Science & Global Security, Volume 6, pp. 79–100
Reprints available directly from the publisher
Photocopying permitted by license only

The Destruction of Weapons Under the Chemical Weapons Convention

Amy E. Smithson[a] and Maureen Lenihan[b]

As the Chemical Weapons Convention (CWC) enters into force, countries with stocks of chemical weapons will begin the task of destroying them. In the U.S. whose stockpile consists of approximately 30,000 tons of nerve and blister agents at eight separate sites in the continental United States and at Johnston Atoll in the Pacific, the Army has designed a highly-automated "baseline" system to dismantle and incinerate the weapons. Although researchers have identified potential alternatives to incineration, involving chemical neutralization and biodegradation, it appears that these techniques are likely to substitute for incineration at most, at two sites: Newport, Indiana, and Aberdeen, Maryland. The Russian destruction program is less advanced than that of the U.S. and probably cannot be carried out effectively without significant and technical assistance from abroad, an urgent requirement given that the Duma Defense Committee has described Russian Chemical weapons storage sites as insecure and unsafe.

INTRODUCTION

Signed by over 155 countries, the Chemical Weapons Convention (CWC) bans the stockpiling, transfer, production, development, and use of chemical weapons. Over a ten-year timeframe after the treaty's anticipated 1996 entry into force, countries participating in the CWC will also destroy their chemical weapons. While the CWC does not stipulate which technologies governments must use to eliminate their stockpiles, it requires that destruction be "irreversible" and safe for humans and the environment.[1]

The most prevalent types of chemical weapons are vesicants or blister agents and nerve agents. Blister agents, such as mustard gas, attack the skin, respiratory system, and eyes, and can cause blistering, blindness, and death. The effects of exposure to nerve agents such as sarin, soman, tabun, and VX include vomiting, confusion, blindness, convulsions, coma, and death.[2] An average-sized person would die from exposure to 15 milligrams of VX or 70

a Senior Associate, The Henry L. Stimson Center, Washington, D.C.
b Research Associate, Commission on Protecting and Reducing Government Secrecy, Washington, D.C.

Table 1: Brief description of some suggested alternative technologies.[a]

molten salt oxidation	Combines chemical and thermal treatment. Wastes and oxygen are fed into a bath of molten caustic salt—usually sodium carbonate or a mixture of sodium and potassium carbonate. The wastes are oxidized, typically producing emissions of carbon dioxide, water, nitrogen, and oxygen; ash and soot are retained in the melt. Salt can later be removed for disposal or for processing and recycling.
fluidized bed combustion	Uses fluidized, granular solid as heat transfer medium. For chemical agent destruction, solid of choice would be aluminum oxide or calcium oxide. The material is kept suspended by gas flow, which is primarily air.
molten metal pyrolysis	Involves use of metals, such as copper, iron, or cobalt, at 3,000 degrees Fahrenheit, to decompose organic compounds like chemical agent.
plasma arc pyrolysis	Involves passing an electric current through a low-pressure airstream to split chemical agent into its atomic elements in a thermal plasma field at a very high temperature (e.g., 10,000 degrees Fahrenheit).
steam gasification	Organic materials are treated with super-heated steam under reducing conditions to produce simple organic molecules. Also known as reformation.
wet air oxidation	Based on the principle that organic compounds can be oxidized slowly at temperatures that are low compared with normal combustion temperatures (e.g., 572 degrees Fahrenheit versus 3,632 degrees Fahrenheit). The oxidation is carried out at high pressure (e.g., 1,000 per square inch in the presence of water).
supercritical water oxidation	Involves mixing chemical agents with water that has been pressurized and heated to a point at which organic compounds become soluble (e.g., above 705 degrees Fahrenheit and at a pressure above 221 atmospheres, or 3,205 pounds per square inch). Solution is oxidized at an elevated temperature, producing carbon dioxide and inorganic acids and salts.
biodegradation	Involves the use of enzymes or cellular systems to degrade nerve agents or reaction productions in dilute (approximately 10 percent) aqueous solutions.

a. *Sources:* U.S. General Accounting Office, *Chemical Weapons: Issues Involving Destruction Technologies*, GAO/T-NSIAD-904-159 (Washington, D.C.: Government Accounting Office, April 26, 1994): 10-15; and *U.S. Army's Alternative Demilitarization Technology Report for Congress* (Aberdeen Proving Ground, MD: Program Manager for Chemical Demiolitarization, April 11, 1994): table 2.3.2-1, 2-10.

milligrams of soman.[3] Therefore, it should be of little surprise that environmentalists and others are apprehensive about the possible dangers associated with eliminating these lethal weapons.

The early experiences with chemical weapons destruction set the stage for the sense of foreboding environmentalists have about the coming stockpile eliminations. For decades, governments disposed of chemical weapons using methods that are primitive by today's standards. Previously this century, the U.S. Army destroyed its corroded or unstable chemical weapons by open pit burning, atmospheric dilution, burial, and ocean dumping. At the end of World War II, British and American authorities dumped an undisclosed amount of German chemical weapons into the Baltic, North, and Skagerrak Seas, and the Soviets sunk approximately 35,000 tons of the German agents in the Pacific Ocean and the Barents, Baltic, and White Seas. The British also dumped over 12,000 tons of their own munitions into the English Channel. After 50 years, these canisters and shells are beginning to rust open with unknown consequences for marine life and humans.[4]

The possessors of the world's two largest chemical weapons stockpiles are Russia and the United States, but U.S. intelligence officials and independent experts believe that some thirty countries possess chemical weapons or the capability to make them.[5] Canada, Germany, and Great Britain have quietly destroyed their small arsenals and an assortment of weapons of World War I vintage that continue to be unearthed. Canada incinerated twelve tons of mustard and neutralized 0.3 tons of nerve agent using a 20 percent solution of methanolic potassium hydroxide diluted with water. The resulting wastes were then incinerated. This effort was carried out with little controversy because an active citizens committee worked effectively with governmental authorities throughout the program's planning and execution.[6] Since 1980, Germany has been destroying chemical weapons made half a century ago. Germany's program incinerates 70 metric tons of mustard agent annually.[7] After deciding to quit the offensive chemical weapons business in 1956, Great Britain began disposing of its chemical weapons using a variety of techniques, including incineration, neutralization, and a two-step process using alkaline hydrolysis with 20 percent sodium hydroxide solution.[8] Moreover, in the aftermath of the Persian Gulf War, the United Nations Special Commission oversaw the incineration of approximately 600 tons of Iraqi mustard and the neutralization of approximately 70 tons of Iraqi nerve agent.[9]

Thus far, neutralization and incineration have been the favored methods of destruction, but a list of alternative technologies is shown in table 1. For the most part, these technologies have been used commercially to destroy other toxic wastes. Experience to date illustrates that the success of a destruction program may rest not just on the technology utilized, but also on a government's ability to reassure its citizens of the technology's safety.

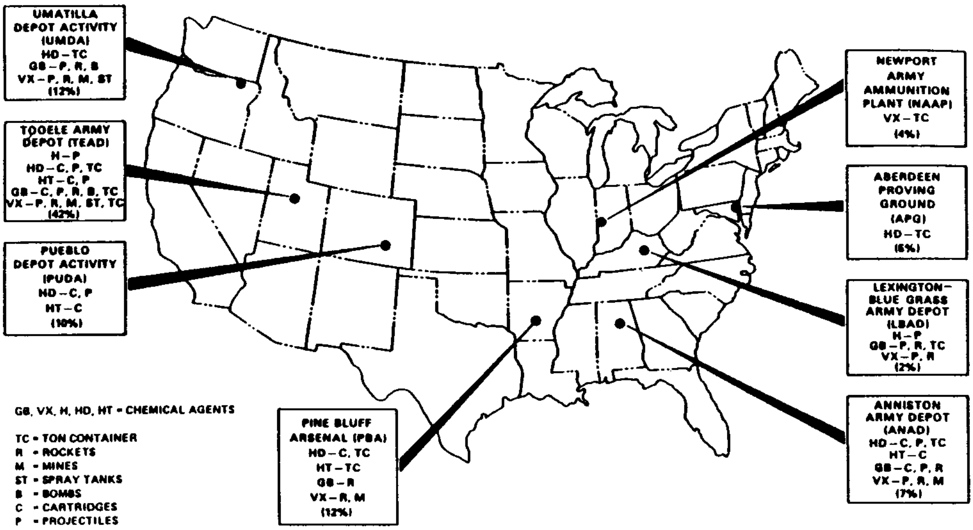


Figure 1: The U.S. chemical weapons stockpile storage sites.

Source: Final Programmatic Environmental Impact Statement (Aberdeen Proving Ground, MD: Program Manager for Chemical Demilitarization, January 1988): A-5.

THE U.S. DESTRUCTION PROGRAM[10]

The U.S. stockpile consists of approximately 30,000 tons of nerve and blister agents located at eight sites across the continental United States and at Johnston Atoll in the Pacific. Figure 1 shows the types of weapons and agents at each of the continental stockpile sites except Johnston Atoll. Approximately sixty percent of the agents is stored in bulk, or ton, containers without an explosive component; the balance is in bombs, mines, rockets, spray tanks, mortars, and artillery projectiles, some of which contain explosive components.[11]

One such munition is the M55 rocket, by far the most hazardous and controversial item in the U.S. stockpile. The warheads of some 478,000 M55s assembled between 1961 and 1965 contain approximately ten pounds of either VX or GB and are designed to explode upon impact.[12] Of uppermost concern is the warhead's vulnerability to accidental ignition because the stabilizer added to the rocket's propellant degrades over time. A 1993 Sandia National Laboratories study concluded that the Army may have been optimistic in its assessment that the M55 could be safely stored until 2004. The Army's July 1993 M55 stability review had utilized data that may have been unrepresentative of the munitions at the storage sites and did not account for the dangers caused by internal leakage in the warheads. Internal leaks can precipitate the decomposition of the propellent stabilizer, the formation of explosive metal salts, and the corrosion of metallic parts in fuses. Pinning down the M55's status and projecting its safety is difficult because the munitions are hazardous to handle.[13] Destruction of these weapons is thus a pressing concern for the five M55 storage sites.

Past Destruction Experience

In 1969, the U.S. Department of Defense commissioned the National Academy of Sciences to review a controversial ocean dumping program known as "Operation Chase" and to evaluate alternative methods for disposing of the Army's surplus chemical weapons. After creating an Ad Hoc Committee composed of experts from industry, academic, and research institutions, the Committee recommended the cessation of ocean dumping and advised the Army to "conduct a study of optimal disposal methods ... which involve no hazards to the general population or pollution of the environment." As an alternative to ocean dumping, the Committee recommended the use of incineration to destroy blister agents and neutralization to destroy nerve agents.[14]

In response, the Army explored the feasibility of neutralization and incineration for destruction of the varied agents and munitions in the stockpile. Between 1972 and 1982, the Army neutralized approximately 8.4 tons of sarin at the Rocky Mountain Arsenal near Denver, Colorado, and at the Tooele Army Depot in Tooele, Utah. Sarin was mixed with other substances, such as water and aqueous sodium hydroxide, to form less toxic compounds. Although expected to take four hours, the neutralization process lasted an average of ten to twenty days, possibly due to difficulties of this large-scale attempt to mix thoroughly the organic material with aqueous sodium hydroxide. The aqueous sodium hydroxide added to accelerate the process resulted in 2.6 to 6 pounds of salt for each pound of agent neutralized, rather than the calculated 1.4 pounds of waste salt. Moreover, small quantities of sarin were later found in the resulting brine, which is a salty water solution.[15] These less-than-optimal results led the Army to cancel plans for industrial-scale tests on VX and mustard, which had chemical impurities.[16] Another drawback was that neutralization could only detoxify the chemical agent. A second process would be required to destroy the explosives and propellants and to decontaminate metal parts.

The Army compared the performance of neutralization to that of incineration, which irreversibly transforms chemical agents into gases and solid residues, namely ash and brine. Incineration effectively destroyed over 6.26 million pounds of mustard and nerve agents as well as the munitions explosives and propellants. Incineration also decontaminated 60,000 containers and munition shells.[17]

In 1981, the Army selected incineration as the method to destroy the U.S. stockpile because it was apparently the only process capable of completely and swiftly destroying an entire chemical weapon without any fear of the agent reforming.[18] The National Research Council (NRC) endorsed the Army's decision in 1984 after reviewing test data and the comparative state of destruction technologies.[19] In 1985, Congress ordered the Army to eliminate all unitary munitions and agents in the stockpile.[20] Whereas a unitary chemical weapon contains pre-mixed, highly toxic agents, a binary weapon has two non-lethal chemicals that are mixed just prior to use to form a deadly chemical agent. Unitary munitions make up well over 95 percent of the U.S. stockpile.

Reason to press ahead with stockpile destruction was found by a 1988 Army study about the comparative risks of continuing to store the stockpile, destroying it on-site via incineration, or moving the weapons to regional or central destruction facilities. The Army determined that the risks associated with long-term stockpile storage, including possible catastrophic agent releases caused by such factors as a tornado or a plane crash, exceeded the risks of the destruction alternatives considered. In addition, the Army based its decision to destroy the stockpile *in situ* on the fact that a more viable emergency response capability could be created at each storage site than along thousands of miles of transportation corridors should the stockpile be moved.[21]

In mid-1990, a prototype incineration facility on Johnston Atoll began destroying munitions to provide additional operating experience and more proof of the safety and feasibility of the incineration technology before similar facilities were built at the eight continental storage sites. Only one such facility has been constructed to date. Destruction operations at this facility in Tooele, Utah, which houses 42 percent of the stockpile, are expected to begin by mid-1996. Barring further research developments, the Army will complete the construction of baseline facilities at the seven other continental storage sites by 2003.

The "Baseline" Destruction System

The Army has designed a highly automated, assembly-line facility, known as the "baseline" system, to dismantle and incinerate chemical weapons. Once the weapons and bulk containers are transported from storage sheds and

Table 2: Monitoring for just the destruction and removal efficiency versus the army's actual monitoring standard.

	monitoring level for 99.99% destruction and removal efficiency[a]	monitoring level for 99.9999% destruction and removal efficiency[a]	general population limit[b]	allowable stack concentration[c]	actual stack monitoring levels
nerve agent GB	1.26mg/m^3	0.0126mg/m^3	0.000003mg/m^3	0.0003mg/m^3	0.00006mg/m^3
nerve agent VX	1.26mg/m^3	0.0126mg/m^3	0.000003mg/m^3	0.0003mg/m^3	0.00006mg/m^3
mustard HD	2.5mg/m^3	0.025mg/m^3	0.0001mg/m^3	0.03mg/m^3	0.006mg/m^3

a. The authors asked the Army's assistance in calculating monitoring levels for columns two and three to enable a comparison. Edwin Muniz, task manager in the Environmental Monitoring Division of the U.S. Chemical Material Destruction Agency, calculated the DRE for nerve agents in the liquid incinerator based upon a feed rate of 700 pounds per hour, the average at the Johnston Atoll facility, and a volumetric flow rate of 14,800 actual cubic feet per minute of gases coming out of the stack. For mustard, he used a feed rate of 1,320 pounds per hour, the average at the Johnston Atoll, and a volumetric flow rate of 13,820 actual cubic feet per minute of gases emerging from the stack.

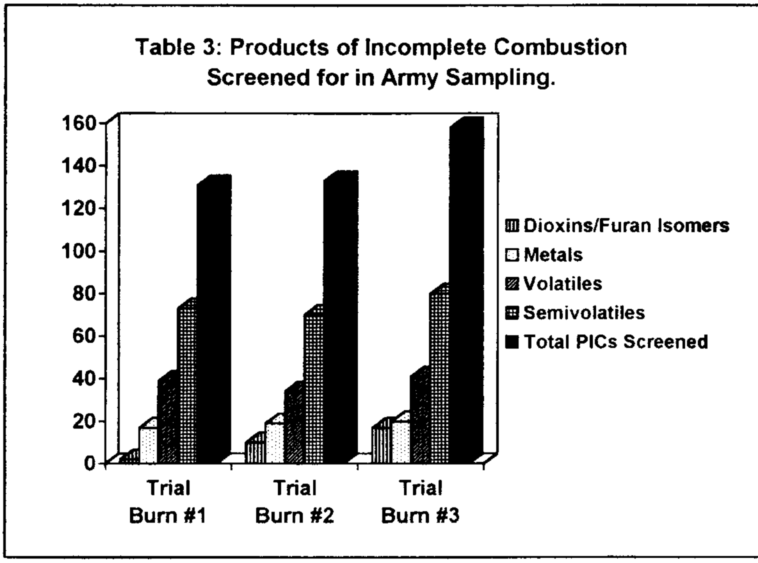
b. How much agent can be present in an exhaust plume outside the facility, taking into account wind conditions. As certified by the Surgeon General and the Department of Health and Human Services, which relied upon the toxicology experts of the Surgeon General and the Centers for Disease Control, these extremely minute quantities are far below the exposure level that would cause harm.

c. How much agent can be present in the emissions of the smokestack.

earth-covered igloos to the facility, they are mechanically drained of their liquid agent and disassembled in a room constructed to contain the release of agent should an explosion occur. The individual components of the weapons are then sent via pipes, chutes, and conveyor belts to three principal incinerators.[22] Exhaust gases from these incinerators go through a joint pollution control system. A quench tower cools gases to approximately 180 degrees Fahrenheit before they enter a venturi scrubber designed to remove 95 percent of all particles measuring larger than 0.5 micron. The resulting brine goes through a steam heat exchanger and drum dryers to evaporate the water from this solution, and the remaining salt is placed in containers for disposal at licensed hazardous waste disposal sites.[23] After leaving the venturi scrubber, the exhaust gases are neutralized in a packed bed scrubber and, finally, run through a mist eliminator. As recommended by the NRC, the Army evaluated the efficacy of charcoal filters and will add them to the pollution control systems at continental baseline facilities pending further research.[24] Figure 2 shows how M55 rockets would be processed through a baseline facility.

The Army added several features and safeguards to the baseline system to enhance its performance and safety. Federal regulations require an incinerator to destroy 99.99 percent of the hazardous wastes put into it—a standard

Table 3: Products of incomplete combustion screened for in army sampling.[a]



Trial Burn #1 was conducted in the liquid agent incinerator using M55 rockets filled with the nerve agent GB.

Trial Burn #2 was conducted in the liquid agent incinerator and furnace that decontaminates explosives and propellants using M55 rockets filled with the nerve agent VX.

Trial Burn #3 was conducted in the liquid agent incinerator and the furnace that decontaminates bulk containers and munitions shells using ton containers filled with mustard agent.

a. *Sources: Health Risk Assessment No.42-21-M1BE-93: Inhalation Risk from Incinerator Combustion Verification Testing—Phase 1; Health Risk Assessment No. 42-21-MQ49-92: Inhalation Risk from Incinerator Combustion Products, Operational Verification Testing, Johnston Atoll Chemical Agent Disposal System;* and *Health Risk Assessment No. 42-21-M1X6-93; Inhalation Risk from Incinerator Combustion Products, Operational Verification Testing—Phase 3* (Aberdeen Proving Ground, MD: U.S. Army Environmental Hygiene Agency).

known as the destruction and removal efficiency, or DRE. At Johnston Atoll, the Army voluntarily established much stricter performance requirements and measuring capabilities unlike any seen in the commercial hazardous waste incineration industry. The chemical agents are incinerated at a higher temperature and for more than four times the length of time needed to destroythe agent.[25] Exhaust gases from each of the incinerators are funneled intoseparate 2,000 degree afterburners that prolong the treatment time and provide a safety backup in the event of operational upsets or malfunctions in the principal incinerators. Another unusual feature is that after artillery shells and ton containers are processed at over 1,400 degrees Fahrenheit for approximately forty minutes, they enter an airlock where the air is sampled twice for the presence of residual agent. If any agent registers, the item is returned to the incinerator until no agent can be detected. No other incinerator in the country uses such post-incineration scanning.[26]

In addition, the Army outfitted the baseline system with hundreds more operational checkpoints and safeguards than federal regulations require. On the furnace that destroys explosives and propellants, the fourteen alarms that federal authorities require for cutting off the waste feed into the incinerator in the event of operational irregularities have been supplemented by another 186 alarms for the Army's own monitoring purposes.[27] These safeguards are intended to allow the Army to obtain the highest possible level of combustion efficiency.

As a result, trial burns at Johnston Atoll show the Army's incinerators performing well beyond the required federal standards, achieving DREs of 99.9999 and even beyond 99.9999999.[28] Nonetheless, the Army decided that the DRE was an insufficient standard to measure the performance of its incinerators. Table 2 compares the DRE monitoring standard with the Army's stricter monitoring standard, which is over 21,000 times and over 400 times more stringent than the federal DRE standards for nerve and mustard agents, respectively.[29] At Johnston Island, the Army installed over 100 monitors that take approximately 20,000 air samples daily.[30] These monitors have detected no release of agent caused by suboptimal incinerator performance.

However, monitors at the perimeter of the facility detected a 0.000000105 mg/cubic meter release of sarin on March 2, 1995, that was caused by malfunctioning silicone gaskets surrounding the doors of filter units. This release was one-third the general population limit shown in table 2.

Two other agent releases occurred when the incinerators were *not* operating. Incidents on December 8, 1990, and March 24, 1994, occurred, respectively, when an incinerator was cooling after it was shut down and during routine maintenance. The Environmental Protection Agency and the Department of Health and Human Services reviewed these incidents and determined that neither presented a significant public health risk.[31]

Though they admit that they do not completely understand the potential effects of incineration, federal officials long ago began regulating incinerators to protect public health and the environment.[32] Contrary to popular misperceptions, fairly innocuous compounds, like nitrogen, oxygen, carbon dioxide, and water vapor make up 99 percent of smokestack emissions. The remaining one percent of a smokestack's plume is believed to be Products of Incomplete Combustion (PICs), about 40 percent of which can be identified and therefore,

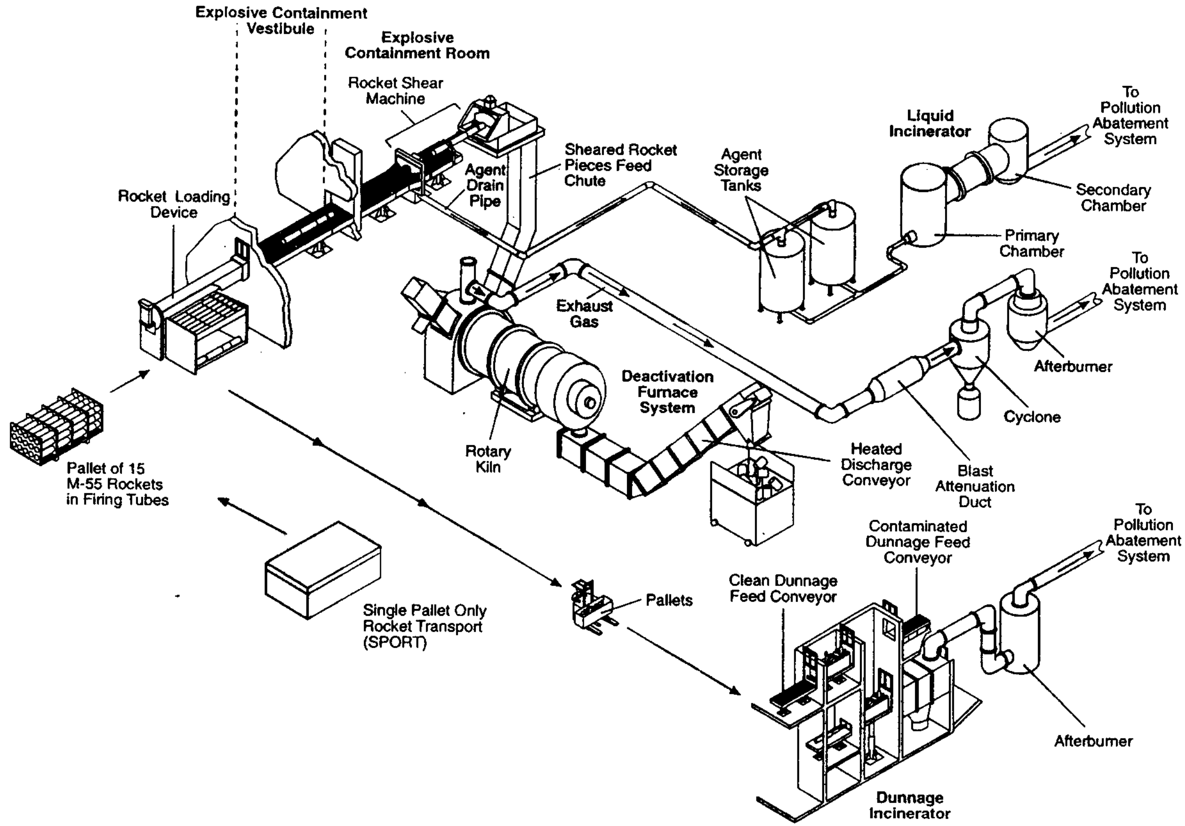


Figure 2: A schematic of the baseline disassembly and high temperature incineration process.

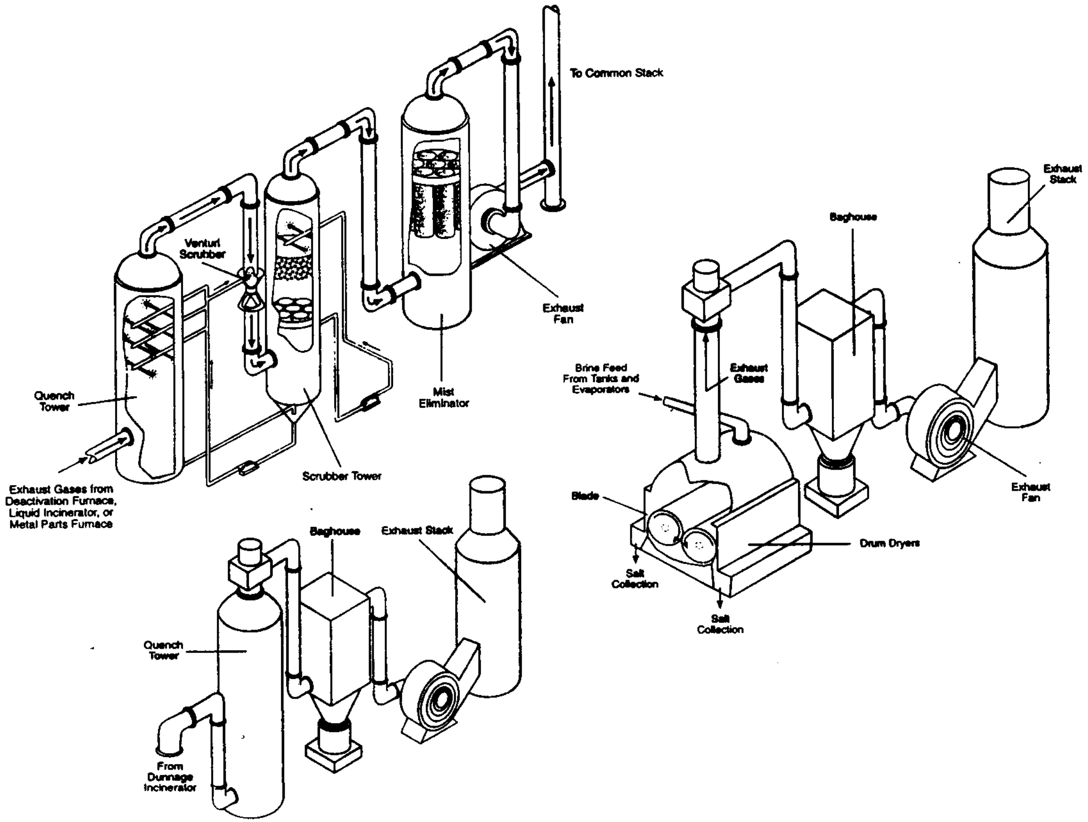


Figure 2 (continued)

Sources: Process Report for the Johnston Atoll Chemical Agent Disposal System (Aberdeen Proving Ground, MD: U.S. Army Chemical Material Destruction Agency, September 3, 1993), pp. 7, 9.

regulated.[33] During the trial burns carried out to obtain operating permits for the Johnston Atoll facility, the Army conducted intensive screening, as depicted in table 3, even though regulations only required testing for a small number of heavy metals and particulates. Most of the known PICs were not detected, and those that were detected were "well below the EPA level of concern."[34]

Alternatives to Incineration

A significant criticism of the baseline program is that the Army chose incineration before thoroughly examining the other possibilities and has since refused to consider new developments in alternative technologies in order to protect the baseline program.[35] To address this criticism, the Army asked the NRC's Committee on Alternative Chemical Demilitarization Technologies (Alternative Committee) to assess the state-of-the-art in destruction technologies. Before releasing their analysis in 1993, the Committee created a list of destruction technology requirements and evaluated a variety of destruction technologies on the basis of functional performance, engineering factors, and development status. Although the final study did not make policy recommendations, it noted that the baseline technology was the only one presently capable of meeting the specified destruction criteria. The NRC estimated that alternative technologies could take at least nine to twelve years to develop and test.[36]

In 1992, Congress directed the Army to conduct an evaluation of any alternative technologies that showed promise of being safer and more cost effective than the baseline program while still meeting the 2004 destruction deadline. The Alternatives Committee conducted another study and, in addition to development status, rated alternative technologies against five key criteria:

(i) Could the technology contribute to a program of disposal that is safer than the baseline program?

(ii) Could the technology treat agents, energetics, metal parts, and dunnage?

(iii) Could the technology destroy all agents?

(iv) Did the waste products meet environmental disposal requirements?

(v) Could the technology achieve treaty requirements for irreversible agent destruction?

In a 1994 report, the NRC recommended that the Army proceed with incineration without delay while continuing to study alternative destruction technologies. The NRC observed that the risk in continued long-term stockpile storage would offset any benefits accrued from a new destruction technology, should one eventually prove successful.[37]

Accordingly, the Army initiated a $45 million program to research both stand-alone neutralization and neutralization followed by biodegradation. The most recently considered neutralization approach for both mustard agent and VX mixes the agent with aqueous alkali or just with water. The resulting solution may then be dried or solidified, possibly in a cement mixture. Or, the partially neutralized agent may be funneled into a biodegradation treatment, where sewer sludge bacteria feed on the residual mustard agent for up to ten days to produce by-products that may be solidified, recycled, or released into the environment. The Army has yet to find a bacteria that will complete the destruction process for VX, but laboratory-scale neutralization tests have shown promise. If current bench-scale tests of these approaches prove successful, neutralization may substitute for incineration *only* at the two sites that store only bulk ton containers: Newport, Indiana, and Aberdeen, Maryland.[38] In other words, incineration will apparently remain the most viable technology for six of the eight storage sites.

Community Involvement

The Army has attempted to assuage the concerns of local citizens and environmental organizations that oppose the Army's destruction program by instituting the aforementioned safeguards and investigating alternative destruction technologies. However, much of the discord surrounding the baseline program has its roots in the historically problematic relationship the Army has had with each community.[39] For stockpile communities to gain confidence in the destruction program, they need access to accurate and timely information regarding all of its aspects. In the past, the Army has appeared to be withholding information and has refused to participate in a point-by-point refutation of opposition claims. In a recent example, the Army waited until December 1994 to release an Inspector General's report on Tooele's safety, claiming that it was an "internal pre-decisional document." The inspection occurred in mid-August 1994, one month before a safety officer was fired and then publicly accused the Army of myriad safety violations at Tooele.[40] Prompt release of the August Inspector General's report would have prevented opposition groups from portraying these circumstances as yet another example of the Army's proclivity for sweeping the program's problems under the rug. The media covered these allegations extensively, but gave comparatively less attention when seven separate investigations of these allegations by state and federal overseers later buttressed the Army's view that nothing serious was amiss at Tooele.[41] Such missteps by the Army color citizens' judgments about the program and heighten their suspicions of its highly technical data.

Lack of trust in those overseeing the destruction program and misunderstanding of the technologies involved have possibly generated enough controversy to derail the U.S. chemical weapons destruction program. Some of the stockpile states have begun to erect legal barriers in an attempt to halt or at least slow the program.[42] The U.S. Government could circumvent state laws that act to impede chemical weapons incineration. Legal expert Barry Kellman notes that the federal government can "waive strict conformity with otherwise applicable environmental protections, where higher national goals are inextricably involved."[43] However, the most productive scenario would be one in which the Army, Congress, and the federal regulatory agencies work together to regain the trust of the stockpile communities, thereby making obstructive state laws unnecessary.

THE RUSSIAN DESTRUCTION PROGRAM

Along with a 40,000 metric ton chemical weapons arsenal,[44] Russia also inherited the Soviet Union's dismal legacy in public health and environmental safety. When Russia's economic crisis and political disarray are added to this mix, the problems the Russian Government faces in mounting a program to destroy the world's largest stockpile of chemical weapons become apparent.

The Soviets attempted to launch a chemical weapons destruction program in 1989, inviting the international community to see their facility at Chapayevsk. Chemical agents were to be neutralized with orthophosphoric acid and then incinerated.[45] Citizens' protests about the plant's safety forced the Soviets to close it in 1989.[46] In the wake of this fiasco, the Russian Government was compelled to rule out incineration as an option for stockpile destruction.[47] Russia's unreliable roads and accident-prone railroads also precluded transporting the munitions, which led to a March 1995 announcement that the stockpile would be destroyed at the seven storage sites shown in figure 3.[48] In July 1995, the Ministry of Defense signed a protocol authorizing Shchuche, in the Kurgan region, as the site for a pilot chemical weapons destruction facility.[49] A safe and successful experience at Shchuche would increase the likelihood of cooperation on the part of local authorities at the other sites.

However, like their American counterparts, the citizens near the stockpile sites have grave misgivings about any destruction efforts, partly because they lack basic information about Russia's stockpile and destruction technologies.

The Soviet Army began storing the blister agent lewisite at Kambarka in the 1950s, but did not inform the local population of this until 1989. The location of the storage sites was classified until mid-January 1994, when *Rossiiskaya Gazeta* published what was stored where.[50] The latent response of local communities to this deception has been to demand new hospitals and better roads in return for their cooperation.[51] Western involvement in Russia's destruction program may, however, bolster the confidence of those wary of Russia's home-grown technologies and managerial practices.

Consequently, the United States is jointly studying Russia's proposed two-step destruction process, which involves neutralization with organic reagents followed by bituminization. Potentially, this approach will be applicable to non-thickened nerve agents, which compose just over 80 percent of the total Russian stockpile. Although Russia has the full range of chemical munitions, it has declared that the agent is not stored with the explosive components, which should alleviate some of the disassembly dangers encountered with the U.S. stockpile. Sarin and soman would be neutralized using equal volumes of the chemical agent and monoethanolamine containing 15-20 percent water. The reaction requires 1.5 hours at 221 degrees Fahrenheit. To neutralize Russian VX, a 1:2 volume ratio of chemical agent to anhydrous potassium isobutylate would be used in a thirty-minute reaction at 194 degrees Fahrenheit. In the bituminization stage, the neutralization by-products are mixed with asphalt and calcium oxide hydrate at 362 degrees Fahrenheit. Insoluble salts, which are suitable for landfilling, are formed.[52] The joint evaluation will develop the technical data that will be a key factor in determining the extent of U.S. assistance to the Russian destruction program, as well as the specific design and construction needs of a Russian destruction facility.[53]

Technical feasibility and public relations problems aside, the Russian Government will be unable to mount a viable destruction program without significant financial and technical assistance from abroad, which it has openly requested. While several countries are weighing what type of aid they may offer, Germany and the United States thus far are the only nations to step forward with assistance. Since 1991, the U.S. Congress has authorized $128 million under the Cooperative Threat Reduction Program, part of which has been used thus far for the joint technology evaluation, training of Russian specialists in operating a destruction facility, and the construction of an analytical laboratory.[54]

While the potential for an ecological and public health disaster undoubtedly looms if Russia cannot safely destroy its stockpile, less appreciated is the potential that Russian chemical weapons might be diverted to proliferating states or terrorists. The Duma Defense Committee has described the chemical weapons storage sites as insecure and unsafe, classifying the situation as an

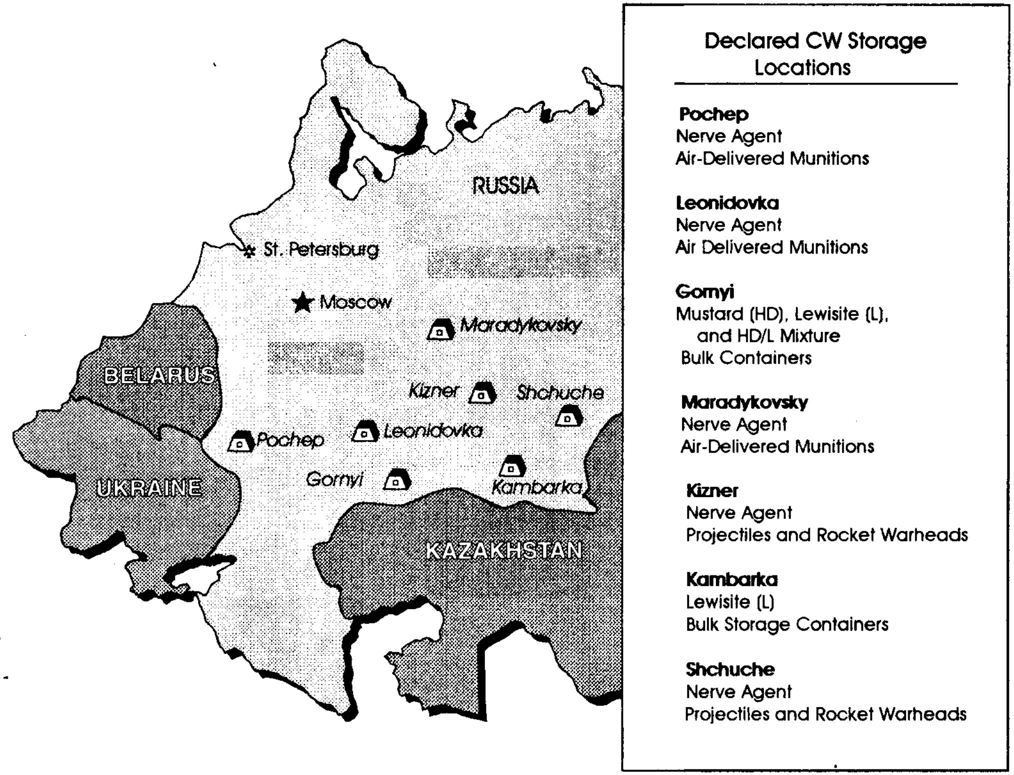


Figure 3: Russia's declared chemical weapons storage sites.

Source: Walter Busbee, "Now for the Heavy Lifting: Destroying CW Stockpiles in the United States and Russia," Brad Roberts, ed., *Ratifying the Chemical Weapons Convention* (Washington, D.C.: Center for Strategic and International Studies, 1994), p. 111.

emergency.[55] Also, a recent study revealed that lax security at Russia's chemical weapons storage apparently leaves them vulnerable to attack from without and theft from within.[56] Japan's horrifying encounter with chemical terrorism last spring should serve as ample warning of the dire consequences of theft or sale of Russia's chemical agents.

CLOSING OBSERVATIONS

Casual observers of arms control have the misleading impression that the most vexing phase of the process is reaching an agreement. That impression would certainly appear to be reaffirmed in the case of the CWC, which took 24 years to negotiate. However, a pathbreaking agreement is worth little if it is not fully and effectively implemented. In other words, the most important part of the effort to rid the world of chemical weapons is yet to come.

As the CWC enters into force, governments around the world will begin the odious and dangerous but necessary task of destroying aging, unstable, and illegal chemical weapons. The CWC will be the international enforcement mechanism and watchdog to ensure complete and responsible destruction of these munitions. For most citizens, however, destruction is a frightening prospect that conjures up images of unsafe and secretive disposal practices from earlier this century. In the U.S., critics have reacted to the inherent dangers of chemical weapons destruction by launching a controversial campaign to halt the baseline program. As a result, the National Academy of Sciences, Congress, several branches of the federal and state governments, local communities, and nongovernmental organizations have been drawn into a debate that mixes technical, political, and emotional factors. With the CWC's destruction requirements looming on the horizon, this confusing, polarizing debate may be replicated in Russia and elsewhere around the globe. While such debates can be constructive, they can also leave the impression that citizens face a zero-sum choice—either green *or* peace—when in fact both goals are desirable and achievable.[57]

By actively soliciting citizen participation and oversight from the initial planning stages through completion of the destruction process, governments may be able to foster a public sense of trust in the technologies and safeguards being used to protect their health and the environment. Otherwise, unwarranted fears may paralyze chemical weapons destruction programs and cripple an historic arms control treaty.

NOTES AND REFERENCES

1. Open pit burning, ocean dumping, and land burial are specifically prohibited as destruction methods. "Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and Their Destruction," Article IV, Part

IV(A) of the Annex on Implementation and Verification. States must have their plans for destruction approved by a new international monitoring agency, the Technical Secretariat of the Organization for the Prohibition of Chemical Weapons. The Technical Secretariat will subsequently monitor the destruction programs.

2. Rodney McElroy, *Briefing Book on Chemical Weapons* (Boston: Council for a Livable World Education Fund, 1989), pp. 3-4. Other types of warfare agents are choking agents, which cause victims to choke (e.g., phosgene), and blood agents, which prevent the utilization of blood oxygen (e.g., hydrogen cyanide and cyanogen chloride). Both choking and blood agents can cause death through asphyxiation.

3. This amount of VX must be absorbed through the skin, whereas the soman dosage must be inhaled at a rate of 70 mg-min/cubic meter. Victor A. Utgoff, *The Challenge of Chemical Weapons: An American Perspective* (New York: St. Martin's Press, 1991), p. 237.

4. Phillip Knightley, "Dumps of Death," *The London Times*, April 5, 1992, 26-8; Frederick Laurin, "Scandinavia's Underwater Time Bomb," *The Bulletin of the Atomic Scientist* 17, no. 2 (March 1991), pp. 11-2.

5. House Committee on Armed Services, *Countering the Chemical and Biological Weapons Threat in the Post-Soviet World*, 102d Congress, 2d Session (Washington D.C.: U.S. Government Printing Office, February 23, 1993), pp. 9-14, 22-4.

6. Key committee requests, which were granted, were the removal of the incinerator after the program's completion in 1992 and the hiring of an independent contractor to monitor incinerator emissions. *Citizens' Environmental Protection Committee* (Alberta, Canada: Department of National Defence, July 1992), pp. 3-4, 16-7.

7. National Research Council, *Alternative Technologies for the Destruction of Chemical Agents and Munitions* (Washington, D.C.: National Academy Press, 1993), p. 66. Germany is destroying World War I and II vintage munitions as they are being recovered. A second incineration facility is being constructed to handle additional munitions and contaminated soil. Telephone interview with Dr. Ralf Trapp, Provisional Technical Secretariat, June 7, 1995.

8. See Graham Pearson, "Farewell to Arms," *Chemistry in Britain* (October 1995), pp. 782-6.

9. Rolf Ekeus, *Report of the United Nations Secretary-General on the Status of the Special Commission's Plan for the Ongoing Monitoring and Verification in Iraq*, S/1995/284 (New York: April 10, 1995), p. 12; National Research Council, *Alternative Technologies*, pp. 72-3.

10. This section of the article draws upon *The U.S. Chemical Weapons Destruction Program: Views, Analysis, and Recommendations*, Amy E. Smithson with the assistance of Maureen Lenihan, report no. 13 (Washington, D.C.: The Henry L. Stimson Center, September 1994).

11. *Process Report for the Johnston Atoll Chemical Agent Disposal System* (U.S. Army Chemical Materiel Destruction Agency, September 3, 1993), p. 3.

12. U.S. Congress, Office of Technology Assessment, *Disposal of Chemical Weapons: Alternative Technologies-Background Paper*, OTA-BP-O-95 (Washington, D.C.: U.S. Government Printing Office, June 1992), p. 7.

13. U.S. General Accounting Office, *Chemical Weapons: Stability of the U.S. Stockpile*, GAO/NSIAD-95-67 (Washington, D.C.: General Accounting Office, December 1994), pp. 2-4.

14. Kevin Flamm et al., *Chemical Agent and Munitions Disposal Summary of the U.S. Army's Experience*, SAPEO-CDE-IS-87005 (Aberdeen Proving Ground, MD: Program Manager for Chemical Demilitarization, September 21, 1987), pp. 2-9.

15. Jim Harmon of The Families Concerned About Nerve Gas Incineration, an opposition group in Anniston, Alabama, argues that the Army's test for assessing the effectiveness of neutralization was flawed and that sarin may not have regenerated after neutralization. Telephone interview with the author, August 9, 1994.

16. The Army also tested neutralization on a small quantity of mustard and the nerve agent VX. Office of Technology Assessment, *Alternative Technologies*, pp. 26, 32; Flamm, *Summary of the U.S. Army's Experience*, p. 3.

17. Flamm, *Summary of the U.S. Army's Experience*, pp. 1-9.

18. U.S. General Accounting Office, *Chemical Weapons Destruction: Advantages and Disadvantages of Alternatives to Incineration*, GAO-NSIAD-94-123 (Washington, D.C.: General Accounting Office, March 1994), p. 3.

19. U.S. General Accounting Office, *Chemical Weapons: Obstacles to the Army's Plan to Destroy Obsolete U.S. Stockpile*, GAO/NSIAD-90-155 (Washington, D.C.: General Accounting Office, May 1990), pp. 9-10.

20. Public Law 99-145, Title XIV (50 USC 1521) November 8, 1985 (Department of Defense Authorization Act, 1986).

21. *Chemical Stockpile Disposal Program: Final Programmatic Environmental Impact Statement*, vol. 1 (Aberdeen Proving Ground, MD: Program Manager for Chemical Demilitarization, January 1988), pp. 2-131.

22. Items such as wooden pallets and other miscellaneous solid wastes are destroyed in a fourth incinerator.

23. For more detail on the baseline system, see *Johnston Atoll Chemical Agent Disposal System* (U.S. Army Chemical Materiel Destruction Agency, September 3, 1993).

24. National Research Council (NRC), *Recommendations for the Disposal of Chemical Agents and Munitions* (Washington, D.C.: National Academy Press, 1994), p. 126. Upon recommendation of the National Research Council and the State of Utah, the Army is currently conducting a study to determine the safety and added value of charcoal filter beds. October 20, 1995, telephone interview with Marilyn Tischbin, public affairs chief for the U.S. Army Chemical Materiel Destruction Agency.

25. At 2,700 degrees Fahrenheit, this incinerator is running at roughly 500 degrees higher than the Canadian and German chemical agent incinerators and approximately 600 degrees higher than typical hazardous waste incinerators. This temperature is also hot enough to destroy the agent in 0.42 seconds, but it remains in the incinerator for one-half a second before exhaust gases are moved into a 2,000 degree Fahrenheit afterburner for another 1.5 seconds. As another point of comparison, the incinerator that treats the explosives, rockets, mines, and other solid materials runs at 1,300 degrees Fahrenheit. August 23, 1994, telephone interview with Y.J. Kim, National Incineration Expert, and Cathy Massimino, senior Resource Conservation and Recovery Act/Superfund technical specialist, both of the Environmental Protection Agency.

26. Most commercial incinerators treat metal items for fifteen to thirty minutes. Telephone interview with Kim and Massimino, August 23, 1994.

27. The agent incinerator at Johnston Atoll has twenty-nine federal "waste cutoff" alarms and seventy-one of the Army's own additional alarms. The furnace decontaminating metal parts has ninety-five total alarms, only twenty-nine of which are federally required. August 23, 1994, telephone interview with Kim and Massimino.

28. The Mitre Corporation, *Summary Evaluation of the Johnston Atoll Chemical Agent Disposal System: Operational Verification Testing*, MTR-930000036 (McLean, VA: Mitre, May 1993), pp. 3-4 and pp. 3-5.

29. Some states, notably Kentucky, Utah, Maryland, and Indiana, have set a requirement that the baseline incinerators perform to the "six nines," or a DRE of 99.9999.

30. Two types of monitors, each with backups, are used in the furnace ducts and in the smokestack. The Automatic Continuous Air Monitoring System is a near real-time detector that operates around the clock on monitoring cycles of three to ten minutes. The Depot Area Air Monitoring System collects samples over a period of hours, which are analyzed with gas chromatography. All detectors are tested every twenty-four hours to ensure that they are operating correctly, with key detectors being tested at four-hour intervals. Interview with Mark Evans, Special Assistant to the Program Manager, U.S. Army Chemical Materiel Destruction Agency, July 21, 1994.

31. Mitre, *Summary Evaluation*, B-1; "Risk Assessment Survey News Release" (Aberdeen Proving Ground, MD: U.S. Army Chemical Materiel Destruction Agency, March 25, 1994); Gregory W. St. Pierre, *Johnston Atoll Chemical Agent Disposal System: Report of the March 23, 1994 Chemical Agent (GB) Release from the Common Stack* (Aberdeen Proving Ground, MD: U.S. Army Chemical Materiel Destruction Agency, March 1994); and U.S. Army Chemical Stockpile Disposal News Release (Aberdeen Proving Ground, MD: U.S. Army Chemical Materiel Destruction Agency, March 22, 1995).

32. As part of their continuing effort to understand incineration and improve regulation, the EPA recently released a study on dioxins, classifying them as a probable cause of cancer and other diseases in humans. Although the EPA already places more than thirty different controls on dioxins, the new study will likely result in even more restrictions, including restrictions on incinerator emissions. Gary Lee, "Dioxin Study Spurs Plea for Restrictions," *The Washington Post*, September 14, 1994, A8; and Gary Lee, "EPA Study Links Dioxin to Cancer," *The Washington Post*, September 12, 1994, A1. See also Kay H. Jones, "Diesel Truck Emissions, an Unrecognized Source of PCDD/PCDF Exposure in the United States," *Risk Analysis*, vol. 13, no. 3 (1993), pp. 245-252.

33. Six-tenths of 1 percent of a smokestack's emissions are still unknown. August 23, 1994, telephone interview with Kim and Massimino.

34. "Dioxins and furans in the common stack emissions were low, ranging from 0 to 0.16 ng/m^3. None of the dioxins found were the 2, 3, 7, 8—tetrachlorodibenzo-p-dioxin (2, 3, 3, 8 TCDD isomer, which is the most toxic form of dioxin). In comparison, municipal incinerators emit dioxins in the 50-7,000 ng/m^3 range." Mitre, *Summary Evaluation*, pp. 3-4.

35. Craig Williams, "Alternatives to Incineration of Chemical Weapons," *Common Sense: A Newsletter of Common Ground* (Berea, KY: The Kentucky Environmental Foundation, April 1992), p. 1.

36. National Research Council, *Alternative Technologies*, 5, pp. 187-9.

37. National Research Council, *Recommendations for the Disposal*, pp. 1-2, 4, 130.

38. Interview with Lt. Col. Steven M. Landry, U.S. Army Chemical Materiel Destruction Agency, Aberdeen Proving Ground, Maryland, June 8, 1995. See Yu-Chu Yang, "Chemical Reactions for Neutralising Chemical Warfare Agents," *Chemistry and Industry* (May 1, 1995), pp. 328-31; Steven Harvey, "Hydrolysis and Biodegradation of HD," Presented at an international workshop entitled "Biocatalytic Degradation of Chemical Warfare Related Materials," April 3-5, 1995, Aberdeen Proving Ground, Maryland; Program Manager for Chemical Demilitarization, *The U.S. Army's Alternative Demilitarization Technology Report for Congress, Executive Summary* (Aberdeen Proving Ground, MD; and Program Manger for Chemical Demilitarization, April 11, 1994), pp. 14-6. Note that the Army has also begun to explore three additional technologies for post-treatment of the wastes resulting from the neutralization process. These technologies are super critical water oxidation, ultraviolet peroxide oxidation, and electron beam bombardment. "Army Identifies Three Potential Alternative Technologies," Public Affairs Office, Program Manager for Chemical Demilitarization (Aberdeen, Maryland, November 13, 1995).

39. Every site, it seems, has tales that reveal the seeds of distrust. For example, Maryland residents recall how three officials who ran a chemical weapons development pilot plant were convicted in 1985 of violating pollution control standards.

40. The individual in question, Steve Jones, listed violations ranging from crumbling walls to the lack of forklift inspections. He also questioned the engineering design of the incinerators. Thomas Lippman, "Army Nerve Gas Incinerator Official in Utah is Fired in Safety Dispute," *The Washington Post,* September 23, 1994, A17.

41. These reviews found Tooele's preparedness was consistent with a facility undergoing final improvements on equipment and procedures before operational tests began to prove its capability to incinerate live agent and meet the federal and state safety standards. Reviews were conducted by the U.S. Army Corps of Engineers, the U.S. Army Safety Center, the Utah Occupational Safety and Health Administration, the U.S. Army Inspector General's Office, the U.S. Department of Labor Wage and Hour Division, the Utah Department of Environmental Quality, and the Utah Citizen's Advisory Commission.

42. For instance, a 1992 Kentucky law requires the Army to show that no safer alternative technology than baseline exists or is likely to exist before permits can be issued for the construction of a destruction facility. Office of Technology Assessment, *Alternative Technologies*, 4.

43. David A. Koplow, *Some Disassembly Required: Eliminating Chemical Weapons While Protecting the Environment* (Washington, D.C.: Lawyers Alliance for World Security, Committee for National Security, July 1994), p. 9.

44. Some uncertainty is associated with the size of Russia's stockpile because a spokesman for the Russian Security Council stated that in 1993 the Russian military had secretly dumped an unknown amount of chemical weapons into the ocean and other whistleblowers have asserted that open air detonation of the weapons has also occurred. See Marcus Warren, "Russian admits deception on chemical-arms stocks," *London Daily Telegraph*, March 21, 1994, p. 8; Vil Mirzayanov, "Dismantling the Soviet/Russian Chemical Weapons Complex: An Insider's Perspective," in *Chemical Weapons Disarmament in Russia: Problems and Prospects*, report. no. 17 (Washington, D.C.: The Henry L. Stimson Center, October 1995).

45. Karen Elliot House, "Toxic Dump," *The Wall Street Journal*, February 25, 1993, A1, A6.

46. *Chemical Weapons Convention Bulletin* 7 (Boston, MA: Federation of American Scientists Fund, February 1990), p. 14.

47. David Alan Coia, "Russia, U.S. to Test Disposal Procedure," *The Washington Times*, December 13, 1994, A16.

48. Associated Press, "Russia to Destroy Chemical Weapons," *The Boston Globe*, March 26, 1995, p. 16.

49. Agreements are now in place for facilities to be built at Gorny and Kambarka as well. Maj. Gen. Roland Lajoie, "Cooperative Threat Reduction Support to the Destruction of Russia's Chemical Weapons Stockpile," in *Chemical Weapons Disarmament in Russia: Problems and Prospects*.

50. Igor Vlasov, "Chemical Splinters in Russia's Body," *Rossiiskaya Gazeta*, January 15, 1994, p. 3.

51. The costs of Russia's destruction program can be expected to run into billions of dollars. Delivery of these *quid pro quos* will inflate this price tag significantly. Irene Kim and Viktor Litovkin, "Russia Defuses a Toxic Time Bomb," *Chemical Engineering* (October 1994), p. 32; "Chemical Weapons Destruction Sites Discussed," *Red Star*, September 24, 1992 (FBIS SOV-92-190, September 30, 1992), p. 2.

52. The Russians favor using potassium isobutylate for neutralizing VX because it results in a low reaction temperature and may produce a reduction in the reaction mass toxicity. For more information, see Kevin Flamm, *U.S. Support to the CW Destruction Program: Overview Briefing* (Washington, D.C.: Department of Defense), and Lajoie, "Cooperative Threat Reduction Support."

53. Lajoie, "Cooperative Threat Reduction Support," p. 46. According to participants in this joint evaluation, the results will lead to a U.S. approval of Russia's proposed destruction technology. U.S. anti-incineration activists are also anticipating that good results that will bolster their efforts to halt the U.S. baseline program.

54. Of the $73 million that Congress authorized in the 1996 DOD Authorization Bill, only $13 million is actually available to be spent until extensive conditions related to Russian arms control compliance are met. Of the remaining $55 million, $30 million will go toward the analytical laboratory. The Department of Defense, "DOD Awards Chemical Weapons Destruction Contract," News Release (Washington, D.C.: Department of Defense, May 20, 1994); Theodor Galdi, *The Nunn-Lugar Cooperative Threat Reduction Program for Soviet Weapons Dismantlement: Background and Implementation* (Washington, D.C.: Congressional Research Service, December 29, 1993), pp. 11-13.

55. "On the Course of Preparation of the Russian Federation for the Process of Destruction of Chemical Weapons and for Ratification of the 'Convention on Prohibition of Development, Production, Stockpiling and Use of Chemical Weapons and On Their Destruction,' " Resolution of the Committee on Defense, State Duma of the Federal Assembly of the Russian Federation (Moscow, October 11, 1994), p. 4.

56. Amy E. Smithson, "Improving the Security of Russia's Chemical Weapons Stockpile," in *Chemical Weapons Disarmament in Russia: Problems and Prospects*.

57. Trevor Findlay, "Green vs. Peace: The Johnston Atoll Controversy," *Pacific Research* 3, no. 2 (May 1990), p. 7.