



# Reverberations of Militarism: Toxic Contamination, the Environment, and Health

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Hazardous and toxic substances, including solvents, petrochemicals, heavy metals, unexploded ordnance, and nuclear waste have been discharged at U.S. military bases here and abroad, contaminating soil, water, and air in and around the bases, and resulting in environmental pollution with potentially serious health consequences for neighboring communities. Until recently, neither the Department of Defense nor the Department of Energy has been subject to environmental standards enforced upon private industry. The author reviews the extent of the contamination, discusses possible health effects, and assesses challenges to epidemiologists and occupational health researchers attempting to characterize the health risks from military toxics. [M&GS 1995:1:7-18]

The mission of virtually every U.S. military facility has required the use of hazardous, toxic substances by military personnel and military contractors over the course of decades. Contamination found at military bases across the nation, in many cases spreading to surrounding communities, threatens public health, including the social and economic well being of the affected communities. Waste has been generated through activities such as the production, testing, cleaning, maintenance, use, and disposal of weapons, explosives, vehicles, aircraft, ships, and electronic equipment, as well as base construction, maintenance, modification, daily operations, and closure.

The urgency of cleanup increases as more facilities are closed under military

reductions, their ownership transferred to the private or public sector. The presence of contamination poses a major obstacle to conversion of these bases to productive civilian use.

This paper will briefly outline the scope of the contamination, discuss some of the health effects that may result from exposure, and outline systematic and methodological barriers to demonstration and avoidance of adverse health outcomes. The author suggests that community participation in the assessment and cleanup debate is necessary for a just and comprehensive response.

This discussion will focus on non-nuclear contaminants. It is important to recognize, however, that in the U.S., environmental contamination with nuclear and mixed chemical nuclear wastes at Department of Energy (DOE) facilities presents not only a substantial human health and ecosystem threat but also a financial burden for environmental restoration much larger than that of the Department of Defense (DOD) [1,2]. According to Thomas P. Grumbly, DOE Assistant Secretary for Environmental Management, hazardous and

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unstable fissile material, such as weapons usable highly-enriched uranium and plutonium, currently presents potentially serious occupational exposure threats and unacceptable environmental risks. Plutonium has been found in the ventilation ducts at the Rocky Flats Plant and the Hanford Reservation. Massive buildings used to separate nuclear materials chemically rank among the largest structures in the world and are highly contaminated with radioactive and chemical hazardous wastes [1].

## The Scope of the Problem

The mission and operation of military bases require a variety of industrial processes, some unique to the military, but many that are similar to functions routinely performed at any industrial facility. Typical operations include:

- \* fuel loading, storage, distribution, and dispensing;
- \* ship, vehicle, and aircraft servicing, cleaning, repair, and overhaul;
- \* weapon and ammunition transfer, assembly, destruction, and storage;
- \* power generation;
- \* electricity transformation and distribution;
- \* sewage collection and treatment;
- \* hazardous waste storage and disposal;
- \* bitumen production;
- \* electroplating;
- \* corrosion protection;
- \* weed and pest control.

These require the use and disposition of chemicals and hazardous substances that may represent a threat to the health of base workers and civilians in surrounding communities who are exposed through direct contact or environmental transport. In addition to the obvious explosive hazard of bombs, rockets, and ammunition, their ingredients may pose a threat during manufacture or disposal. Broader ecosystem impacts also result from the use of these munitions.

## Environmental Transport

Until 1992, with passage of the Federal Facility Compliance Act [3], U.S. military bases were exempt from complying with U.S. environmental regulations. Past practice patterns allowed substances such as oils, greases, solvents, sludge, fuels (including rocket propellant, jet fuel, diesel fuel, and gasoline), nuclear waste, unexploded ordnance, nitrates, heavy metals, PCBs, dioxins, cyanides, acids, alkalis, and pesticide residues to be emitted, discarded, or discharged directly onto soil or into air or water, creating environmental contamination

that may remain on site or migrate some distance over varying time frames. The fate and transport of each substance in the environment depends on its chemical and physical properties and on the nature of the media into which it is released. Air pollution may blow or drift long distances before settling onto soil or water. While airborne, some substances interact with sunlight, aerosols, or particles, creating more complex and longer-lived hazards.

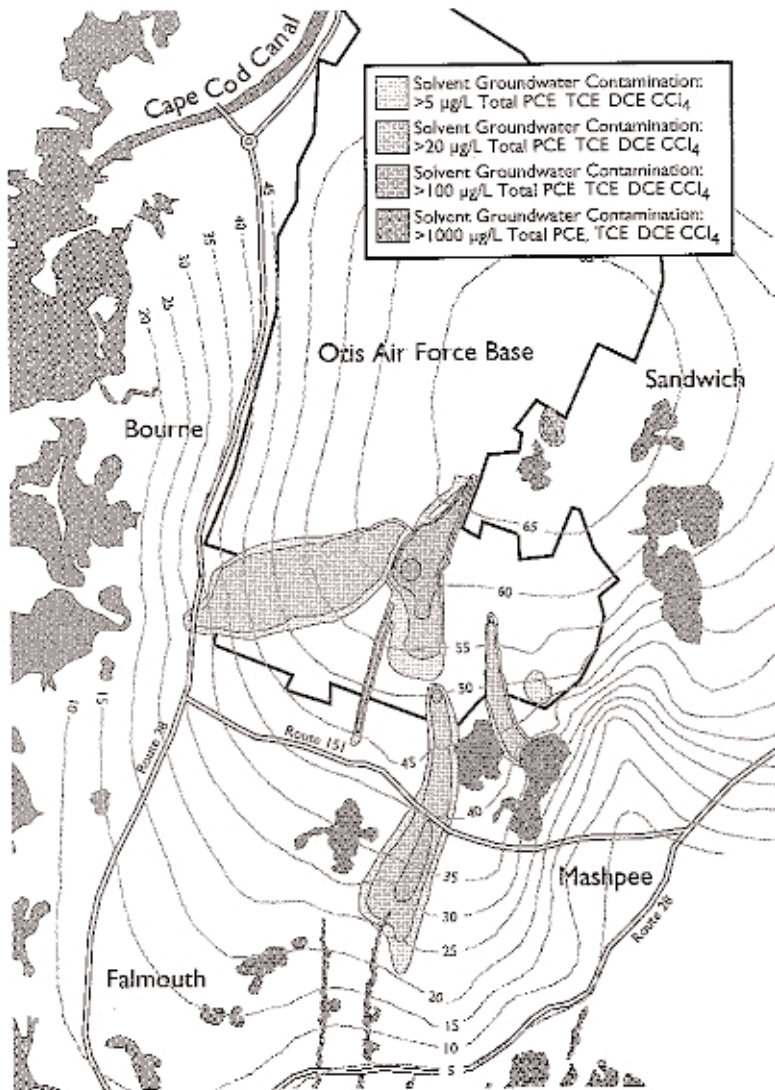
Soil contaminants may remain on the surface, adhere tenaciously to soil particles at varying depths, or leach downward, finally reaching groundwater that, in turn, migrates over time. Soil contaminants may also be taken up by plants through the roots, entering the consumable portion of a crop.

Groundwater supplies drinking water to about half the U.S. population -- 35% in urban and 95% in rural areas [4]. Surface runoff makes its way into rivers and streams carrying pollutants into the waters where aquatic life, including edible fish and shellfish, may bio concentrate toxic substances (e.g., mercury, PCBs, and dioxins) many thousand times. Wildlife or humans who eat the fish or shell fish are then exposed to large amounts. Sediments also become contaminated with toxic compounds, providing a continuing source of pollution.

The complex mixture of contaminants found on many military and industrial sites is, therefore, dynamically moving through the environment, presenting increasing and persistent opportunities for human exposure through direct skin contact, ingestion, or inhalation. The DOD has identified more than 19,000 polluted sites at 1,722 domestic military installations and more than 2,800 sites at 1,632 former defense facilities in the U.S. [5]. Other potential sites are being investigated. More than 100 DOD facilities in the U.S. are on the National Priority [Superfund] List. Similar circumstances exist on foreign soil at the sites of current or former U.S. military bases. According to a U.S. Government Accounting Office (GAO) report, host countries at increasing numbers of U.S. bases are taking legal action against the bases or the officials responsible for hazardous waste management, because of past practices of improper handling, storage, or disposal of hazardous waste [6]. Information emerging from the former Soviet Union and other Warsaw Pact nations confirms that this problem is widespread and not unique to the U.S. DOD.

## Examples from U.S. Sites

A review of 14 major facilities in the nuclear weapons complex scattered throughout the U.S. [7] uncovers evidence of widespread environmental contamination resulting from past practices, including soil, sedi-



**Figure 1.** Groundwater plumes of solvents at the Massachusetts Military Reservation on Cape Cod. Not illustrated are two smaller plumes containing fuels (e.g., benzene) and ethyl dibromide. Source: Analisis Corp., Oak Ridge, TN, 1994

ment, groundwater, and surface water pollution with radioactive isotopes, heavy metals, volatile and semi-volatile organic compounds, PCBs, fuels, oil, and grease. Many smaller facilities in a number of states, used or previously used for research, testing, weapons production, or waste storage are similarly contaminated. Several examples graphically illustrate the spectrum of hazards and the geographical extent of the problem [7,8].

### California

\* At McClellan Air Force Base in California, sites filled with oils, greases, solvents, and sludge are as large as football fields and 30 feet deep. Some of the contaminants found in groundwater and soil samples include ben-

zene, carbon tetrachloride, toluene, perchloroethylene (PCE), xylenes, chloroform, trichloroethylene (TCE), vinyl chloride, lead, arsenic, cadmium, mercury, and PCBs. Volatile chemicals in the soils have permeated silts, sands, and clays to a saturated zone that extends up to 700 feet below grade. Much of the upper 50 feet of ground water is contaminated. The deepest plume extends a half-mile in both length and width [9]. Two municipal and several base wells have been closed because of groundwater pollution. More than 500 families living west of the airbase have been connected to city water because of the contamination. Chemicals of concern include the volatile organic compounds dichloroethane, dichloroethene, and vinyl chloride; arsenic and cadmium [10].

### Wisconsin

\* Private wells south of the Badger Army Ammunition Plant perimeter in Wisconsin are contaminated with carbon tetrachloride and chloroform at levels up to 13 times state water standards. Other ground water contaminants at this site include dinitrotoluene (DNT), resulting from the manufacture of TNT, and benzene. DNT, in some areas present in excess of 37,000 micrograms/gram subsurface soil, will continue to leach into the groundwater until remedial action is taken [11].

### Cape Cod

\* Groundwater plumes of solvents (TCE, PCE, dichloroethylene, and carbon tetrachloride), fuels (benzene, ethylbenzene, toluene, xylene [BETX]), and fuel additives (ethylene dibromide) have been mapped on the Massachusetts Military Reservation on Cape Cod (Figure 1)[12]. One such plume, now extending nearly four miles south from the site of original soil contamination and more than three miles beyond the base perimeter, has reached residential drinking water wells. The pollution probably results from two sources -- the sewage treatment plant and an inactive fire training area. Activities at the latter included pouring spent fuels and solvents onto the ground and igniting them for firefighting exercises. This practice in unlined pits, previously common at mil-

itary bases around the country and overseas, results in groundwater contamination as unburned chemicals leach through the soil to the aquifer. Substantial reservoirs in the soil may continue to supply the aquifer over long periods of time. Total solvent concentrations in some areas of this groundwater plume exceed 2,200 micrograms/liter [EPA maximum allowable contaminant levels (MCL) for TCE and PCE are 5 micrograms/liter]. In 1979 one public residential well was closed because of this pollution. Other nearby public and private wells are threatened. Another plume, more than three miles in length, advancing off base to the west from an on-base landfill site, contains total volatile organic compounds in excess of 200 micrograms/liter and threatens the well supply for the entire town of Bourne. A third plume detected on private property east of the base contains benzene at concentrations up to 1,100 micrograms/liter and ethylene dibromide at concentrations greater than 100 micrograms/liter. In some areas, because of the nature of the soils, the contaminants advance up to five or more feet per day.

### *California*

\* At the Lawrence Livermore National Laboratory, groundwater on-site and beyond facility boundaries is contaminated with volatile organic compounds (VOCs), gasoline, organic lead, and chromium. Approximately 20 local drinking water supply wells had been closed as of 1991 because of contamination.

### *Washington State*

\* Groundwater at the Hanford Reservation in Washington, containing radioactive isotopes, metals, and VOCs, discharges to the Columbia River, a source of drinking water downstream.

### *Tennessee*

\* Similarly contaminated ground and surface water at the Oak Ridge Reservation in Tennessee discharges to water supplies consumed by a large population [7].

\* Unexploded ordnance poses a major hazard at some military bases

considered for closure and transfer to civilian use. Large tracts of land, such as sections of the Jefferson Proving Ground (JPG) in Indiana, are of little non-military use to humans in their present states and may, ironically, represent a new source of wildlife habitat without cleanup efforts certain to require large sums of money and many years of effort. More than 35,000 acres of land within JPG are heavily or moderately contaminated with unexploded munitions [13].

Cleanup efforts have begun in some instances. In others, nothing at all has been done. Some of the thousands of contaminated sites have yet to be investigated. Persistent contamination may forever restrict some parcels of land from ever being utilized as the local community might wish; undetected, contamination may present health threats long after conversion to civilian use has occurred.

Annual DOD cleanup appropriations in the U.S. were nearly \$2.6 billion in fiscal year (FY) 1994. This includes \$1.97 billion for the Defense Environmental Restoration Account (DERA), covering cleanup at active and former bases, and \$618 million for Base Realignment and Closure (BRAC) facilities. For FY1995, appropriators reduced DERA funding to \$1.78 billion, \$400 million less than DOD requested [14].

The FY 1996 DOE request for \$6.5 billion included \$843 million for new work not considered in previous requests, a transfer from other DOE responsibilities. Of the total, \$1.64 billion was requested for environmental restoration (remedial action and decontamination), \$2.72 billion for waste management (foreign and domestic plutonium and spent fuel, regulatory compliance), \$1.68 billion for landlord responsibilities, stabilization, deactivation, and security, and \$390 million for technology development. The administration request was for \$500 million less [2]. Congress threatens much larger cutbacks. Though savings are likely through increased efficiency, there is concern that DOE may not be able to meet its legal obligations for cleanup in coming years.[15,16].

### **Risk Assessment and Health Effects**

For historical, political, and economic reasons, including ignorance, potentially toxic chemicals and other substances have been and still are released into the environment without comprehensive understanding of their health and environmental effects. Corrective responses, if considered, are often

based on incomplete health hazard and risk characterization. Environmental assessment and remediation have become growth industries that are coevolving with the capacity of toxicology, epidemiology, ecology, sociology, and anthropology to provide a fuller understanding of health and environmental risk. Debates about the toxicity of a substance often entail real political and economic consequences. Resultant tensions are apparent throughout the literature of many disciplines and in the work of regulatory agencies, whose task is virtually impossible as presently structured [17,18,19].

Of more than 60,000 manufactured chemicals in the world today, only about 10,000 that are used commercially have been tested for toxicity in animals, and complete health hazard characterization has been carried out on far fewer. An extraordinary number of chemicals are completely unstudied [20.] There are minimal data on the health hazard of mixtures of these substances. Furthermore, animal studies and epidemiological analyses in humans exposed accidentally, occupationally, or other wise have important limitations.

Depending on the nature of the contaminant(s), the route and degree of exposure, and the identity of the person exposed, a range of adverse human health effects may result. U.S. regulatory agencies commonly use a four-step health risk assessment model, defined in the 1983 National Research Council committee report "Risk Assessment in the Federal Government: Managing the Process":

1. hazard identification, based on the toxicological profile of the substance(s);
2. delineation of the dose-response relationship, ideally including the full range of biological responses to various doses;
3. quantitative and qualitative exposure assessment (amount, route, and time frame of exposure); and
4. quantitative and qualitative characterization of the risk (i.e. the risk to a population of interest), based on information assembled in the first three steps. Environmental remediation decisions may be similarly based, but each step is often subject to intense debate.

## **Hazard Identification/Dose-Response Characterization**

### *Animal Studies*

In animal studies, used to infer human toxicity, the exposure may be orders of mag-

nitude larger than environmental levels to which humans are typically exposed, making low dose extrapolations dependent on assumptions. Such extrapolations may have substantial economic or regulatory repercussions. Further, interspecies variability resulting from species specific metabolic and detoxification pathways, and intraspecies differences resulting in subpopulations with increased susceptibility, make some animal data of questionable relevance.

Regulatory standards often attempt to allow for these differences by using compensatory factors. Estimating multiple human health effects is even more problematic. In contrast to procedures for identifying carcinogens, guidelines for identifying reproductive, developmental, neurological, and immunological toxins are in various stages of development. The Agency for Toxic Substances and Disease Registry (ATSDR), established by federal legislation in 1980 but unfunded until several years later, now considers these high-priority outcomes requiring further study [21]. A regulatory standard based on, for example, carcinogenic potential in animal studies may fail to protect against reproductive toxicity in humans. Finally, there is considerable concern about additive, synergistic, or subtractive effects of multiple exposures [22,23], which more realistically characterize the world in which we live than a laboratory experiment in genetically similar animals exposed to a single substance or to a carefully controlled mixture of substances devoid of the dietary, background level, genetic, and socioeconomic variables that typify the human condition.

### *Epidemiologic Studies*

Depending on the outcome of concern, epidemiological studies also vary in their ability to identify human health effects of environmental exposures. For those diseases with some incidence in an unexposed population, but for which there may be significant increases in risk following an environmental exposure, interminable debates over bias and confounding factors characterize the response to epidemiologic studies that attempt to address them. Though necessary and appropriate, this demonstrates the limited capacity of epidemiological analysis to provide definitive answers in those cases.

Occupational exposures, often larger and occurring in a pattern different from non-occupational exposures, provide some useful information. It is debatable, however, whether and when dose-response relationships at occupational levels of exposure in a working population of adults should be used to draw conclusions about non-occupational

exposures occurring at lower levels, with different durations and patterns, in a more varied population. Fetuses, infants, children, adults (including pregnant women), and men and women of all ages with chronic disease, some taking multiple medications, all living under widely varying conditions, represent a spectrum of social, biological, and physiological states that differ substantially from the "average" working adult subject to occupational exposures.

Given the available toxicological and epidemiological data that, unfortunately, may be limited for some or all of the biological effects of a given substance, political and economic considerations influence who weighs the evidence, from which sources, about which risks, or to whom. The implications for the polluter, academia, industry, the individual, the community, an ecosystem, a regulator, and a politician all differ -- stakes are high. Tension between individual rights and aggregate cost-benefit analysis is implicit in the discussion of regulatory or environmental remediation standards. Accounting methods, such as the use of discount rates applied to health effects with long latent periods, may effectively ignore or trivialize a serious future illness resulting from environmental exposure, obscuring an ethical bias in mathematical analysis [24].

### **Problems With Assessing Exposure and Health Outcome**

Whether or not adverse effects have actually occurred in an exposed population is a substantially different question from whether or not potential health effects may result from such exposures. Agencies responsible for investigating sites of environmental contamination may address both issues, using the above four-step process to characterize risk. Public perception of excessive disease, such as cancer in a particular community, often motivates an appeal to investigators for formal analysis of disease trends and causation. But clusters of disease may occur by chance alone, for reasons unrelated to environmental exposures, or as a direct result of exposure. Alternatively, public awareness of exposures resulting from activities at a particular industrial or military site may trigger a similar request for analysis and demands for exposure mitigation.

Whether or not excess disease is present and causally related to environmental exposures in a particular population is an epidemiological question, the answer to which depends on the availability of adequate exposure and outcome data. ATSDR is required to investigate "potential public health problems associated with environmental exposures to

hazardous substances from waste sites and releases of hazardous materials into the environment" [21]. Health studies, surveillance projects, and exposure registries are the means by which the agency addresses its mandate. ATSDR is not a regulatory agency, however, nor are ATSDR personnel empowered to generate new data when performing an initial health assessment in a community of concern. They are left, therefore, to a review of often inadequate data such as hospital records that provide no information about diseases or conditions not requiring hospitalization, information from city or county health departments that are almost always incomplete and lack information relevant to environmental exposures, and personal interviews with community members. Inasmuch as there is little systematic collection of population-based exposure data and incomplete health outcome data, including some diseases with long latent periods, conclusions drawn by ATSDR and other state or local agencies are necessarily limited.

The importance of quantitative exposure assessment to the process of linking pollution with health effects can not be over-emphasized. Among the criteria necessary for causal inference is data sufficient to identify degree of exposure and a dose-response relationship, if it exists. Individuals or groups must, therefore, be accurately classified with respect to exposure levels. In fact, this level of detail rarely exists and, in a retrospective study, must be reconstructed by use of techniques subject to bias. Even where communities currently exposed to contaminated air, food, or water are identified, an accurate study requires some quantitative reconstruction of past exposure levels as well as adequate surveillance for adverse health effects over time.

With regard to health outcome data, some states do not have -- or have only recently begun -- cancer registries so that, in those instances, the geographical distribution of cancer by type is not known. Without such information it is impossible to identify a census tract with excessive cancer incidence. Furthermore, residents who have moved from the area after a period of exposure are lost to surveillance. There are no population-wide area-specific data on spontaneous abortion or infertility. In fact, most spontaneous abortions are unrecognized [25]. Similarly, neurobehavioral or immunological abnormalities may go unrecognized or undiagnosed and are not documented in a population-wide database.

Therefore, a negative causal exposure-disease conclusion at a particular site may result either from there truly being no

**Table 1. Partial List of Contaminants Often Found in Environmental Media at Military Bases**

Contaminant	Biological Effect
Polycyclic aromatic hydrocarbons (present in fuels and produced during the combustion of fossil fuels)	Immune system depression; liver enzyme induction; carcinogenesis
Petroleum hydrocarbons (these include jet fuel, diesel, gasoline, greases, oils, kerosenes; many have additives with their own toxicity)	Carcinogenesis (e.g. benzene, ethylene dibromide) [44] Reproductive disorders; hematological disorders; immunological disorders; CNS depression; nausea vomiting
Solvents (TCE, PCE, TCA, chloroform, carbon tetrachloride, etc.)	Higher exposure - CNS depression, dizziness, arrhythmias, neuropathies, liver and kidney toxicity Lower exposure - Irritability, loss of concentration, memory loss, carcinogenesis [28,32,31,33] reproductive toxicity [45,46,37]
PCBs and dioxins	Liver enzyme induction; immunosuppression; humoral & cell-mediated [41] Carcinogenesis (IARC); reproductive toxicity [47]
Pesticides	Widely varying toxicity depending on type, e.g.: Organochlorines: Reproductive toxicity in wildlife; estrogenic effects; Immune system effects; carcinogenesis(?) [48,49] Chlorophenoxy herbicides (2,4 D and 2,4,5 T - contain dioxin): carcinogenesis
Wood preservatives (e.g. pentachlorophenol (PCP) contain dioxin; creosote (contains high concentration of PAHs and often present with PCP, copper, chromium, and arsenic in sludge)	Possible carcinogen [50] (see PCBs and dioxins)
Explosives (e.g. TNT, DNT, RDX)	Higher exposure: cardiovascular disease, anemia, hepatotoxicity, spermatotoxicity, anemia, methemoglobinemia, neurotoxicity [51,52,53] Lower exposure: ?carcinogenesis, spermatotoxicity anemia, methemoglobinemia, neurotoxicity [51,52,53]
Unexploded ordnance	Trauma
Metals - Many different metal contaminants found at military bases (antimony, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, tin, vanadium, zinc); each has its own toxicity. Some in the form of organometals (e.g., organotin present in anti-fouling paints or sandblasted onto soil or into water)	Examples: lead: Anemia, neuropathy, reproductive toxicity (men/women) intellectual impairment of children mercury (organic/inorganic): Psycho-motor retardation birth defects, neuro-toxicity; organotin: Neurotoxicity; arsenic: Carcinogenesis neurotoxicity.
Asbestos	Pleural disease, asbestosis, mesothelioma, lung cancer, ?GI malignancy
Radioactive material	Carcinogenesis; reproductive toxicity

References for many of the biological effects noted here and in following tables are found in [29]. Supplemental references are noted.

adverse effects or from a lack of data sufficient to demonstrate such effects. In each case it would be truthful to say that there is no evidence of causally related disease.

ATSDR health assessments have been criticized for failing to portray available data as inadequate and for failing to point out that, in many cases, the population being studied was too small to reveal a significant increase in certain health outcomes, even if such an increase actually existed [26]. These deficiencies, among others acknowledged by the agency, will be addressed if the proposed agenda, which includes better data collection, use of biomarkers to aid in exposure assessment, and better measurement of health outcome, is carried out [21].

1. International Agency for Research on Carcinogenesis. "IARC 1" designates a known human carcinogen, "IARC 2A" a probable human carcinogen, "IARC 2B" a possible human carcinogen, "IARC 3" a substance not classifiable as to carcinogenicity in humans, and "IARC 4" a substance that is probably not a human carcinogen.

## Potential Adverse Health Effects

A wide range of adverse health outcomes may result from environmental exposures, including malignancies, birth defects, disorders of reproductive, immune, neurological, and neurobehavioral functions, and solid organ failure or dysfunction. Historically, EPA has used non-threshold assumptions when

considering carcinogenic risks. This may not always be appropriate and EPA is revising risk assessment guidelines for carcinogenesis [27]. For most non-carcinogenic risks, exposure thresholds are generally thought to exist. Identifying dose-response thresholds for each of the possible health outcomes, however, may be difficult. For example, an exposure occurring at a critical time-window during gestation may present a substantial reproductive risk to offspring at what would be an otherwise safe maternal exposure at a different time of pregnancy.

What follows is a brief overview concentrating on low-dose exposures (except where otherwise indicated) to pollutants commonly

found on or near military bases. Table 1 is not intended to be comprehensive. A complete listing of the hazards found at significantly contaminated sites would be long indeed. Health effects resulting from larger exposures may be quite different and are particularly relevant to former or current base workers and to individuals involved in site remediation. Concern at any particular site will depend on the identity and level of contamination, past, present, and future exposure pathways, and the population exposed.

### Carcinogenesis

Known or suspected human carcinogens, often found in environmental media at military bases, include, among others, polycyclic aromatic hydrocarbons (PAH-IARC I<sup>1</sup>), some fuel components (e.g. benzene-IARC I) and fuel additives (e.g. ethylene dibromide-IARC 2A), solvents (e.g. PCE-IARC 2B), dioxin (IARC 2A), metals (e.g. As-IARC I, beryllium IARC 2A), asbestos (IARC I), and radioactive materials (see Table 1). Fuels and solvents, relatively mobile in soil, have been dumped, spilled, or disposed of improperly over decades, and commonly contaminate ground water. They may then easily migrate off-base into surrounding communities. Other organic compounds and metals vary in their mobility. For example, PCBs and dioxins, adhering tenaciously to soil and sediment particles, are environmentally persistent and bioconcentrate.

The fate, transport, and toxicity of metals varies considerably. For example, the carcinogenic potential of arsenic, found in some pesticides and wood preservatives, varies with the oxidation state. Chromium VI (IARC I), mobile in non-flooded soils, is transformed in flooded soils and bottom sediments to less toxic Chromium III (IARC 3). Cr VI, however, is probably only of carcinogenic concern when inhaled, as it is poorly absorbed from the GI tract.

The IARC monograph on PCE [28], additional epidemiological studies, and toxicological demonstration of reactive epoxide formation, hepatic, and renal toxicity [29] are cumulative evidence of the human carcinogenic potential of this one common contaminant. In a study criticized as being subject to recall bias and for using unusual statistical techniques [30], Lagakos, et al [31] concluded that childhood leukemia rates were more than double the expected rates in children to whom well water contaminated with TCE (267 ppb), PCE (21 ppb), and chloroform (12 ppb) was available. Ashengrau, et al [32] demonstrated excess risk of leukemia and bladder cancer in a community exposed to PCE in drinking water. PCE is considered

**Table 2. Reproductive Disorders Associated with Environmental Exposures**

Lead	Stillbirth, preterm delivery, low birth weight, spontaneous abortion, mental retardation, spermatotoxicity [34]
Mercury	Spontaneous abortion, blindness, deafness, mental retardation, delayed development, brain damage [35]
Benzene	Spontaneous abortion, low birth weight [54]
Chlorinated solvents (TCE, PCE, DCE)	Eye, ear, oral cleft [31], cardiac abnormalities, [37]
Polychlorinated biphenyls (PCBs)	Preterm delivery, low birth weight, reduced head circumference, growth deficiencies [55, 47]
Ethylene dibromide	Spermatotoxicity [56]

probably carcinogenic in the dry cleaning industry [33]. When debating remediation or exposure mitigation, regulators, the polluters (DOD, DOE), and affected communities must decide "how clean is clean?" using data that refuse to reveal a "bright line of safety."

### Birth Defects and Reproductive Disorders

Birth defects and reproductive disorders include infertility, spontaneous abortion and premature birth, perinatal mortality, low birth weight, major and minor birth defects, and developmental abnormalities resulting from in utero exposures. For minor birth defects, spontaneous abortion, infertility, and many developmental abnormalities there is neither systematic population-wide collection of data nor, indeed, even recognition of some of the more subtle conditions. It is therefore difficult to identify, retrospectively, where there might be increased incidence, making epidemiological analysis difficult.

Table 2 identifies reproductive disorders known or suspected to be associated with some exposures. The toxic effects of lead are well known and some effects (e.g. IQ defi-

**Table 3. Hematological and Immune System Alterations Associated with Environmental Exposures**

Arsenic	Leukopenia, eosinophilia
Beryllium	Granulomatous hypersensitivity
Asbestos	Depressed cell-mediated immunity, increased auto-antibodies including anti-nuclear antibodies [41]
Mercury	Immune complexes deposited in kidney [41]
Benzene	Lymphocytopenia, autoimmunity, aplastic anemia [40]
PCBs	Depressed immunoglobulins, atrophy of lymphoid tissue, decreased antibody response, increased susceptibility to infection
TNT, DNT	methemoglobinemia
Solvents	T-cell abnormalities, autoimmunity [42]



**Table 4. Adverse Neurological Effects Associated with Environmental Exposures**

Arsenic	Peripheral neuropathy
Lead	Encephalopathy (high levels), peripheral neuropathy, neurobehavioral impairment
Mercury	Central and peripheral neuropathy
Trimethyltin	Diffuse neuronal injury
Solvents (TCE, PCE)	Subtle neurophysiological and neuropsychological effects at low levels

ciencies) may occur at low levels [34]. Inorganic mercury, converted to organic mercury in aquatic environments, may significantly contaminate seafood, thereby causing psychomotor retardation of human offspring if maternal consumption exceeds 800-1,700 ng Hg/maternal kg body weight/day in the pre-gestational and gestational period [35].

Studies of the teratogenic potential of TCE, a widespread groundwater contaminant, have produced conflicting results (negative in some small mammal studies, but significantly positive for cardiac abnormalities in chickens) [36]. At least two epidemiological studies have demonstrated an association between human birth defects, including cardiac abnormalities, and maternal consumption of water contaminated with TCE [31,37].

### *Immune Function and Hematologic Disorders*

Many environmental contaminants alter immunological and hematological parameters [22, 41, 38, 39, 40], though the significance of such changes is not always readily apparent. Clinical manifestations of immunological changes may include allergic and autoimmune disorders, increased susceptibility to other exposures including infections, or increased cancer incidence, requiring a long period of surveillance because of latency [41]. For example, Hong et al demonstrated that mice exposed to a mixture of 25 frequently detected groundwater contaminants have a significantly slower recovery of bone marrow progenitors after radiation exposure than mice not exposed to the contaminated water, even weeks after cessation of exposure to the water when all hematological parameters are normal [22]. Byers et al [42], further studying family members of patients with leukemia who had been exposed to well water contaminated with TCE, PCE, and chloroform, at levels mentioned above [31], demonstrated T-cell lymphocytosis and altered T4/T8 cell ratios as well as an increased incidence of auto-antibodies, particularly anti-nuclear antibodies.

Table 3 lists hematological and immune

system alterations associated with some environmental exposures that might be expected to occur at sites contaminated by base activity.

### *Neurological and Neurobehavioral Disorders*

Neurotoxic effects of environmental exposures may be expressed as peripheral neuropathies or central nervous system disorders including encephalopathies and behavioral abnormalities. As with other health outcomes, extent and duration of exposure are important determinants. Detailed neuropsychological and neurophysiological testing demonstrates changes associated with chronic low-dose exposures to common contaminants. Kilburn and Warshaw showed significant impairment of certain central neurological functions including intelligence, affect, and memory in subjects exposed to well water contaminated with TCE (6-500ppb) [43]. In children without signs or symptoms of lead intoxication, impairment of neurobehavioral development has been associated with mean blood levels as low as 10 micrograms/dl [34].

Table 4 lists adverse neurological effects associated with some relevant environmental exposures.

### *Other Organ Dysfunction*

In general, exposures larger than those commonly encountered in the environment are believed necessary to cause pulmonary, cardiac, hepatic, or renal failure or significant dysfunction. This may not always be the case, however. For example, although evidence for autoimmunity caused by environmental exposures in humans is limited, there appear to be individuals with increased susceptibility [41]. Chronic, low-dose exposures or less frequent, sensitizing exposures, may be of importance in the pathophysiology of, for example, asthma or renal failure.

### **Conclusion**

Environmental contamination of military bases in this country and abroad by the DOD and DOE, for decades subject to no enforceable standards, represents a threat to public and environmental health. Numerous short- and long-term health effects resulting from human exposure to these contaminants, both on and off the bases, necessitate remediation decisions. Far from insignificant ecosystem effects broaden concern. The response now underway will need to continue for many years, at thousands of sites in the U.S. alone, at a cost of hundreds of billions of dollars. The political will necessary to maintain this effort over time is beginning to show signs of weakening as funding is restricted

and U.S. government agencies project significant shortfalls in coming years. U.S. pollution of overseas bases, only reluctantly acknowledged and not yet openly addressed, presents a moral responsibility even where no legal obligation exists. (See sidebar, "Military Base Contamination in the Philippines: The U.S. Role," below.)

Risk characterization, far from an exact science as it continues to evolve, may be subject to substantial economic and political influence. Representatives of affected communities must continue to participate in site remediation decisions as full partners. The health of individuals and communities, including environmental, social, and economic considerations, is at stake. Despite admitted limitations, evolving toxicological and epidemiological information about the range of health hazards of many common contaminants must continue to inform the process. Beyond technical biochemical and medical analysis, in a time of reduced willingness to appropriate funds for cleanup rather than weapons, cost-benefit analysis of remediation options requires scrutiny as transparent and rigorous as that which characterizes the medical debate [57]. Inadequate site remediation will pass attendant costs on to state and local governments, families, and individuals in the form of disease burden, depressed property values, and limits on socioeconomic development opportunities.

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## **Military Base Contamination in the Philippines. The U.S. Role**

From the turn of the century until 1991, except for the period of Japanese occupation during World War II, U.S. military forces used lands in Central Luzon and around Subic Bay in the Philippines far what grew to be among the largest U.S. overseas bases in the world. As early as 1908, only a few years after the U.S. occupation of the Philippines, Fort Stotsenburg, now known as Clark Air Base, included 156,204 acres in central Luzon. The area from which more recent U.S. operations were conducted was 9,158 acres. Additional large areas in Crow Valley were used for bombing practice. Subic Naval Base includes an area of more than 37,000 acres -- 16,451 acres for the operational base, with the remainder having been used for training exercises.

The main purpose of Subic Bay Naval Base was to service the U.S. Navy Seventh Fleet. Clark Air Base served as a major operations and support facility during the Korea and Vietnam conflicts. In 1991, more than 7,000 military personnel, in addition to dependents and civilian support, were stationed at Clark Operations carried out on the bases included fuel handling; ship, aircraft, and vehicle servicing and repair; ammunition transfer, assembly, destruction, and storage; aviation operations; power generation; electricity transformation and distribution; steam generation; water treatment and distribution; sewage collection and treatment; hazardous waste storage and disposal; bitumen production; electroplating; corrosion protection; and weed and pest control.

These activities -- for many years not conducted in a manner protective of the environment -- led to substantial contamination of the air, soil, groundwater, sediments, and coastal waters of the bases and the surrounding areas. Contaminants included petroleum hydrocarbons, aromatic hydrocarbons, chlorinated hydrocarbons, pesticides, PCBs, metals, asbestos, acids, explosives, and munitions. Whether or not radioactive wastes are present is uncertain.

The Philippine Senate voted in 1991 not to renew the bases agreement between the two countries. In June 1991, Mount Pinatubo erupted, hastening U.S. withdrawal from Clark Air Base. U.S. forces left Subic Naval Base in 1992, ending almost a century of occupation of these vast areas of Luzon.

Notwithstanding initial DOD protestations to the contrary, substantial amounts of hazardous materials and wastes were left behind at the time of U.S. departure, both on the surface and in the various environmental media. According to a U.S. Government Accounting Office report issued in 1992, "if the United States unilaterally decided to clean up these bases in accordance with U.S. standards, the costs for environmental clean-up and restoration could approach Superfund proportions. Environmental officers at both Subic Bay Naval facility and Clark Air Base have proposed a variety of projects to correct environmental hazards and remedy situations that pose serious health and safety threats."

None of these projects was undertaken prior to U.S. departure from the baselands. A study commissioned by the WHO in 1993, in order to assess potential environmental risks at Subic Bay, identified a number of contaminated and potentially contaminated sites and recommended a complete environmental assessment.

Two study teams visited the sites in 1994, under the sponsorship of the Unitarian Universalist Service Committee. The teams not only found evidence of environmental contamination, but carefully documented the lack of existing capacity in the Philippines, whether in the government, university, or private sectors, to assess and remediate the complex problem.

The health and safety issues are not theoretical or contingent on future development of the bases. At the present time rusting and bulging barrels of hazardous materials are sitting uncovered at Clark. There are reports of exposed, fragmenting asbestos insulation in buildings vacated by departing U.S. personnel. For years waste materials from the ship repair facility were dumped or discharged directly into Subic Bay, contaminating sediments. Residents from surrounding communities eat fish and shellfish harvested from this area.

Thousands of evacuees, displaced from homes destroyed by the Pinatubo eruption and by the lava flows that followed, have been temporarily housed in tents and makeshift wooden structures on Clark Air Base on a site previously occupied by a motor-pool. They obtain drinking and bathing water from groundwater wells. Just beyond the gate, about 300 yards from this evacuation center, is the permanent community of Dau where thousands of residents routinely use groundwater for drinking, cooking, and bathing. Because of complaints of gross contamination of water from some of the wells in the evacuation area, including visible oily sheen, foul taste, and gastrointestinal illness, one sample was tested at the laboratories of the University of the Philippines in early 1994 and found to contain oil and grease. Limited by laboratory capability, the analysis could not include the wide range of volatile and semi-volatile organic compounds, fuels, fuel additives, and other compounds that commonly contaminate groundwater in the U.S. and in other countries where similar military and industrial activities have taken place. It is likely that groundwater contaminants from the resettlement area will or have already migrated into the drinking water supply of the nearby community. This is only one of numerous sites of concern at both bases, and one that is beyond existing Philippine capacity to address.

When President Clinton visited the Philippines in November 1994, both he and President Ramos acknowledged that the issue of base contamination would need to be investigated further. President Clinton stated, however, that "We have no reason to believe at this time that there is a big problem that we left untended. We clearly are not mandated under treaty obligations to do more." He went on to say, "...we decided we should focus on finding the facts now, and when we find them, deal then with the facts as they are." To date there has been no comprehensive testing of the groundwater at this site.

Though there may be no treaty obligation to address this issue, the obvious moral and public health arguments have been made to President Clinton, DOD, and the U.S. State Department. There are other overseas bases (e.g., in Canada, Germany, Italy, and Japan) where, in response to host country discovery and complaints of environmental contamination, the U.S. has provided assessment and cleanup. After nearly a century of occupation of these Philippine baselands the obligation at these sites is no less real. Meanwhile, as the political resolution of this issue unfolds, thousands of Filipinos, many of whom are living in marginal refugee conditions, are drinking and bathing in water that is contaminated with hazardous substances resulting from U.S. military activities.