hydrazine exposure. Only sixty-six percent (66%) of installations specifically documented the importance of flushing and decontamination. Additionally, only sixty-six percent (66%) of installations instructed medical providers to administer benzodiazepines for treatment of seizures which is considered gold-standard for acute seizure treatment (Brophy et al., 2012). Pulmonary edema is a severe delayed reaction and eighty-three percent (83%) of facilities described the importance of following patients closely because of potential delayed symptom presentation. Finally, as per the literature review, the use of Vitamin B6 (Pyridoxine) was also controversial among the six USAF installations with only fifty percent (50%) of installations recommending it's use (and only in cases of moderate to severe exposure).

Discussion

Given the uniformity bred into military personnel, it is interesting to see that among certain subcomponent areas, each installation was indeed similar whereas in other subcomponent areas, there was a marked diversity in recommendations to response protocols for hydrazine. Initial emergency response was similar among all six installations with all having identical patterns. This would be expected as military medics are trained at the same location and emergency response protocols to hazmat exposures are steered by federal guidelines.

Once initial emergency response by the Fire Department and EMS occurred, small differences began to emerge. As seen in Appendix A, one of the most unusual variances is that one third of installations reviewed do not discuss the mandatory OSHA requirement to document hydrazine exposure or instruct their providers to complete an exposure report form and provide this information to their appropriate occupational health tracking agency (USAF public health or bioenvironmental engineering flights). Additionally, though not mandatory, inclusion of a flow-sheet or work protocol would be extremely helpful in responding to such a rare event as a hydrazine exposure and could be easily given to the occupational health agency to meet the OSHA requirement. Appendix C shows a modified flow-sheet used by three USAF installations that could be implemented to assist medical responders when responding to hydrazine incidents.

The subcomponents of medical evaluation showed the greatest variance among the six installations (though a majority followed best practice recommendations). Only sixty-six percent (66%) mentioned completion of a history and physical examination to include critical organ system evaluations (dermatological in case of skin exposure, respiratory in case of inhalation etc.). The most likely reasoning behind this is that the installation ‘assumes’ first responders will automatically perform a history and physical exam.

Regarding laboratory and radiological testing, all installations agreed on the importance of obtaining a baseline CBC, UA, and ALT/AST. However, as discussed in the methods section, instead of obtaining a stand-alone ALT/AST, best practice recommends a CMP which in addition to ALT/AST testing, also provides a baseline renal function evaluation and obtains real time glucose levels. Additionally, one half of installations recommended obtaining a Gamma-Glutamyl Transferase (GGT). This test, similar to AST and ALT is helpful in detecting hepatocellular damage and is most often used to screen for chronic alcohol abuse or to confer additional liver specificity in evaluating elevated alkaline phosphatase (AP) levels (O'Shea, Dasarathy, & McCullough, 2010). In an emergency hydrazine response, GGT levels would not provide any additional insight that an AST/ALT level would provide. Thus, GGT levels are not recommended for best practice.

Given the possible respiratory complications that may occur from an exposure, it is interesting only sixty-six percent (66%) of installations recommended completing a PFT and CXR. A baseline CXR will greatly assist the treating physician by providing a comparison in case of worsening lung disease (i.e. development of pulmonary edema). Additionally, a PFT would be a great asset in determining readiness to return to work or duty when comparing the individual's prior pre-placement screening PFT. Thus, CXR and PFT are recommended as a best practice for hydrazine exposure.

Immediate medical treatment is of utmost importance during exposure. Gross decontamination followed by 15 minutes of flushing with water to the affected area(s) such as exposed skin or eyes, greatly assists in decreasing the concentration of hydrazine exposure. However, only sixty-six percent (66%) of installations either discussed or recommended flushing the affected body part with water. In case of central nervous system exposure, only sixty-six percent (66%) recommended use of benzodiazepines for seizure treatment and fifty percent (50%) recommended use of Pyridoxine. Likely reasons for not including seizure treatment is again the assumption that providers will automatically treat with appropriate medications or the understanding that USAF installation EMS's do not carry or use benzodiazepine injectors. Another potential reason for not including seizure treatment is that developers of the installation specific MDGI were not aware of the CNS risks posed by hydrazine. Regarding the use of

Pyridoxine, this medication is not given in the field by EMS, thus may have not been discussed because it would be expected to be given in the emergency department (ED) or hospital.

Unfortunately, only NASA and hydrazine manufacturing facilities stock large amounts of IV Pyridoxine and most military treatment facilities have no IV Pyridoxine in stock (T. Ali, personal communication, March 18, 2016). Even more concerning is a study published by Gospe and Bell (2005) who analyzed the availability of IV Pyridoxine in United States ED's. Though it is recommended that all hospitals keep 10 grams of IV Pyridoxine in stock for emergency antidote administration, only 16.7% of general hospital ED's examined had readily available access to IV Pyridoxine (Gospe, & Bell, 2005). Thus, even though Pyridoxine is recommended as a best practice, it may be difficult to acquire and administer in a timely manner.

There are limits to this analysis as only six USAF installation MDGIs were evaluated and compared to each other representing only approximately 10% of all active duty flying bases. Increasing the number of installation evaluations would increase the overall strength of this analysis. Additionally, obtaining both civilian industry and other federal agency response protocols would greatly improve the generalizability of these best practice recommendations. Another major limitation in creating a best practices approach is the lack of hydrazine studies. This lack of toxicological medical literature makes it difficult to establish appropriate guidelines. Thus, current recommendations are very conservative to address emergency response.

Many recommendations could be made from the evaluation and analysis of these six USAF installations. I will briefly consider two I feel warrant discussion. Given the overall standardization engrained into military personnel, it is interesting to see differences in various aspects of the six medical group emergency response protocols Though overall, I observed uniformity in the majority of emergency response protocols, I feel a standardized hydrazine

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response MDGI should be created and implemented across the USAF. As previously discussed, one-third of analyzed installations do not follow OSHA recommendations by informing the appropriate personnel of an individual's exposure. The most likely reason for this diversity would be the idea of empowering each base to implement location specific requirements (i.e. United States responses likely differ from overseas locales). However, emergency response procedures should rarely differ with uniformity being the ideal goal. If implemented, local medical groups could still review the standardized hydrazine protocol but be given an option of adding to it any site specific requirements to assure they meet all local civilian or foreign national policies. By implementing a single standardized protocol, all medical groups will be assured they are following current best practice recommendations.

Second, I recommend the implementation of a best practices hydrazine worksheet for all USAF installations with hydrazine response protocols. Implementation of this recommendation would assist with the first recommendation of standardizing response protocols. Additionally, it would assure all USAF medical groups adhere to current federal guidelines as well as ensure medical providers are delivering the best currently published medical recommendations. During this review and analysis of hydrazine emergency medical management procedures, I modified a hydrazine response worksheet currently used by three USAF installations by including current best practice recommendations. This worksheet (or a similar design) could easily be inserted as an appendix into all USAF MDGI's ensuring ease of accessibility during a hydrazine medical response.

Conclusion

Hydrazine is a toxic chemical that imposes an occupational health risk to individuals employed to work with this chemical. USAF installations where potential hydrazine exposure may occur have developed emergency response plans to be implemented by first responders in case of a hydrazine leak or spill. However, each medical facility has developed its own MDGI and some installation response plans are more comprehensive than others. Because of this variance, I reviewed recommendations from six facilities actively engaged in hydrazine operations, current federal guidelines, and current recommendations from the medical literature. From this review and comparative analysis, I developed a list of components that should be included in a best practices approach for an emergency medical response to hydrazine. Additionally, a medical evaluation flow-sheet, adapted from military specific installations, was created for use by any agency responding to a hydrazine spill.

Though exposures are rare, given the occupational health risk hydrazine poses, continued medical surveillance is highly recommended. As future studies and case reports clarify occupational health hazards, monitoring and updating the best practices recommendations and the protocol driven flow-sheet will be needed.

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Appendix A – Best Medical Practices for Hydrazine Incidents

Core Emergency Response Tasks for a Suspected Hydrazine Exposure

	Emergency Response Tasks for a Suspected Hydrazine Exposure
1	Fire Services respond with appropriate Personal Protective Equipment (PPE)?
2	If hydrazine suspected, gross water decontamination performed by Fire Services?
3	Emergency Medical Services required to respond to suspected hydrazine exposure?
4	Physician evaluation required for suspected hydrazine exposure?
5	Hydrazine Response Team responds if hydrazine confirmed?
6	With moderate to severe exposure, immediate transfer to Emergency Department/hospital?
7	Is there a medical response protocol/flow sheet?
8	Requirement stated to document exposure to Public Health or Bioenvironmental Engineering?
9	Is there a discussion to treat EPU exhaust as ammonia and not as hydrazine?
10	Are permissible exposure limits documented?

Medical Evaluation Tasks for Hydrazine Exposure

	Core Medical Evaluation Tasks for a Suspected Hydrazine Exposure
1	Vital Signs: blood pressure, pulse, respiratory rate, temperature, and oxygen saturation
2	Head and neck exam (with focus on pupillary reflex and conjunctiva)
3	Cardiovascular physical exam
4	Pulmonary physical
5	Abdominal exam
6	Neurological exam
7	Dermatological exam
8	Pulmonary Function Test (PFT)
9	Complete Blood Count with differential (CBC)
10	Complete Metabolic Profile (CMP)
11	Urinalysis
12	Chest X-ray (discussion of delayed pulmonary edema risk?)
13	24-hour follow-up examination required?
14	7-day follow-up examination required?
15	Return to work discussion?

Immediate Medical Treatments to be considered for Hydrazine Exposure

	Immediate Medical Treatments to be Considered for an Acute Hydrazine Exposure
1	Immediate flushing with water to exposed area for 15 minutes?
2	Use of anticonvulsant medication for seizures (benzodiazepine)?
3	Consideration of Vitamin B6 (Pyridoxine) administration?
4	Consider hospitalization for 24-hour observation due to pulmonary edema concern?

Appendix B – Analysis of Six United States Air Force Installation's Emergency Medical Management to Hydrazine Exposure

Analysis of Emergency Response Tasks by Installation for Initial Fire Department and Emergency Medical Services response

		United States Air Force Military Installation					
		(1)	(2)	(3)	(4)	(5)	(6)
1	Fire Department Response with Personal Protective Equipment?	YES	YES	YES	YES	YES	YES
2	Gross decontamination by Fire Department?	YES	YES	YES	YES	YES	YES
3	Medics Respond with Fire Department?	YES	YES	YES	YES	YES	YES
4	Physician evaluation required?	YES	YES	YES	YES	YES	YES
5	Hydrazine Response Team responds if hydrazine confirmed?	YES	YES	YES	YES	YES	YES
6	Severe exposure requires immediate Emergency Room evaluation?	YES	YES	YES	YES	YES	YES
7	Hydrazine Worksheet?	YES	YES	NO	NO	YES	NO
8	Occupational Safety and Health Administration documentation?	NO	YES	NO	YES	YES	YES
9	Emergency Power Unit exhaust treated as Ammonia, not Hydrazine?	NO	YES	YES	YES	YES	YES
10	Permissible Exposure Limit documented?	NO	YES	YES	YES	NO	YES

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Analysis of Core Medical Evaluation Tasks by United States Air Force installation.

		United States Air Force Military Installation					
	Medical Evaluation	(1)	(2)	(3)	(4)	(5)	(6)
1	Vital Signs (BP, Pulse, RR)	YES	YES	NO	YES	YES	NO
2	Pupillary Reflex	YES	YES	NO	NO	NO	NO
3	CVS exam	YES	YES	NO	YES	YES	NO
4	Pulm exam	YES	YES	NO	YES	YES	NO
5	ABD exam	YES	YES	NO	YES	YES	NO
6	Neuro exam	YES	YES	NO	YES	YES	NO
7	Skin exam	YES	YES	NO	YES	YES	NO
8	Initial PFT	YES	YES	NO	NO	YES	YES
9	CBC w/ diff	YES	YES	YES	YES	YES	YES
10	CMP	NO (YES ALT/AST)	NO (YES ALT/AST)	YES	YES	YES	NO (YES ALT/AST)
	ALT/AST only	YES	YES	YES	YES	YES	YES
	GGT	YES	YES	NO	NO	NO	YES
11	UA	YES	YES	YES	YES	YES	YES
12	CXR	YES	YES	NO	NO	YES	YES
13	24 HR Follow-up exam	YES	YES	YES	YES	YES	YES
14	7 Day Follow-up exam	YES	YES	YES	YES	YES	YES
15	Return to Work discussion?	NO	NO	YES	YES	YES	YES

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Analysis of Immediate Medical Treatment by United States Air Force installations

		USAF Military Installation					
	Medical Treatment	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1	**15 minutes of flushing with water?**	NO	YES	NO	YES	YES	YES
2	**Seizures (Benzodiazepines)**	NO	NO	YES	YES	YES	YES
3	**Use of Pyridoxine (Vitamin B6)?**	NO	NO	YES	NO	YES	YES
4	**Consider hospitalization for 24-hour observation due to pulmonary edema concern?**	NO	YES	YES	YES	YES	YES

Appendix C – Hydrazine Exposure Worksheet (adapted from three United States Air Force Military Installations)

Name:	**SSAN:**	**Phone:**
Workplace ID:	**Supervisor:**	**Location of Exposure:**
Description of How Exposure Occurred:		
EVALUATION		
Initial	**24 Hours Post Exposure**	**7 Days Post Exposure**
Date/Time:	Date/Time:	Date/Time:
Pulm Function Test	Pulm Function Test	Pulm Function Test
FEV_1 = FVC = FEV_1/FVC=	FEV_1 = FVC = FEV_1/FVC=	FEV_1 = FVC = FEV_1/FVC=
Laboratory Findings	**Laboratory Findings**	**Laboratory Findings**
ALT: AST: BUN/Cr: Glucose: Other:	ALT: AST: BUN/Cr: Glucose: Other:	ALT: AST: BUN/Cr: Glucose: Other:
CBC:	CBC:	CBC:
UA:	UA:	UA:
INITIAL EXAMINATION		
Blood Pressure:	Pulse:	Respiration:
Pupillary Reflex:	HEENT:	Cardiovascular:
PA/Lateral CXR:		
Abdomen:	Lungs:	

<table>
<tr><td colspan="3">Neurological Examination:
Gross Sensory = CNII-XII, Vibratory, Pin Prick

Cerebellar= Finger-Nose, DTRs, Rhomberg, Rapid Alternating Movement

Gait= Heel/Toe</td></tr>
<tr><td colspan="3">Skin:</td></tr>
<tr><td colspan="3">Other Notes/Comments:</td></tr>
<tr><td colspan="3">Disposition:</td></tr>
<tr><td colspan="3">Date, Time and Location where patient is to report for 24Hr Follow-Up:</td></tr>
<tr><td colspan="3"></td></tr>
<tr><th colspan="3">24 Hour Post Exposure EXAMINATION</th></tr>
<tr><td>Blood Pressure:</td><td>Pulse:</td><td>Respiration:</td></tr>
<tr><td>Pupillary Reflex:</td><td rowspan="2">HEENT:</td><td rowspan="2">Cardiovascular:</td></tr>
<tr><td>PA/Lateral CXR:</td></tr>
<tr><td>Abdomen:</td><td>Lungs:</td><td></td></tr>
<tr><td colspan="3">Neurological Examination:
Gross Sensory = CNII-XII, Vibratory, Pin Prick

Cerebellar= Finger-Nose, DTRs, Rhomberg, Rapid Alternating Movement

Gait= Heel/Toe</td></tr>
<tr><td colspan="3">Skin:</td></tr>
<tr><td colspan="3">Other Notes/Comments:</td></tr>
</table>

7 Days Post Exposure EXAMINATION		
Blood Pressure:	Pulse:	Respiration:
Pupillary Reflex:	HEENT:	Cardiovascular:
PA/Lateral CXR:		
Abdomen:	Lungs:	
Neurological Examination: Gross Sensory = CNII-XII, Vibratory, Pin Prick Cerebellar= Finger-Nose, DTRs, Rhomberg, Rapid Alternating Movement Gait= Heel/Toe		
Skin:		
Other Notes/Comments:		
HAS PUBLIC HEALTH AND/OR BIOENVIRONMENTAL ENGINEERING BEEN INFORMED FOR OSHA DOCUMENTATION AND NOTIFICATION OF EXPOSURE? YES NO		
Final Disposition or Recommended Follow-Up:		

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Appendix D – List of Competencies Used in CE

Tier 1 Public Health Competencies

Domain #1: Analytic/Assessment Skills
Applies ethical principles in accessing, collecting, analyzing, using, maintaining, and disseminating data and information
Selects valid and reliable data
Identifies gaps in data
Collects valid and reliable quantitative and qualitative data
Describes how evidence (e.g., data, findings reported in peer-reviewed literature) is used in decision making
Domain #2: Policy Development/Program Planning Skills
Gathers information that can inform options for policies, programs, and services (e.g., secondhand smoking policies, data use policies, HR policies, immunization programs, food safety programs
Describes implications of policies, programs, and services
Domain #3: Communication Skills
Communicates in writing and orally with linguistic and cultural proficiency (e.g., using age-appropriate materials, incorporating images)
Conveys data and information to professionals and the public using a variety of approaches (e.g., reports, presentations, email, letters)
Describes the roles of governmental public health, health care, and other partners in improving the health of a community
Domain #4: Cultural Competency Skills
Describes the effects of policies, programs, and services on different populations in a community
Domain #5: Community Dimensions of Practice Skills
Describes the programs and services provided by governmental and non-governmental organizations to improve the health of a community
Provides input for developing, implementing, evaluating, and improving policies, programs, and services
Domain #6:Public Health Sciences Skills
Retrieves evidence (e.g., research findings, case reports, community surveys) from print and electronic sources (e.g., PubMed, Journal of Public Health Management and Practice, Morbidity and Mortality Weekly Report, The World Health Report) to support decision making
Recognizes limitations of evidence (e.g., validity, reliability, sample size, bias, generalizability)
Describes evidence used in developing, implementing, evaluating, and improving policies, programs, and services
Domain #7: Financial Planning and Management Skills
Describes government agencies with authority to impact the health of a community
Adheres to organizational policies and procedures
Describes program performance standards and measures
Domain #8: Leadership and Systems Thinking Skills
Incorporates ethical standards of practice (e.g., Public Health Code of Ethics) into all interactions with individuals, organizations, and communities

Concentration Specific Competencies Checklist

Emergency Preparedness
Demonstrate the mastery of the use of principles of crisis and risk management
Use research and/or evaluation science methodologies and instruments to collect, analyze and interpret quantitative and qualitative data
Employ ethical principles in the practice of public health emergency preparedness
Demonstrate an understanding of the protection of worker health and safety