DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

ASSEMBLED
CHEMICAL
WEAPONS
ASSESSMENT

Assembled Chemical Weapons Assessment Program

Supplemental Report to Congress

30 September 1999

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Appendices

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A Message from Michael A. Parker, Program Manager

A tremendous effort to identify and demonstrate alternative technologies to the baseline incineration technology for chemical weapons destruction has recently been completed. A critical and extremely helpful component of this effort has been meaningful stakeholder involvement throughout the entire process. I believe now, more than ever, that establishing and promoting cooperative working relationships and understanding among a broad spectrum of stakeholders can and will yield positive results. It is my recommendation to maintain appropriate vehicles for public involvement during the possible future implementation of alternative technologies. I would like to take this opportunity to thank each and every member of the Assembled Chemical Weapons Assessment (ACWA) Dialogue; the ACWA staff and support contractors; the technology providers; and the other related government agencies, specifically the managers of the demonstration test sites, for an outstanding, sustained and consistent team effort. An incredible amount of work has been accomplished in a very short time.

The evaluation of the technology demonstrations was presented to the ACWA Dialogue and released to the public during the Dialogue meeting held in Washington, D.C. 25-28 August 1999. The results and subsequent conclusions concerning the technologies tested can be found in Sections II.C and III respectively. The technical aspects are the backbone of any technology demonstration project. While the technical aspects of the ACWA program were less visible than the Public Involvement activities and did not necessarily contain the transparent nature of the overall program, they were most significant in scope and accomplishment. Over the course of the last two and a half years, 12 technical proposals were received, six were found to be worthy of demonstration, 3 were actually demonstrated, and within the 3 demonstrations, 15 major process unit operations were tested. During testing, approximately 2,300 samples were taken, and we conducted 11,500 analyses at 19 laboratories, yielding 210,000 data results. All of this work was possible by virtue of the Program Evaluation Criteria developed very early in the program in conjunction with the Dialogue. One truly innovative and constructive aspect of the program, the Citizens’ Advisory Technical Team (CATT), enabled stakeholder involvement throughout the entire procurement process.

Looking towards the future, continued efforts must be made to maintain the momentum the ACWA program has established. To that end, open communication with interested stakeholders must continue and better and consistent collaboration with the Program Manager for Chemical Demilitarization (PMCD) is essential. Combining implementation expertise with a truly open and collaborative process will yield the best results toward finally ridding the nation of these lethal weapons of mass destruction.

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A Message from the Dialogue on Assembled Chemical Weapons Assessment

The Dialogue on Assembled Chemical Weapons Assessment (ACWA) was formed in May 1997 to facilitate and accelerate the destruction of the United States (U.S.) stockpile of chemical weapons and to ensure integration of the concerns, input, and ideas of the full diversity of interests involved in the destruction of chemical weapons. The Dialogue includes: individuals from the nine states with stockpiles of chemical weapons;[1] state regulators; tribal representation; U.S. Environmental Protection Agency (EPA) staff; Department of Defense (DOD) staff from affected sites and headquarters; and representatives from national citizen groups that regularly work on these issues.

In order to make recommendations for this Report, the Dialogue has worked side-by-side with ACWA staff to: develop criteria for assessing alternative technologies; oversee the technology demonstrations; and ensure the fair and consistent application of criteria to the demonstration data. In the past two and a half years, this unique cooperative exercise has required thousands of hours of volunteer time and resulted in decisions that the Dialogue and ACWA staff jointly support and believe are technically sound and publicly acceptable.

The following message contains:

- ❑ A Programmatic Assessment of ACWA by the Dialogue
  - *An assessment of the successes and limitations of the ACWA program.*
- ❑ Dialogue recommendations regarding continuity of the ACWA program
  - *Recommendations regarding the ACWA program data and how it should be applied to follow-on programming.*
- ❑ Information on criteria development and application and Dialogue comments on public acceptability
  - *Discussion of criteria and Dialogue input regarding public acceptability and site specific considerations.*

PROGRAMMATIC ASSESSMENT OF ACWA

- ❑ **Meeting the mandates of Public Laws (PL) 104-208 and 105-261.** The Program has met the minimum requirements of the law by identifying and demonstrating “not less than two alternatives” to “baseline” incineration for the destruction of assembled chemical weapons. The ACWA program identified six promising technologies and demonstrated three alternatives to baseline incineration for the destruction of assembled chemical weapons. Additionally, as mandated by PL 105-261, the ACWA program is working on preparatory efforts for any follow-on programming directed by Congress.

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[1] Alabama, Arkansas, Colorado, Hawaii (Johnston Atoll), Indiana, Kentucky, Maryland, Oregon, Utah

- **A model government program.** The ACWA program combines the best science and engineering available with the concerns of the affected communities and the political realities of chemical weapons destruction. This program has been a model for involving stakeholders in a highly technical program that has real implications for the health and welfare of over 279,000 people who live within the Immediate Response Zone of the eight continental U.S. stockpile sites where over 30,000 tons of chemical weapons are stored. The Dialogue believes that by building on the ACWA model, DOD has within its grasp a process through which the ultimate goals of the Chemical Demilitarization Program can be achieved safely, expeditiously, and cooperatively. In April of 1999, the ACWA program was recognized as one of 98 semi-finalists, from a pool of 1600 applicants, for an Innovations in Government award administered by Harvard University.
- **An innovative approach to sensitive procurement source selection.** The Citizens' Advisory Technical Team (CATT), composed of four Dialogue participants with a diversity of perspectives and the support of a technical consulting firm that was chosen based on the Dialogue's input, worked with the DOD Technical Team to ensure that the evaluation criteria were applied systematically to each technology demonstrated. This was an innovative approach to provide transparency and public involvement in a process with procurement sensitive and proprietary information.
- **A comprehensive evaluation of technologies.** The ACWA technologies were evaluated against the Program Evaluation Criteria created in 1997, with advice from the Dialogue and their respective communities. The joint development of these criteria has served as a common basis for DOD, community members, regulators, and others to fairly compare and evaluate the technologies. The National Research Council (NRC) chose to base their evaluations on these same criteria.
- **Rebuilt trust between government and communities.** Through the Dialogue process, a level of trust has developed between the various stakeholder groups and DOD, which had been lost in previous chemical demilitarization efforts. The decision to allow citizen participation in the procurement process through the CATT engendered confidence in the decisions made by the program even when those decisions were at odds with individual stakeholder positions. The process has been a leap forward from the traditional "decide, announce, defend" approach to government decision-making and should be seen as a foundation for future chemical demilitarization decisions.
- **Limitations of the ACWA program due to funding constraints.** Funding limitations in fiscal year (FY) 1999 allowed for only three of the six identified alternative technologies to be awarded demonstration contracts at that time. As a result, ACWA conclusions in this report will not benefit from the data those demonstrations would have provided and a level of uncertainty remains regarding the potential viability of those untested technologies. DOD has subsequently committed to FY 2000 funding for additional technologies identified by the demonstration selection criteria, but the delay in demonstrating these technologies will postpone timely assessment and comparison of alternative technologies. Additionally, continued lack of funding for technology demonstrations of individual process operations submitted through the Broad Agency Announcement (BAA) may further limit the range of potential options available to the chemical demilitarization program.

RECOMMENDATIONS REGARDING CONTINUITY OF THE ACWA PROGRAM

When the Dialogue convened in 1997, it was clear that the group represented the full range of views on the issues of incineration of chemical weapons and on alternative technologies for destroying chemical weapons. These differences still exist and in many ways have been clarified. However, despite the differences of opinion, the Dialogue supports the destruction of the nation's stockpiled chemical weapons in a safe, cost-effective, environmentally sound, expeditious, and publicly acceptable manner.

The Dialogue agrees to and recommends the following regarding the continuity of ACWA (one member of the Dialogue disagreed with several of the recommendations, please see Appendix D for this minority report):

- **The ACWA program should move forward with technologies that have been successfully demonstrated.** The Dialogue recommends that alternative technologies be pursued and, if suitable, piloted and scaled up at appropriate sites. The technologies successfully demonstrated by the ACWA program show potential for:
  - Addressing the complex technical challenges associated with destroying assembled chemical weapons—agent, explosives, metal and other parts; and
  - Addressing public acceptability concerns.

  Unless modified by Congress, PL 105-261 requires that, prior to proceeding to pilot, the Under Secretary certify that an alternative technology is:

  - "As safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions, and
  - Is capable of completing the destruction of such munitions on or before the later of the date by which the destruction of the munitions would be completed if incineration were used or the deadline date for completing the destruction of the munitions under the Chemical Weapons Convention."

- **DOD and the Army should assess the applicability of alternatives for all sites with assembled chemical weapons.** The Dialogue fully endorses PL 99-145 requiring the Secretary of Defense to provide maximum protection to the environment during the destruction of chemical weapons. The Dialogue recommends that as the technologies are piloted and scaled up to implementation, the individual unit operations continue to be monitored and assessed for potential application at baseline incineration sites destroying assembled chemical weapons. If, in comparing alternatives to baseline incineration, individual unit operations emerge as providing a higher level of protection to the environment and/or safety of the public and the workers, then DOD should consider the option of retrofitting existing baseline facilities. In deciding whether to pursue retrofit approaches, DOD should not only consider criteria such as safety, process efficacy, and environmental impact, which many people believe are threshold issues, but should also consider impacts of retrofitting on both the destruction schedule and overall program costs. Additionally, Dialogue members recommend that the analysis comparing alternative technologies to baseline incineration be done in a transparent process to bring credibility to the comparison product and to ensure all relevant issues and questions are addressed.

- **The ACWA program should complete additional demonstration of promising alternative technologies that successfully met the Demonstration Selection Criteria.** In August, 1999, the DOD committed to members of the U.S. Congress that DOD would proceed "with demonstration of the remaining technologies." The Dialogue urges the DOD to move forward expeditiously on this commitment.
- **The ACWA program should pursue technology demonstrations of unit operations submitted through the BAA process.** The BAA was established by ACWA to encourage innovative development of technology components, which may be useful in the Chemical Weapons Destruction Program.
- **The ACWA program should continue to expedite future deployment by beginning environmental and program planning.** The Dialogue has helped to initiate and strongly endorses efforts to expedite future deployment of ACWA-demonstrated solutions by beginning early, cooperative environmental and programmatic planning for pilot and full-scale operating facilities at appropriate sites. These efforts will focus on ways to expedite planning, but in no way will attempt to circumvent existing regulatory and public involvement requirements. This recommendation is in concert with the FY99 Defense Authorization Act which encourages the ACWA program Manager to "establish program requirements," "prepare procurement documentation," and "develop environmental documentation" for "the design, construction, and operation of a pilot facility…" (PL 105-261).
- **DOD should continue the tradition of intensive public involvement for any follow-on effort.** The Dialogue recommends DOD continue to include a diversity of stakeholders in a meaningful public involvement process on a national and site-specific level. This effort should include a diversity of perspectives from the community; DOD; tribal, state, and federal environmental regulators; national and local citizen groups; and others to ensure maximum opportunity for the successful implementation of effective and broadly acceptable destruction methods. While public acceptability was but one of the nineteen rigorous criteria used in the evaluation of technologies demonstrated in the ACWA program, the Dialogue believes that this criterion will take on even greater importance in any implementation efforts. Therefore, the Dialogue believes it is imperative that the impacted communities are early participants in a collaborative effort that is able to address community and regulator concerns. This is also in concert with FY99 legislation to "identify and prepare to meet public outreach and public participation requirements" (PL 105-261).
- **Congress should maintain the continued independence of ACWA.** The Dialogue applauds and supports the success of the ACWA program to date and believes that the program's independent association within DOD has contributed to that success. While many members of the Dialogue emphasize the importance of retaining this successful arrangement while actively pursuing coordination with all government parties involved in chemical weapons destruction, other members of the Dialogue believe that program Manager for Chemical Demilitarization (PMCD) and ACWA should work

together—bringing their respective strengths and experiences—to deploy alternative technologies.

- **The ACWA program should consider using combinations of unit operations if a pilot-scale alternative technology is pursued.** The Dialogue supports the NRC General Finding No. 12, which states "The optimum system for a particular chemical weapons storage depot might include a combination of unit operations from the technology packages in this report." The Program Manager for ACWA is encouraged to review the best features of each of the technologies for possible inclusion in a total solution.
- **The ACWA program should provide input and output information for processing of all assembled chemical weapons and bulk agent at stockpile sites.** The Dialogue believes that providing input and output information for processing of all assembled chemical weapons and bulk agent by the technologies demonstrated in the ACWA program will be beneficial to community members and decision makers.
- **DOD should encourage entities within DOD, other agencies, and industry to review the ACWA data and selection criteria for possible application in other clean-up and waste management programs.** The Dialogue believes that the alternative technologies tested in the ACWA program and the criteria used to evaluate them may be applicable to other chemical weapons programs such as the Non-Stockpile program, as well as in other waste management applications. The Dialogue recommends making the products of the ACWA program available to a wide audience among government agencies and industry.

CRITERIA DEVELOPMENT AND APPLICATION AND PUBLIC ACCEPTABILITY RECOMMENDATIONS

Criteria Development and Application

The Threshold Criteria, Demonstration Selection Criteria and Implementation Evaluation Criteria have served as the foundation for the ACWA program. The Criteria, developed by the Program Manager in concert with the Dialogue on ACWA in May, June and July of 1997, have been used to evaluate technologies throughout the ACWA program. The Threshold (Go/No Go) Criteria were the minimum threshold criteria that technologies had to meet to be considered in the program. The Demonstration Selection Criteria were used by the Program Manager, in coordination with the CATT, to select technologies for demonstration. The Implementation Evaluation Criteria represent the basis for the conclusions that are being made in this Report to Congress.

During the development of the criteria, input was solicited through multiple venues. Initially, Dialogue members collected criteria developed by Citizens' Advisory Commissions (CACs) and other groups and provided this information to DOD. These criteria were considered by DOD as they were developing a first draft of the ACWA criteria for Dialogue review. The Dialogue on ACWA held three meetings in May, June and July of 1997 that largely focused on criteria development. Input from Dialogue members was critical in the development of the criteria, including lessons learned from activities in Hawaii, Indiana, and Maryland. In addition to Dialogue meetings, the CATT liaison group met to discuss criteria development.

In the Spring of 1997, input on the criteria was solicited through various community forums, including meetings that ACWA staff and Dialogue members attended. This community input was incorporated, through the participation of community members in the Dialogue on ACWA, into the criteria. In addition to these Dialogue-oriented activities, the Program Manager sponsored two technical workshops and a Pre-Solicitation Conference for potential technology providers.

Throughout the ACWA program, the Dialogue has monitored how the criteria have been used to evaluate the technologies. To help monitor application of the criteria throughout the confidential elements of the ACWA program, CATT members have worked with the DOD Technical Team to ensure proper application of the criteria. In addition, throughout the program, information has flowed from the ACWA program to communities and from communities to the ACWA program.

The Implementation Evaluation Criteria represents the basis for the recommendations from the Dialogue on ACWA and the conclusions from the Program Manager.

While the Dialogue has made specific recommendations on “Public Acceptance,” it is important to recognize that this is only 1 of 19 criteria. All 19 criteria serve as the basis for the Program Manager’s conclusions and detailed information about criteria 1 through 18, made available through the technology demonstrations, significantly influenced the Dialogue members’ recommendations about public acceptability. In addition, Dialogue members’ recommendations about public acceptability are based on members’ experience and understanding of their communities’ concerns.

Implementation Evaluation Criteria, Criteria No. 19—Public Acceptability

Given that the ACWA program’s main objective is to demonstrate whether any potentially viable alternative technologies to incineration exist, the first 16 criteria endorsed by the Dialogue, are technical criteria. Criteria 17, 18, and 19 are part of the category "Potential for Implementation." Criteria 17 and 18 were used to compare the life cycle cost and schedule for full-scale facilities at Pueblo and Blue Grass. The last criteria, number 19, addresses the issue of public acceptability. This criterion is designed to inform Congress of any major barriers to implementation in a community due to public concerns. It should be noted that these statements are based on the collective knowledge the Dialogue participants have about their communities and is meant to provide a general, informed reaction for Congress by highlighting any major concerns. The Dialogue recognizes that if an alternative were to be chosen for a community, a National Environmental Policy Act (NEPA) process, conducted by DOD, and a permitting process, working in cooperation with the EPA and the state regulators, will be undertaken to assure compliance with all statutes and regulatory requirements including requirements for public input and involvement.

It should be noted, as stated above, that while the first 18 criteria are technical in nature, they were developed with input from citizens, communities, and regulators and, as such, relate to public acceptability. In essence, criteria 1 through 18 serve as the basis for determining public acceptability. Dialogue members have consistently stated that factors such as process efficacy, impact to human health and environment, and safety are critical in determining “public acceptability.”

To help the Dialogue participants, who represent a diversity of perspectives regarding the appropriate destruction methods for chemical weapons, a series of public meetings were conducted and feedback was sought from community members regarding the criteria being developed in the ACWA program. The communities' concerns were (1) registered in the final version of the comprehensive three-tiered criteria (described above) for the ACWA program and (2) used in the sections below to help Dialogue members evaluate the technologies against the Implementation Evaluation Criteria.

Public Acceptability (Factor #19)

The Dialogue provided input to the ACWA Technical Team on Factor #19, Public Acceptability, to assist them in completing the Technical Evaluation Report. This input was based on the information available to Dialogue members as of 27 August 1999. As additional information becomes available, Dialogue members' assessment of potential public acceptability for these technologies may change. It should be emphasized that this is only an assessment of potential public acceptability. In keeping with the rest of the Technical Report, their input was NOT by site, but rather a general comment on the likelihood of public acceptability.

- ☐ **General Dialogue Recommendations.**
  - Burns and Roe: The Dialogue agreed by full consensus that the technology solution proposed by Burns and Roe is unlikely to be publicly acceptable.
  - General Atomics: The Dialogue agreed by full consensus that the technology solution proposed by General Atomics is likely to be publicly acceptable.
  - Parsons/AlliedSignal: All but one Dialogue member agreed that the technology solution proposed by Parsons/AlliedSignal is likely to be publicly acceptable for destroying mustard agent, but not for destroying nerve agent. One participant noted that since the proposed technology was not found to be technically adequate for all types of munitions, that the public would likely find this technology publicly unacceptable in general.[2]

- ☐ **Site Specific Recommendations.** In addition to providing general feedback regarding public acceptability, the Dialogue participants made site-specific observations and recommendations. For all sites, the Dialogue participants identified issues that would likely be of concern if an alternative technology were to be considered for implementation at their site. For some sites, Dialogue members provided consensus recommendations.

Alabama

Through various community outreach efforts, a broad-based community consensus has formed that (1) public health and environment and (2) safety are the primary acceptability issues related to the destruction technology. Process efficacy is also important as a threshold issue, and to the

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[2] Please refer to Appendix D for the minority report and further information regarding this individual's concern.

extent it affects the other two. The public acceptability for the demonstrated alternative technologies is based on data generated to address these two critical acceptability issues.

If an alternative method of destruction for assembled chemical weapons were to be considered for Anniston, it would likely be an improvement to the current baseline facility under construction with some or all of the process components replaced with alternatives. Assuming the primary acceptability issues as defined above have been adequately addressed, the remaining issues of concern would likely center on destruction schedule, economic impacts (jobs), and cost—issues of significantly less importance than the primary acceptability issues of Public Health & Environment and Safety. In that context, the issues of schedule, economic impact and cost become discriminators between alternatives and the baseline, rather than positive determinants.

Therefore, if the primary acceptability issues of alternatives compare favorably to baseline, we would foresee no obstacles to a change to improve with an alternative in Alabama with regard to public acceptability. If, however, the primary acceptability issues compare marginally with baseline, then the schedule, economic impact, and cost issues could become central issues for discussion in the community.

Therefore, Dialogue members from Alabama recommend that alternate technologies solutions and individual unit operations continue to be assessed for potential application as improvements to the baseline facility, and that piloted unit operations include those with specific application to baseline facilities.

Submitted by: David Christian, Serving Alabama's Future Environment
Wm. Gerald Hardy, Alabama Department of Environmental Management
George Smith, Alabama Citizens' Advisory Commission

Arkansas

If an alternative method of destruction for assembled chemical weapons were to be considered for Pine Bluff, the discussion would likely focus on two options:

- Build a new facility using an "alternative technology facility."
- Retrofitting segments of the Pine Bluff incineration currently under construction.

Key issues that would need to be addressed with input from a diversity of stakeholders in the community, if an alternative were pursued include:

- Safety and health of workers and the public;
- Environmental and permitting issues;
- Economic impacts;
- Cost; and
- Schedule.

In a new or future program, these factors would be considered for any potential option. Given that a baseline incineration facility is under construction at the Pine Bluff facility, any community discussion would inevitably be compared to this baseline facility also.

Recommendations

The three Arkansas representatives on the Dialogue have worked on chemical weapons issues for a combined total of 19 years. These representatives all agree that the community desires that the stockpile be destroyed as quickly as possible, although they have differing views on the best method for destroying the weapons. All three representatives agree that to the extent that alternative technology improvements to the baseline are feasible and appropriate, they should be considered.

Submitted by: Daniel Clanton, Arkansas Department of Environmental Quality
Wesley Stites, Arkansas Citizens' Advisory Commission
Evelyn Yates, Pine Bluff for Safe Disposal

Colorado

Dialogue members from Colorado identified factors that would be especially important if an alternative technology were considered for their site. Should the decision be made to select an alternative technology for Pueblo, the Dialogue Participants from the State of Colorado all agree there appears to be a general willingness by citizens, local officials, and DOD to use the Pueblo site to pilot an alternative technology. This willingness is based on three factors: the recognition that the types of munitions stored at the Pueblo Depot are not as complicated as those at other sites; the realization that some of the alternative technologies have already proven successful at destroying mustard gas; and the desire to destroy the stockpile as soon as possible using a safe method.

Dialogue members from Colorado believe the following issues will be important to the community of Pueblo and affected stakeholders, regardless of the technology employed:

- ☐ Potential for generation and release of agent and/or toxic by-products during demilitarization and secondary waste, as well as other wastes, discharges and emissions resulting from the process;
- ☐ Amount of water required/consumed and the energy and infrastructure needs for each technology;
- ☐ Real and perceived effects on local agricultural products and impact on market potential;
- ☐ Community and worker health and safety;
- ☐ Level of government and contractor commitment to openness and involvement of the public and regulators in decisions throughout the process;
- ☐ Impact fees for the community;
- ☐ Concern for a boom and bust economy and local employment opportunities associated with the technology chosen; and
- ☐ A desire by some to ship weapons to Utah instead of destroying them in Colorado.

Dialogue members identified the top four items in the above list as being of greatest concern to the local public.

In addition to the above, the Dialogue members identified several issues that they believe the local public will raise if an alternative technology is pursued over baseline:

- Comparison of the alternative technologies to incineration in regards to health, safety, and efficacy;
- Concern regarding cost issues if alternative technologies cost substantially more than baseline incineration; and,
- Concern regarding schedule issues if alternative technologies take substantively longer to complete than baseline due to:
  - Taxpayer cost;
  - Economic development potential of property and the inability to take advantage of it until the chemical demilitarization mission is accomplished; and
  - Community interest in completing the mission.

Recommendations

In regard to next steps at the Pueblo site, the Colorado Dialogue participants recommend that:

- The ACWA program should continue;
- The Dialogue and CATT team should continue;
- The Program Manager should continue to manage technology through the pilot stage;
- Every effort be made to fully fund the lifecycle cost estimated for all chemical demilitarization activities;
- Congress authorize and appropriate funds for the permitting, design, and construction of a chemical demilitarization facility at Pueblo;
- The Colorado Dialogue members urge Congress to encourage all relevant federal agencies to support and cooperate with efforts by the state of Colorado and citizens of Pueblo to expedite permitting;
- The Colorado Dialogue members endorse the efforts of DOD to facilitate an Integrated Process Team at other chemical demilitarization sites and request the same at Pueblo, and
- Every consideration should be given to a technology's ability to recycle effluents and by-products.

Submitted by: Kathryn Cain, Pueblo Chemical Depot
Irene Kornelly, Colorado Citizens' Advisory Commission
Joan Sowinski, Colorado Department of Public Health and the Environment
Ross Vincent, Colorado Citizens' Advisory Commission

Kentucky

Dialogue members from Kentucky identified the following factors that would be especially important if an alternative technology were considered for their site:

- In general, high temperature or high-pressure treatment of agent is not likely to be acceptable to the public, based on long-term input from the public.
- The technology offered by Burns and Roe is not likely to be acceptable since it didn’t demonstrate it could destroy agent and it is a high temperature system (introduction of neat agent into high temperature) perceived by the public to be similar to incineration.
- The technologies offered by Parsons/AlliedSignal and General Atomics are based on neutralization of agent at low temperature and pressure prior to secondary treatment.
- Although Parsons/AlliedSignal is a low temperature and pressure system, it would likely not be acceptable since it has not demonstrated effectiveness on nerve agent by-products and it generates large quantities of solid waste that would have to be landfilled.
- Of the three technologies under consideration, General Atomics would be the most likely to be acceptable for Kentucky, based on its ability to handle the total Kentucky stockpile and based on long-term input from the public.
- Kentucky would like to see the other three technologies identified in the ACWA program demonstrated concurrently with the planned maturation testing to refine the neutralization/SCWO process.

Submitted by: Ralph Collins, Kentucky Department for Environmental Restoration
Doug Hindman, Kentucky Citizens’ Advisory Commission
Worley Johnson, Kentucky Citizens’ Advisory Commission
Dane Maddox, Blue Grass Army Depot
Craig Williams, Chemical Weapons Working Group

Oregon

If an alternative method of destruction for assembled chemical weapons were to be considered for Umatilla, several issues would need to be addressed with a diversity of stakeholders in the community. The discussion would likely focus on three possible options:

- Replacing the Umatilla baseline incineration facility with a new "alternative technology facility" that destroys chemical weapons using a technology demonstrated during ACWA;
- Replacing the existing facilities with a combination of unit operations that provide a total solution; or
- Retrofitting segments of the Umatilla facility (e.g., dunnage incinerator).

Key issues that would need to be addressed would include the:

- Re-use capability of the site which is part of the BRAC process;
- Real or perceived impact to agriculture from facility effluents;

- Resource usage, consumption, and outputs;
- Impact to the CWC deadline;
- Impact to life-cycle cost and schedule;
- Applicability to both assembled chemical weapons and bulk agent (HD, VX, GB);
- Worker and public safety;
- Technology maturity and permitting experience (i.e., chemical demilitarization and commercial facilities);
- Legal and regulatory requirements;
- Potential impacts to threatened or endangered species;
- Disposition of the facility after weapons destruction is complete;
- Impacts to human health and the environment;
- Protection of Tribal Treaty resources;
- Continued risk of storage, and;
- Ability to process M-55 rockets and problematic munitions.

In a new or future program, these factors would need to be considered for any potential option and also in comparison to the current baseline technology.

The Confederated Tribes of the Umatilla Indian Reservation remain concerned about the safe and cost effective disposal of the Umatilla Depot stockpile. The Board of Trustees for the Tribes has not taken a formal position regarding the methodology for disposal.

Submitted by: Karyn Jones, G.A.S.P.
Bob Palzer, Sierra Club Air Committee
Wayne Thomas, Oregon Department of Environmental Quality
J.R. Wilkinson, Confederated Tribes of Umatilla

Utah

If an alternative method of destruction for assembled chemical weapons were to be considered for Utah, several issues would need to be addressed with a diversity of stakeholders in the community. The discussion would likely focus on three possible options for a pilot or full scale operation:

- Replacing the existing incinerator facilities with a new "alternative technology facility;"
- Replacing the existing facilities with a combination of unit operations that provide a total solution; or
- Retrofitting segments of the current facilities for the destruction of assembled chemical weapons.

Key issues that would need to be addressed would include:

- The impacts to human health and the environment;

- Worker safety;
- Permitting issues;
- Economic Impact;
- Cost; and
- Schedule.

In a new or future program, these factors as well as others would need to be considered for any potential option and also in comparison to the current baseline technology.

Submitted by: Dan Bauer, State of Utah Office of Planning and Budget
Dennis Downs, Utah Department of Environmental Quality
Cindy King, Utah Chapter of Sierra Club

DIALOGUE PARTICIPANTS

The above Message is submitted by the 33 members of the Dialogue on Assembled Chemical Weapons Assessment. The observations and recommendations above that are national in scope (e.g., A programmatic assessment of ACWA by the Dialogue, Dialogue recommendations regarding continuity of the ACWA Program, and General Dialogue recommendations on public acceptability) were made by full consensus of the Dialogue except where otherwise noted. Site-specific recommendations were drafted and agreed to by consensus by Dialogue members from each state.

Dan Bauer
State of Utah

Pua'Ena Burgess
Pacific & Asia Council of Indigenous People

Kathryn Cain
Pueblo Chemical Depot

David Christian
Serving Alabama's Future Environment

Daniel Clanton
Arkansas Department of Environmental Quality

Ralph Collins
Kentucky Department for Environmental Protection

Elizabeth Cotsworth
U.S. Environmental Protection Agency

Carl Daly
U.S. Environmental Protection Agency

Dennis Downs
Utah Department of Environmental Quality

Pamela Ferguson
Indiana Citizens' Advisory Commission

Wm. Gerald Hardy
Alabama Department of Environmental Management

Hugh Hazen
U.S. Environmental Protection Agency

Douglas Hindman
Kentucky Citizens' Advisory Commission

Worley Johnson
Kentucky Citizens' Advisory Commission

Karyn Jones
G.A.S.P.

Cindy King
Utah Chapter Sierra Club

Irene Kornelly
Colorado Citizens' Advisory Commission

Thomas Linson
Indiana Department of Environmental Management

Dane Maddox
Blue Grass Army Depot

Jim Michael
U.S. Environmental Protection Agency

Sara Morgan
Citizens Against Incineration at Newport

John Nunn
Maryland Citizens' Advisory Commission

Bob Palzer
Sierra Club Air Committee

Michael Parker
Assembled Chemical Weapons Assessment

William Pehlivanian
Assembled Chemical Weapons Assessment

George Smith
Alabama Citizens' Advisory Commission

Joan Sowinski
Colorado Dept. of Public Health and Environment

Wesley Stites
Arkansas Citizens' Advisory Commission

Wayne Thomas
Oregon Department of Environmental Quality

Ross Vincent
Environmental Strategy Team Sierra Club

Paul Walker
Global Green USA Legacy Program

J.R. Wilkinson
Confederated Tribes of Umatilla

Craig Williams
The Chemical Weapons Working Group

Evelyn Yates
Pine Bluff for Safe Disposal

EXECUTIVE SUMMARY

This report responds to the requirements contained in Title VIII, section 8065 of the Omnibus Consolidated Appropriations Act, 1997 [Public Law 104-208]. This report presents the results of the evaluation on “the effectiveness of each alternative chemical munitions demilitarization technology identified and demonstrated” under the Assembled Chemical Weapons Assessment program (ACWA) to demilitarize assembled chemical weapons, “while meeting all applicable Federal and State environmental and safety requirements.”

In accordance with Public Law 104-208, the Under Secretary of Defense for Acquisition and Technology appointed Mr. Michael Parker the Program Manager for Assembled Chemical Weapons Assessment (the Program Manager). The Program Manager’s mission was to “demonstrate not less than two alternatives to the baseline incineration process for the demilitarization of assembled chemical munitions.” Assembled chemical weapons for this purpose represent the chemical weapons stockpile configured with fuses, explosives, propellant, chemical agents, shipping and firing tubes, and packaging materials.

An important aspect of this program is stakeholder involvement and identification of their concerns about the program. Participants of the Dialogue include (see Appendix A for a complete list of Dialogue participants and alternates):

- representatives from communities adjacent to chemical weapon stockpile sites;
- appropriate state and/or tribal representation;
- relevant Environmental Protection Agency staff;
- appropriate Defense staff from stockpile sites;
- representatives from national citizen groups that work regularly on this issue; and
- other concerned entities.

Development of Program Selection and Evaluation Criteria

The Program Manager developed in May, June, and July 1997 the Program Evaluation Criteria in concert with the Dialogue. During the development of the criteria, input was solicited through multiple means including; Citizens’ Advisory Commissions, various community forums attended by program staff and Dialogue members, Program Manager-sponsored public meetings and community updates, and Dialogue member interactions with their communities. This criterion was used to evaluate the technologies throughout the program. The Program Manager used the Demonstration Selection Criteria in coordination with representatives of the Dialogue to select technologies for demonstration. The Implementation Evaluation Criteria used to evaluate the demonstration results, are summarized into 4 categories as follows:

(1) <u>Process Efficacy/Process Performance</u>—summarizes performance, maturity, operability, process monitoring and control, and applicability;

(2) <u>Safety/Worker Health and Safety</u>—summarizes worker safety, normal operations and facility accidents, and public safety during facility accidents as well as off-site;

(3) Human Health and Environment—summarizes effluent characterization, completeness of effluent characterization, effluent management, permitting and compliance, and resource requirements; and

(4) Potential for Implementation—summarizes life cycle cost, schedule, and public acceptance.

All of the criteria were developed with input from citizens, communities, and regulators and as such, they relate to public acceptability. The last criterion, number 19, addresses the issue of public acceptability at particular sites using specific demilitarization processes. This criterion is designed to inform Congress of any major barriers to implementation of a technology in a community due to public concerns. Dialogue members have consistently stated that factors such as process efficacy, impact to human health and environment, and safety are critical in determining "public acceptability." Criterion 19 "Public Acceptance" specifically asks, "What is the likelihood of public acceptance?"

Demonstration Planning and Execution

Together, the Program Manager's team, the technology providers, personnel at the test sites, other related government agencies, and the members of the Dialogue have completed the ambitious task of identifying and demonstrating alternative technologies. Based on the evaluation of the Demonstration Work Plans submitted by the selected technology providers and on a determination of best value to the Government, three technology providers were awarded task order contracts on July 29, 1998 to conduct demonstration testing. They were Burns and Roe, General Atomics, and Parsons/AlliedSignal.

The Program Manager, in conjunction with the Dialogue, determined that due to the tight program schedule, testing of fully integrated systems from start to finish was not feasible. Further, many of the technologies proposed to incorporate proven unit operations (such as those used for munitions accessing in the baseline incineration program). It was also determined that government personnel would conduct tests independently in government test facilities. This required the use of existing facilities due to the aggressive schedule and budgetary constraints, which precluded the construction of any new test facilities.

The technology demonstrations were designated to be a series of tests on critical, less proven unit operations to show their effectiveness and repeatability and to establish confidence that they can be incorporated into an overall system or "total system solution." The unit operation selections were based on information (test scale size, use of readily available equipment, prior test data, technology maturity, etc.) in the technology providers' original proposals and in their Data Gap Resolution Reports produced during the assessment phase of the program. The unit processes judged to be critical to prove the successful application of each technology being demonstrated and evaluated are listed in Table 1.

Section II of this report includes brief descriptions of the technologies demonstrated, the acquisition selection process, test objectives, planning activities, analytical issues, operations, and the results and evaluation. The Technical Evaluation Report (Appendix B) contains the details of these topics. The Program Manager met with and communicated with representatives

Table 1. Summary of Unit Operations Demonstrated

Technology Provider	Unit Operations Demonstrated
Burns and Roe	Plasma Waste Converter Energetics Deactivation Chamber
General Atomics	Neutralization of Agents and Energetics Energetics Rotary Hydrolyzer Dunnage Shredding and Hydropulping Supercritical Water Oxidation (SCWO)
Parsons/AlliedSignal	Neutralization of Agents and Energetics Rocket Cutting and Fluid Washout Immobilized Cell Bioreactor (ICB™) Metal Parts Treater

of the Dialogue throughout the demonstration planning, execution, and evaluation to discuss actions, reach consensus, and develop conclusions.

All testing conducted under the ACWA Program was conducted at each site in compliance with all Federal, State, Army, local, facility and safety and environmental regulations as well as with the Chemical Weapons Convention. Transparency measures (to verify and document) dealing with Schedule 2 compounds[3] generated in the neutralization processes were approved by the Organization for the Prohibition of Chemical Weapons Executive Council to include witness by Treaty Inspectors.

The overall Demonstration Test Program included 15 unit operations and was conducted in five geographical locations over a period of five months. The Demonstration Test Program resulted in:

- ☐ The collection of approximately 2,300 samples for chemical characterization;
- ☐ Approximately 11,500 sample analyses; and
- ☐ About 210,000 analytical data results.

Life Cycle Cost and Schedule

The results of the life cycle cost and schedule evaluations will be discussed in follow-on correspondence to Congress dealing with the requirements set forth in the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 (PL 105-261). An Integrated Process Team has been established within the Department of Defense to determine if the demonstrated alternative technologies described within this report meet certification requirements set forth by PL 105-261. The certification requirements are as follows:

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[3] The toxic chemicals and their precursors (the components used to create the toxic chemical) as defined by the Chemical Weapons Convention.

The Under Secretary of Defense must certify in writing to Congress that an alternative is

- "As safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions; and
- Is capable of completing the destruction of such munitions on or before the later of the date by which the destruction of the munitions would be completed if incineration were used or the deadline date for completing the destruction of the munitions under the Chemical Weapons Convention."

National Research Council

The National Research Council reviewed and evaluated seven technologies for potential implementation: AEA Technology, ARCTECH, Burns and Roe, General Atomics, Lockheed Martin, Parsons/AlliedSignal, and Teledyne Commodore. There was a strong alignment between the National Research Council Report and the findings in the Technical Evaluation Report.

ACWA Technology Evaluation Summaries

The summaries and conclusions from the test and evaluation of the each of the three technologies are contained in Section II.C of this report and Section 5.1 of the Technical Evaluation Report (Appendix B). The conclusions are summarized below.

Burns and Roe. The Burns and Roe process, using a plasma arc process to demilitarize chemical weapons, was not validated for agent destruction during demonstration testing due to the lack of maturity. In addition, based on input from the Dialogue, it is unlikely that this process will be publicly acceptable. Therefore, this process cannot be considered a viable total solution

General Atomics. The General Atomics process of neutralization followed by SCWO was validated during demonstration. In addition, based on input from the Dialogue, it is likely that this process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of all assembled chemical weapons.

Parsons/AlliedSignal. The Parsons/AlliedSignal process of neutralization of mustard followed by treatment in the Immobilized Cell Bioreactor (ICB) was validated during demonstration. In addition, based on input from the Dialogue, it is likely that the mustard process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of chemical weapons with mustard agent. The process for the demilitarization of chemical weapons with nerve agent was not validated during demonstration. Based on input from the Dialogue, it is unlikely that the nerve agent process will be publicly acceptable. Therefore, this process is not considered a viable total solution for the demilitarization of chemical weapons with nerve agent.

I. Introduction

This report responds to the requirements contained in Title VIII, section 8065 of the Omnibus Consolidated Appropriations Act, 1997 [Public Law 104-208]. This report presents the results of the evaluation on “the effectiveness of each alternative chemical munitions demilitarization technology identified and demonstrated” under the Assembled Chemical Weapons Assessment program (ACWA) to demilitarize assembled chemical weapons, “while meeting all applicable Federal and State environmental and safety requirements.”

In accordance with PL 104-208, the Under Secretary of Defense for Acquisition and Technology appointed Mr. Michael A. Parker the Program Manager for ACWA (the Program Manager) with the mission to “demonstrate not less than two alternatives to the baseline incineration process for the demilitarization of assembled chemical munitions.” Assembled chemical weapons for this purpose represent the chemical weapons stockpile configured with fuzes, explosives, propellant, chemical agents, shipping and firing tubes, and packaging materials.

The foundation of the ACWA program is based on stakeholder involvement from each of the chemical stockpile storage sites and identification of their concerns about the program. In response to the desire to integrate stakeholder input, The Keystone Center, a non-profit, neutral facilitation organization specializing in environmental and health policy issues, was asked by a diversity of individuals from DOD and community organizations to convene a Dialogue on ACWA and to facilitate Dialogue meetings.

Participants of the Dialogue on ACWA include representatives from affected communities; appropriate state and/or tribal representation; relevant U.S. Environmental Protection Agency (EPA) staff; appropriate DOD staff from affected sites and headquarters; representatives from national citizen groups that work regularly on this issue; and other concerned entities (see Appendix A for a complete list of Dialogue participants and alternates). Many Dialogue participants noted the need for involvement throughout the source selection process. This was clearly impractical for the entire Dialogue. Therefore, four Dialogue members, chosen by the Dialogue, agreed to sign confidentiality agreements and to dedicate their time to participate in technical evaluations along with the government’s Technical Evaluation Team. Because of the need for independent technical assistance to advise these citizens, as well as the entire Dialogue throughout the program, the Program Manager agreed to fund a technical consulting firm, selected from among qualified competitive bidders, with the advice and consent of the Dialogue. Together, the four Dialogue members and the consulting firm comprise the Citizens’ Advisory Technical Team (CATT). The CATT works on behalf of Dialogue participants and is charged with overseeing, consulting, and reporting duties regarding complex and technical information during the program.

The ACWA program involves a three-phased approach—evaluation criteria development, technology assessment, and demonstration of not less than two technologies. The evaluation criteria development phase took place during the months of May, June, and July 1997. During this phase, the Program Manager, in concert with the Dialogue on ACWA, developed the program evaluation criteria. The criteria were divided into three general groupings: Threshold (Go/No Go) Criteria, Demonstration Selection Criteria, and Implementation Evaluation Criteria.

The technology assessment phase took place during the September 1997–June 1998 time frame and consisted of four steps: (1) Go/No Go Evaluation, (2) Initial Assessment/Data Gap Resolution, (3) Final Assessment/Technology Ranking, and (4) Demonstration Work Plan Development/Review. Figure 1 shows the process which was used in evaluating the alternative technologies.

The actual demonstrations of alternative technologies took place during the January–May 1999 time frame. The evaluation of the demonstrations took place during the June 1999–August 1999 time frame. The evaluations were an integrated effort involving the technology providers, Dialogue participants, contractor personnel, and ACWA personnel. The purpose of the demonstrations was to validate the chosen technologies' ability to safely destroy chemical munitions and their associated materials. The Program Manager's Program Evaluation Team (PET) and representatives from the Dialogue performed the assessment of the technology demonstrations. Using the previously approved program implementation criteria, the PET and representatives from the Dialogue assessed each of the technologies demonstrated. The information used for these assessments included the technology providers' demonstration reports, the Program Manager's milestone reports, the validated demonstration data, and all previous documentation submitted by the technology providers.

This report builds on the ACWA program's December 1997 and December 1998 Reports to Congress. The 1997 and 1998 reports provide complete details of ACWA activities during fiscal years (FY) 1997 and 1998. Both reports are available on the Internet at http://dialogue.pmacwa.org.

II. DEMONSTRATIONS

A. Demonstration Preparations

1. Technology Selection Process

The purpose of the technology assessment phase of the ACWA program was to select technologies for demonstration. The following summary of the four-step process, as shown in Figure 1, is provided to show how, where and what type of data and information were obtained throughout the program prior to demonstration testing.

Step 1—Threshold (Go/No-Go) Criteria. The *Technology Proposals* were assessed as to overall responsiveness and evaluated against the Threshold (Go/No-Go) Criteria. As a result of the evaluation, a basic task-order contract was awarded to all offerors judged to be responsive to the solicitation requirements and whose technology met the Threshold (Go/No-Go) Criteria.

Step 2—Initial Assessment/Data Gap Resolution. The initial assessment of each technology against the Demonstration Selection Criteria identified data gaps in describing the technology or demonstration and targeted data gap resolution. The technologies for all technology providers receiving a task order contract were evaluated by the PET against the Demonstration Selection Criteria shown in Appendix B to identify data or information missing from the proposal. The missing data and information were identified as data gaps. *Data Gap Identification Reports* (DGIRs) were provided to the technology providers.

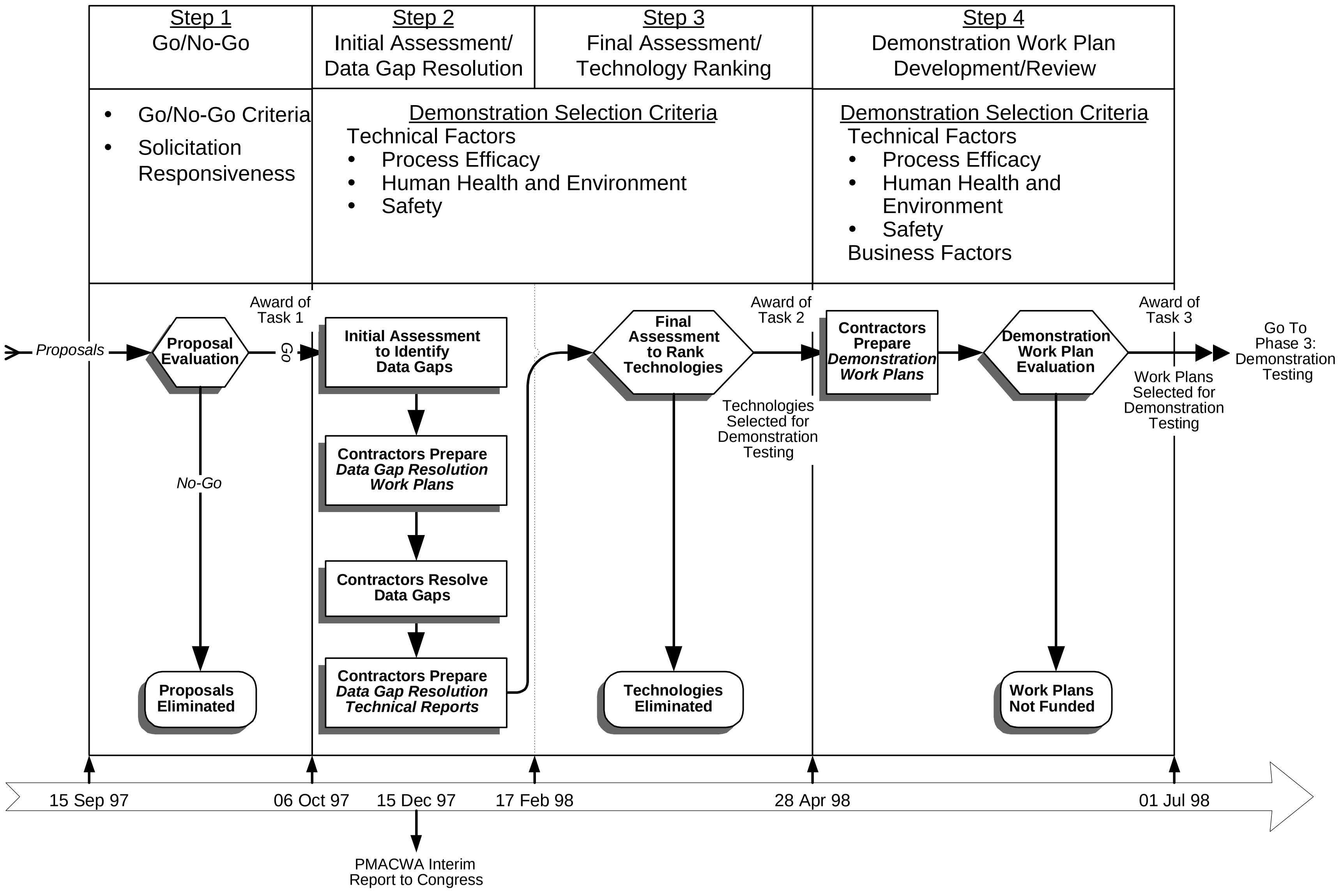

Figure 1. The Four Steps of ACWA Phase 2, Technology Assessment

Using the appropriate DGIR, each contractor prepared a *Data Gap Work Plan (DGWP)* and submitted it to the government by December 10, 1997. The DGWP provided a detailed description of how the contractor would resolve the data gaps (including any testing) and included a milestone schedule for completion of the work. With the approval of the DGWP, the technology provider was authorized to proceed with the approach presented in the DGWP and prepare the *Data Gap Resolution Report (DGRR).* This completed the initial assessment of the proposals.

Step 3 – Final Assessment/Technology Ranking. The PET conducted a final assessment of each technology using all provided information (Technology Proposal and DGRR) against the Demonstration Selection Criteria. The CATT participated throughout this process. Six technology providers were recommended for demonstration testing: AEA Technology, Burns and Roe, General Atomics, Lockheed Martin, Parsons/AlliedSignal, and Teledyne Commodore. Each of these technology providers received a task order to prepare a Demonstration Work Plan.

Step 4 – Demonstration Work Plan Development/Review. Each of the six technology providers that were awarded task orders prepared a detailed *Demonstration Work Plan* that was evaluated by the PET against the full set of Demonstration Selection Criteria: technical factors (process efficacy; worker health and public safety; human health and environment) and business factors. Besides the likelihood of conducting a successful demonstration based on the evaluation, the constraint of program resources also was used to determine which technologies continued into the demonstration phase. Based on the evaluation of each of the Demonstration Work Plans and a determination of best value to the Government, three technology providers were awarded task order contracts to conduct demonstration testing. They were Burns and Roe, General Atomics, and Parsons/AlliedSignal.

2. Technology Overview

The demonstration testing phase of the ACWA program began with the award of tasks to teams led by Burns and Roe, General Atomics, and Parsons/AlliedSignal on 29 July 1998. Because of the tight program schedule, the demonstration planning activities were conducted concurrently with the technology evaluation process and continued after the award of tasks. Equipment installation began in the fall of 1998 at the three demonstration test sites: the West Desert Test Center, Dugway Proving Ground (DPG), UT; the Chemical Agent Munitions Disposal System (CAMDS), Deseret Chemical Depot (DCD), UT; and the Edgewood Chemical and Biological Center (ECBC), Aberdeen Proving Ground (APG), MD. Demonstration testing started in early February and was completed on 7 May 1999.

The total technology solutions proposed by the three teams chosen for demonstration are summarized in Table 1. The unit processes that were selected for demonstration are identified in Table 2.

Table 1. Technology Descriptions for the Three Technology Providers Awarded Demonstration Task Orders

Offeror	Munitions Access	Agent Treatment	Energetics Treatment	Metal Parts Treatment	Dunnage Treatment
Burns and Roe Foster-Miller STARTECH	Minor modifications to baseline reverse assembly	Plasma arc	Thermally initiated explosives detonation followed by plasma arc	Plasma arc	Size reduction followed by plasma arc
General Atomics	Parts of baseline reverse assembly, cryofracture	Caustic or water hydrolysis followed by supercritical water oxidation (SCWO)	Caustic hydrolysis followed by SCWO	Caustic hydrolysis followed by thermal treatment	Size reduction/ pulping followed by SCWO
Parsons/ AlliedSignal	Modified baseline reverse assembly (fluid-abrasive cutting and fluid mining)	Caustic or water hydrolysis followed by biotreatment	Caustic hydrolysis followed by biotreatment	Thermal treatment with steam	Thermal treatment with steam

Table 2. Summary of Unit Operations Demonstrated

Technology Provider	Unit Operations Demonstrated
Burns and Roe	Plasma Waste Converter Energetics Deactivation Chamber
General Atomics	Neutralization of Agents and Energetics* Energetics Rotary Hydrolyzer Dunnage Shredding and Hydropulping Supercritical Water Oxidation
Parsons/AlliedSignal	Neutralization of Agents and Energetics* Rocket Cutting and Fluid Washout HD, VX, GB Immobilized Cell Bioreactor (ICB) Metal Parts Treater

*The government provided agent and energetic hydrolysates for the General Atomics supercritical water oxidation (SCWO) tests and the Parsons/AlliedSignal ICB tests. The Program Manager offered three technologies to any of the potential offerors when the request for proposal asking for total solutions to destroy assembled chemical munitions was published. The three technologies included the agent neutralization process for mustard (HD) and nerve agent (VX) developed by PMCD's Alternative Technologies and Approaches program; the current PMCD baseline reverse assembly process; and the smelting of 5X metal parts at Rock Island Arsenal.

3. Demonstration Objectives and Planning

It is important to note how ACWA defines technology demonstrations. First it was determined that testing of a fully integrated system, from start to finish, was not feasible due to schedule and budgetary constraints. The schedule dictated that testing be conducted using existing government facilities. Second, it was determined that the tests would be conducted independently by government personnel at these government test facilities. The ACWA technology demonstrations were designed to be a series of tests on each technology providers critical unit operations to validate their performance, characterize the intermediate and final effluents, and to establish confidence that they can be incorporated into an overall system or "total system solution." The unit operation selections were based on information (test scale size, use of readily available equipment, prior test data, technology maturity, etc.) in the technology providers' original proposals, their Data Gap Resolution Reports, and meetings with them to discuss their test matrices.

Based on this definition of demonstration, the following overall test program objectives were established:

- Independent validation of selected unit operations needed to achieve the stated performance objectives for a technology;
- Characterization of major feed materials, intermediate process streams, and final products/effluents; and
- Independent validation of analytical methods for constituents of interest (including agents and energetics) used during demonstration testing.
- To ensure a successful demonstration test program, specific test objectives that were in full alignment with the overall program test objectives were developed. A detailed test program was designed to meet specific test objectives, which were clear, concise, definitive, measurable, and practicable within the ACWA program schedule, resources, and budget limitations. The specific test objectives were developed with consistency across all technology providers.
- The Program Manager's Demonstration Working Group (DWG) consists of representatives of the Technical Team, Environmental Team, and support contractors. The DWG worked in an iterative process with test installation representatives, technology providers, support contractors, and members of the CATT in performing detailed planning activities. Planning was an essential part of this test program. The technology demonstration phase was very complex and its success depended upon the timely completion of critical, preparatory activities, such as:
    - Test facility modifications;
    - Test facility, technology provider coordination;
    - Feed materials (agent, metal parts, etc.) availability and transport;
    - Agent/energetic hydrolysate production;
    - Analytical methods identification/validation;
    - Test facility standard operating procedures (SOP) requirements;
    - Test facility safety (pre-operational) requirements;
    - Quality Assurance/Quality Control (QA/QC) program development and implementation; and
    - Sampling and analysis support coordination.

The primary product of the demonstration planning process was a *Demonstration Test Matrix* (test matrices) for each technology provider. These matrices were carefully developed so that the technology demonstrations could meet requirements of PL 104-208 and be responsive to the Program Implementation Criteria. For each technology, a consensus was reached on the critical unit operations to be tested, and the definition of clear, concise, and measurable test objectives for each of those critical unit operations. Specific elements of the test matrices included the following:

- Unit operations to be demonstrated;
- Feed materials (type and quantity);
- Test location(s);
- Number/duration of test runs;
- Process monitoring parameters;
- Utility requirements;
- Operating personnel requirements;
- Sampling locations/methodologies/frequency;
- Analytical methodologies/validation;
- QA/QC program;
- Data requirements/reduction; and
- Final report requirements.

These test matrices were the core of the Demonstration Study Plan and were essentially, the core of each demonstration test. There were several demonstration issues and considerations that were identified during the demonstration planning process that were generic to all the technologies to be demonstrated. The major issues and considerations are summarized below:

- *Polychlorinated biphenyls (PCBs)*. PCBs were not tested as part of the demonstration, since doing so would have triggered regulatory requirements under the Toxic Substances Control Act (TSCA) that would have added considerably to the cost and difficulty of the demonstration. It was anticipated that testing with pentachlorophenol (PCP) would provide some information regarding contaminated dunnage. Therefore, PCPs were used to simulate contaminated wood for each technology tested.
- *Baseline Operations*. Processes used in the baseline operations such as reverse assembly, brine reduction, condensers, gas scrubbers, and carbon filtration are processes that were determined not to be necessary to demonstrate due to the available database. Feed material was provided in the configuration anticipated from Baseline or modified baseline reverse assembly.
- *Environmental and Regulatory Compliance*. Compliance was achieved at each site following all Federal, State, Army, local, and facility environmental regulations. The safety SOP and the pre-operation survey ensured the application of environmental regulations. Operational activities, chemical method development, and waste storage and disposal followed all applicable environmental guidelines. In addition, the

demonstrations were conducted under treatability studies coordinated with the states of Utah and Maryland to increase the amount of material that could be treated under the Resource Conservation and Recovery Act (RCRA) treatability study regulation. There were several examples where environmental and regulatory compliance impacted the demonstration tests. As discussed above, PCBs were not tested. Another example was in the method for producing the M28 propellant hydrolysate. The lead stearate from the M28 had to be added to the hydrolysate at the test site rather than at the site where the M28 hydrolysate was produced, because it would have resulted in the hydrolysate being considered a hazardous waste by the EPA.

- ☐ *Treaty Compliance*. All related testing conducted under the ACWA Demonstration Program was done in compliance with the CWC and witnessed by Treaty Inspectors. Transparency measures (to verify and document) dealing with compounds generated in the neutralization processes were approved by the Organization for the Prohibition of Chemical Weapons (OPCW) Executive Council. In addition, a modification to an existing Facility Agreement was approved for the agent-related testing that was planned for one of the technology providers.

4. Facility Support

Due to the limited time to complete the tests (not being able to construct new facilities), the nature of the demonstration program requiring use of agent and energetics, and the need to maintain Government independence in conducting the testing, there were a limited number of qualified facilities. The demonstration equipment needed to be configured so that tests could be carried out in the designated facility and meet all requirements associated with that facility.

Demonstration testing of the proposed technologies was conducted at three Army test sites: APG, Maryland; DCD, Utah; and DPG, Utah. The Pantex Plant in Amarillo, Texas and Radford Army Ammunition Depot in Radford, Virginia were used to generate energetics hydrolysates. A summary of the test facilities that were used for the ACWA demonstrations and the unit operations that were demonstrated can be found in Table 3. Appendix C provides a description of the test locations and the unit operations conducted at that site. All of these facilities had a number of common elements, which were a requirement for the ACWA demonstrations. The facilities had redundant containment mechanisms and safety systems to virtually eliminate the potential for releases to the environment. In addition, protocols were already in place to ensure safe management of any materials used in the demonstrations.

For each test facility, modifications or renovations were completed by test site personnel, their contractors, or the technology providers. The test sites and their contractors assisted the technology providers with the installation and systemization of the test equipment; however, the test sites were solely responsible for conducting the demonstration tests. The technology providers thoroughly trained all test operators. The test sites also prepared the necessary SOPs and test plans, as required by the installation. In most cases, the test sites were also responsible for the collection and coordination of analytical samples (with the exception of gas samples, which were collected by ACWA contractors).

Table 3. Summary of Test Facilities for ACWA Demonstrations

Test Site	Unit Operation Demonstrated (Technology Provider)	Test Facility
Aberdeen Proving Ground, MD—Edgewood Chemical and Biological Center	Plasma Waste Converter System (Burns and Roe)	Toxic Test Chamber (Building E3566)
	HD/Tetrytol Immobilized Cell Bioreactor (Parsons/AlliedSignal)	Building E3570
	Neutralization Reactor System for HD (generated by Program Manager)	Chemical Transfer Facility
Deseret Chemical Depot, UT—Chemical Agent Munitions Disposal System	Energetics Rotary Hydrolyzer (General Atomics)	Explosive Containment Cubicle #1
	GB/Comp B and VX/CompB/M28 Immobilized Cell Bioreactors (Parsons/AlliedSignal)	Chemical Test Facility
	Metal Parts Treater (Parsons/AlliedSignal)	Chemical Test Facility
	Neutralization Reactors System for GB and VX (generated by Program Manager)	Bulk Item Facility
Dugway Proving Ground, UT—West Desert Test Center	Rocket Cutting and Washout System (Parsons/AlliedSignal)	Suppressive Shield Facility (Building 8321)
	Dunnage Shredder and Hydropulper (General Atomics)	Receipt Inspection Building (Building 3342)
	Supercritical Water Oxidation Unit (General Atomics)	Old Chemistry Laboratory (Building 4165)
Pantex Plant, TX	Neutralization Reactor System for Comp B and Tetrytol (generated by Program Manager)	Hydrolysis Pilot Plant (Building 11-36)
Radford Army Ammunition Plant, VA	Hydrolysis Reactor Vessel for M28 Propellant (generated by Program Manager)	N/A

5. Analytical Support

The technology providers were responsible for providing all analytical methods and procedures for the constituents in each test. Any nonstandard methods provided by the technology provider needed to be validated in an independent laboratory designated by the Government, prior to its use in the analysis of any demonstration samples. In some cases, samples could not be analyzed because standard methods did not exist, and new methods were not developed.

Prior to demonstration testing, a total of 64 analytical method evaluation studies were conducted. Five of these studies involved the analysis of energetics and agents in the hydrolysate solutions and were undertaken by government laboratories. U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) conducted the evaluation of the analysis of energetic materials in three different hydrolysate mixtures, while the analytical laboratories at ECBC, Dugway, and CAMDS conducted method evaluation studies of Agent GB and Agent VX in the hydrolysate solutions. The remaining 59 method evaluations were undertaken by commercial analytical laboratories. Analytical methods were considered to be validated if they met the precision and accuracy requirements stipulated in the Program Manager's QA/QC Plan and/or, based on professional judgment, they could be effectively used to evaluate the technologies tested and provide information to meet the objectives of the demonstration tests.

The primary purpose of the Demonstration Testing validation sampling and analysis support was to implement the sampling and analysis approach developed by each Technology Provider as detailed in the Final Study Plans. The overall Demonstration Test Program, including the preparation of the agent and energetic hydrolysate feed materials, consisted of the sampling and analysis of 15 unit operations conducted in five geographical locations over a period of five months. The Demonstration Test Program resulted in:

- The collection of approximately 2,300 samples for chemical characterization;
- Approximately 11,500 sample analyses; and
- About 210,000 analytical data results.

The management of these activities included coordination of, and support to, 16 teams of sample collection personnel, the submittal of samples to 19 analytical laboratories in approximately 1,100 shipments and the data processing of the analytical results submitted to the Program Manager by the laboratories for subsequent transmission to the technology providers. More details pertaining to the analytical approaches can be found in Appendix C.

B. General Demonstration Operations

1. Hydrolysate Generation

In order to test the post-treatment processes for General Atomics and Parsons/AlliedSignal—supercritical water oxidation (SCWO) and biodegradation—agent and energetics hydrolysates were required. The Government supplied the agent and energetics hydrolysates (as Government Furnished Material) for these tests to avoid duplication of equipment, save money, conserve limited test facilities, and enhance demonstration results through feedstock consistency.

Two of the three technologies selected for demonstration involved hydrolysis of both agent and energetics. Agent hydrolysis was a Government technology offered as part of a total solution. Because of this, the Government provided these feeds. The energetic hydrolysate was also provided by the Government, due to the expertise within the Government, the limited availability of demonstration site facilities, and costs associated with having to conduct two separate demonstrations if it were to be conducted as part of the technology provider's demonstration.

a. Agent Hydrolysates

The objective of this effort was to produce hydrolysates of HD, GB, and VX for use as feed material for the demonstration testing of technology providers' secondary treatment processes, i.e., biotreatment (Parsons/AlliedSignal) and SCWO (General Atomics). These technology providers elected to use the agent (HD and VX) neutralization processes developed by the U.S. Army Product Manager for Alternative Technologies and Approaches (PMATA) for the destruction of agent in their proposed total solutions for the disposal of assembled chemical weapons. Due to time constraints and Treaty (CWC) limitations, bulk HD, GB and VX were used for demonstration testing. The details of each agent reaction are discussed in Appendix C.

Approximately 1,290 pounds of HD, 1,120 pounds of VX and 616 pounds of GB were hydrolyzed to support demonstration testing. In excess of 4,000 gallons of HD hydrolysate were produced in a campaign of 120 batch runs made over the period 8 June—11 September 1998. A total of 1,100 gallons of GB hydrolysate was produced in a campaign of 11 batch runs made over the period 18 December 1998—19 January 1999. Following the GB hydrolysis campaign, and using the same equipment, 400 gallons of VX hydrolysate were produced in four batch runs conducted from 2 March—2 April 1999.

The hydrolysates were produced in two separate reactors. The HD hydrolysate was produced by the Chemical Biological Services Directorate personnel using an existing 40-gallon stirred tank reactor at the Edgewood Chemical and Biological Center (ECBC), in Maryland. The GB and VX hydrolysates were produced in a 100-gallon stirred tank reactor that was designed and fabricated at Arthur D. Little in Cambridge, MA in eight separate modular skid units. The PMATA and their contractor (Stone and Webster) reviewed and provided input to the design. The system was installed (September 1998) and operated by CAMDS personnel in Tooele, UT.

b. Energetics Hydrolysate

Approximately 184 pounds of Tetrytol, 470 pounds of Composition B (Comp B), and 973 pounds of M28 propellant were hydrolyzed to support demonstration testing. The operations conducted to produce this feed were carried out by the Pantex Plant, Amarillo, TX, and the Radford Army Ammunition Depot, Radford, VA. The Pantex Plant hydrolyzed the Comp B and Tetrytol explosives resulting in nearly 1,000 gallons of Comp B hydrolysate and over 160 gallons of Tetrytol hydrolysate. The Radford Army Ammunition Plant hydrolyzed the M28 propellant that resulted in 2,100 gallons of M28 hydrolysate.

2. Demonstration Issues

There were several demonstration issues and considerations that were identified during the demonstration planning process that were generic to all the technologies to be demonstrated. The major issues and considerations included facility limitations, analytical methods and procedures, hydrolysate production, toxic materials, baseline operations, environmental and regulatory compliance, and analytical issues. Appendix C provides further discussion on the analytical methods, hydrolysate production, and facilities.

Throughout demonstration testing, problems and issues surfaced that required modification to the Demonstration Study Plan for each technology provider. There were also changes to the test equipment and test procedures throughout the demonstrations. Any changes were submitted in accordance with the Program's Manager's Configuration Management Plan where each change was developed by the technology provider, reviewed by the ACWA staff and support contractors, and then discussed with the CATT, prior to the change being approved and incorporated. As a result of the research and development nature of the demonstration tests, there were modifications made to the test matrices to accommodate schedule slippage, operational issues and/or equipment failures. Although these types of modifications were made throughout demonstration, all planned unit operations were tested. In addition, most of the planned analytical samples were taken.

C. Results and Evaluation

1. Burns and Roe

The components of the system proposed by Burns and Roe for the demilitarization of chemical weapons that were demonstrated included the Energetics Deactivation Chamber (EDC), the Plasma Waste Converter (PWC), and the Gas Polishing System. In addition, a Box Feed Module, a Liquid Feed Module and Thermal Oxidizers were necessary for the demonstration tests. The Box Feed Module consisted of a conveyor system and a ram assembly, which fed small boxes of material (M28 propellant, dunnage, or metal parts) into the PWC. The Liquid Feed Module fed liquids from steel canisters or drums into the PWC. It also provided the mechanism for feeding steam into the PWC. Energetics (Comp B and Tetrytol) were detonated in the EDC, a steel pressure vessel, and the resulting gases were processed in the PWC. The PWC uses an electrically driven plasma arc torch that produces an intense field of radiant energy causing the dissociation of chemical compounds. Nitrogen, introduced through the torch, was used as the plasma gas. The materials left the vessel in two forms: a Plasma Converted Gas (PCG) and liquefied solids. The Gas Polishing System cooled and treated the PCG from the PWC. Thermal Oxidizers, which were required for the demonstration testing at ECBC but are not required for full-scale, consumed or flared the gas before it was released to the atmosphere.

a. Installation and Systemization Summary

The main components of the PWC system were pre-erected on skids and assembled at the contractor's facility prior to shipment to the test site. The PWC system was installed in the ECBC Toxic Test Chamber (Building E3566) at the APG-Edgewood Area, Maryland. There were significant site preparation activities, which included repairing and upgrading the carbon dioxide system and the facility's electrical service, and installing a transformer, a chilled water system, a propane system, and a nitrogen feed system. On-site installation of the demonstration equipment, which began on 18 December 1999, primarily consisted of placement of equipment, completion of utility connections, piping and plumbing, installation of analytical equipment, and installation of a trellis system to support pipes, wires, and sample lines of the various subsystems. In conjunction with several equipment contractors, Burns and Roe designed and built automated gas sampling and analytical units. The sampling and analytical equipment included two multiple gas chromatograph systems, a set of three standard continuous gas analyzers and two multi-train extractive gas sampling systems. The systems were designed to be as automated as possible.

Some delays were experienced during the installation of the PWC system beginning with the shipment of equipment to the test site. There were also problems encountered during installation, which contributed to additional delays. The major problems included wiring the plasma torch to the power supply, an inadequate transformer when carbon dioxide was used as the plasma medium, switching the plasma medium to nitrogen, and problems associated with the sampling and analytical equipment.

Systemization included operational testing of the test hardware, system controls, process monitoring equipment, and sampling and analytical equipment. Some of the initial systemization activities of the subsystems took place at the manufacturer's facilities. After installation of the subsystems at the test site, they were brought on-line one by one and tested. The relevant process monitoring and sampling and analytical equipment were also tested. When all the systems were operational, they were integrated and additional systemization activities of the integrated system were conducted. The main systemization activities, which began on 9 January 1999, included curing of the refractory of the PWC and the Thermal Oxidizers, performing operational tests on all subsystems, performing integrated operational tests, calibrating analytical equipment, training the operators, and conducting a pre-operational survey. Systemization activities were conducted concurrently with the completion of installation during January and February 1999. There were two SOPs prepared for the demonstration testing—one for non-toxic campaigns and one for toxic campaigns. Informal visits by the ECBC Risk Management offices allowed for the resolution of many issues and concerns prior to the Pre-Operational (Pre-Op) Survey. The Pre-Op for the non-toxic campaigns was conducted on 16 February 1999. The findings were few and minor. The SOP was approved on 22 February 1999 with authorization to proceed with testing of non-toxic materials.

Some equipment problems were also encountered during systemization, most of which contributed to some degree to a delay. The more significant problems include those associated with operating the torch with carbon dioxide as the plasma gas, inadequate power source, and poor operational life of the torch copper electrodes. In addition, problems were experienced with the Gas Polishing System.

b. Demonstration Operations

The PWC system was tested to demonstrate an alternative to the baseline for destroying chemical weapons. The objectives of the demonstration testing included the following:

- ☐ Characterize the detonation gases and residues from Comp B and Tetrytol from the EDC for suitability to be processed in the PWC.
- ☐ Validate the ability of the PWC process to achieve a Destruction and Removal Efficiency (DRE) of 99.9999% for the following agents: HD, GB, VX, and 10% liquid GB heel in a simulated mortar body.
- ☐ Validate the ability of the Energetic Deactivation Chamber and the PWC unit operations to achieve a DRE of 99.999% for the following energetics: Comp B and Tetrytol.
- ☐ Validate the ability of the PWC unit operation to achieve a DRE of 99.999% for M28 propellant.

- ☐ Validate the ability of the PWC unit operation to meet a 5X condition for metal parts and dunnage.
- ☐ Demonstrate the ability to remove the melt from the PWC.
- ☐ Evaluate the impact of operations on refractory life.
- ☐ Characterize gas, liquid, and solid process streams from the PWC for selected chemical constituents and physical parameters, and the presence/absence of hazardous, toxic, agent, and Schedule 2 compounds.

The Burns and Roe PWC system processed energetics, dunnage, metal parts, and liquid feeds from 4 March 1999 to 7 May 1999. The energetics testing consisted of processing Comp B, Tetrytol, and M28 Propellant, as planned. Comp B and Tetrytol pellets were detonated in the Energetic Deactivation Chamber and the resulting gases processed through the PWC. The PCG from these energetic runs was then processed in the Gas Polishing System and stored in the Hold/Test/Release Tank (for analytical sampling) prior to being released to the Outdoor Thermal Oxidizer. The M28 Propellant was processed using a conveyor and ram assembly and loaded directly into the PWC. In separate tests, Comp B and Tetrytol were detonated, and M28 Propellant pellets were ignited with the resulting detonation gases characterized.

It was originally planned that the dunnage campaign would consist of processing the dunnage materials separately: wood spiked with PCP demilitarization protective ensemble (DPE), carbon, and fiberglass firing tubes. However, mixed feed validation runs were conducted due to delays and schedule constraints. Boxes of shredded dunnage were prepared and were loaded into the PWC using a conveyor and ram assembly. The resulting PCG was then processed through the Gas Polisher and the Outdoor Thermal Oxidizer. Decontamination fluid was pumped into the PWC through the liquid feed system concurrently with the carbon feed.

It was also originally planned that chemical agents (HD, VX, GB and GB in a simulated mortar body) would be processed during the liquid feed and metal parts campaigns. The agent was to be pumped from containers, mixed with steam in the feed line, and processed in the PWC. The PCG resulting from the liquid feed was then to be processed through the Gas Polisher and Indoor Thermal Oxidizer. Due to delays in the test program, mainly caused by equipment problems, chemical agent testing was not conducted. After a number of modifications to the test equipment were implemented, there was a short amount of time left in the test program. The Program Manager determined that it was in the best interest of the program to conduct additional non-toxic tests to demonstrate improved reliability and operability of the PWC system in this short period of time. The remainder of the demonstration period was focused on testing non-toxic liquids. An agent simulant (DMMP) and agent hydrolysate (HD hydrolysate and VX hydrolysate) runs were conducted in the same manner as the planned agent tests to demonstrate the improved operability and reliability of the PWC system.

There were also two demonstration test campaigns planned for metal parts. For one of the agent campaigns, it was planned for simulated munition bodies to be spiked with GB. Since no agent testing was performed, the uncontaminated simulated munition bodies were processed to demonstrate the ability to melt metal. In addition, 4.2-inch mortar bodies were processed to demonstrate the ability to melt an entire inert munition.

c. Technology Evaluation

The Burns and Roe process, using a plasma arc process to demilitarize chemical weapons, was not validated for agent destruction during demonstration testing due to the lack of maturity. In addition, based on input from the Dialogue, it is unlikely that this process will be publicly acceptable. Therefore, this process cannot be considered a viable total solution. The basis for this conclusion is summarized below.

(1) Process Efficacy and Performance

The Burns and Roe team’s proposed total solution uses a Plasma Waste Converter (PWC) as the sole destruction mechanism. The PWC represents a robust, indiscriminate thermal treatment technology capable of destroying organic materials. The proposed process uses multiple PWCs, with similar configurations, to destroy all assembled chemical weapon materiel. The demonstration utilized a single, multi-purpose PWC for the objective of testing several different feeds.

The demonstration results indicate a lack of process maturity for the PWC—this translates into a need for significant redesign, development, and testing before full-scale implementation of the system. Problems with PWC operation and reliability during systemization and operation of the equipment led to changes in test configuration and schedule delays resulting in an inability to complete all of the planned tests. The most significant impact of the operational and reliability problems experienced during systemization and operations was the Army’s decision to cancel the planned campaigns with chemical agent. The result of not testing chemical agents is an inability to validate the technology at this time for 99.9999% DRE of chemical agents. Other planned demonstration tests were completed and provided valuable data for the evaluation of the technology. The ability of the process to destroy energetics, metal parts, and secondary wastes of assembled chemical weapons was validated, and additional operations were successfully conducted with an agent simulant and an agent hydrolysate. Characterization for materials that were tested was completed; however, there remains a lack of agent-derived intermediate and final product characterization.

The PWC process uses commercially available controls and instrumentation, but the monitoring/control strategy is not fully defined or demonstrated. Many of the sampling and analysis methodologies for constituents in the process streams were verified, but several still require optimization while others require significant effort to complete the verification process.

(2) Safety

The plasma arc process poses moderate, but manageable risk to workers during normal operations. The PWC process chemicals and intermediates are low-to-moderate health hazards. The PWCs rely on negative pressure to achieve equipment-level containment. The observation of fugitive gaseous emissions during demonstration leads to concern over the PWC containment capability. This indicates the potential for worker exposure and will necessitate a significant increased use and reliance on personal protective equipment to provide worker protection.

Although PWC operations are isolated, maintenance operations around the PWC could cause unnecessary exposure to hazardous intermediates and nickel particulates. Proposed solutions to minimize or eliminate demonstrated fugitive emissions and steam surge, or potential M28 processing upsets, will require an extensive redesign effort. While severe physical hazards such as extreme temperature during PWC operations are present, the demonstrated use of engineering and administrative controls should greatly reduce both the probability and severity of an accident.

While the process does not generate any materials that are highly volatile or acute inhalation hazards, it does generate and store limited quantities of flammable gas. Secondary facility containment, administration procedures, automated process controls, and hold, test, and release capability mitigate the hazards posed by potential facility accidents and result in negligible public risk. The process involves low volumes of process chemicals and solid waste products that are not highly volatile, flammable, or an acute inhalation hazard. Therefore, there are no unusual transportation accident response requirements and minimal public risk.

(3) Human Health and Environment

Nominal operating parameters were not established during demonstration and are not well defined. Concerns and impacts to human health and the environment cannot be properly assessed without effluent characterization data from standardized demonstration runs. Air infiltration to the PWC during demonstration and the lack of agent derived data prevented complete characterization of the effluents. The PCG sampling for energetics and dunnage runs indicated an absence of hazardous constituents; however, predicted conversion of feed materials to a synthesis gas was not demonstrated. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Effluents appear to be treatable and disposable; however, the provider's permit strategy is dependent on the RCRA synthesis gas exemption. Yet, data in demonstration indicates this exemption may not be achieved (e.g., BTU content, specified pollutants, etc.). The provider did not include information on permits for similar processes, and there is no history of permitting a PWC for treatment of agent waste. It is unclear how regulatory agencies will evaluate the process.

(4) Potential for Implementation (Including Cost, Schedule, and Public Acceptance)

Life Cycle Cost and Schedule: The results of the life cycle cost and schedule evaluations will be discussed in follow-on correspondence to Congress dealing with requirements set forth in the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 (PL 105-261). An Integrated Process Team has been established within the Department of Defense to determine if the demonstrated alternative technologies described within this report meet certification requirements set forth by PL 105-261. The certification requirements are as follows:

The Under Secretary of Defense must certify in writing to Congress that an alternative is

- "As safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions; and
- Is capable of completing the destruction of such munitions on or before the later of the date by which the destruction of the munitions would be completed if incineration were used or the deadline date for completing the destruction of the munitions under the Chemical Weapons Convention."

Public Acceptance: The plasma arc process was deemed unlikely to obtain public acceptability due to the incomplete demonstration and the perceived similarity to incineration.

2. General Atomics

Three components of a comprehensive system proposed by General Atomics for the demilitarization of the chemical weapons stockpile were demonstrated, the Energetics Rotary Hydrolyzer (ERH), the Dunnage Shredding/Hydropulping System (DSHS), and the SCWO System. The ERH, a rotating drum with internal flights, is designed to deactivate the energetics components of the chemical munitions (e.g., fuzes, bursters, and propellant) by immersion in a strong solution of sodium hydroxide. The goal of the DSHS is to reduce dunnage to a size where the shredded product can be slurried in a hydropulper for subsequent processing in a SCWO unit. The SCWO system is designed to oxidize an aqueous organic feed to CO_2 and H_2O and mineral salts.

a. Installation and Systemization Summary

Energetics Rotary Hydrolyzer. The ERH had been fabricated and constructed at GA's own facility through the summer and fall of 1998, and then transported to the CAMDS site. The ERH system was installed in the Explosives Containment Cubicle #1 (ECC-1) at the CAMDS site in Tooele, Utah. Installation was accomplished in November 1998.

Systemization activities took place at the ECC in December 1998 through February 1999 until the commencement of testing (workup runs) in late February. Systemization involved testing of equipment as well as revision and refinement of the test plan. Assessments of technology operational readiness included: system hardware, system controls, test plans, operator familiarity, process monitoring, and sample collection. CAMDS conducted a number of pre-operational surveys covering engineering, operator, safety, and environmental concerns, and also conducted numerous walkthroughs of the operations process. Most of the operator training occurred informally during the runs and walkthroughs. Systemization was completed approximately one month later than scheduled; the delay caused mainly by a number of test plan revisions and minor equipment problems. The many reviews and walkthroughs resulted in a relatively problem-free system that was operated smoothly and efficiently by well-trained operators.

Dunnage Shredding/Hydropulping System. The DSHS system consists of three operations: wood shredding (low speed shredder, hammermill, and micronizer), plastic shredding (low speed shredder, cryocooler, and granulator), and hydropulping (hydropulper, grinding pump, and progressive cavity pump, all mounted on one skid). All of the equipment was purchased from commercial vendors. The DSHS system was installed in two parts in two separate locations at the DPG in Dugway, Utah. The shredding units were installed in Building 3342, while the hydropulper skid was installed in Building 4165 near the SCWO system. Installation of the shredding units took place in November and December 1998. Installation of the hydropulper began in December 1998 with the arrival of the skid and lasted until March 1999, although minimal installation was accomplished until February 1999.

Shredder systemization activities began in December 1998, when equipment was first tested after installation. Systemization of the shredding units and the pre-operational reviews proceeded smoothly. Shredding systemization officially ended at the end of January 1999 when the first workup run (wood shredding) was held. However, because of feed consistency and clogging problems, an extended systemization period was not conducted until late February 1999, during which several modifications to the equipment and operating procedures were made.

Hydropulper systemization was never completed as planned. It began in March 1999 and continued off and on until the end of General Atomics demonstration testing on 7 May 1999, when one workup run (to prepare SCWO feed) was made.

Supercritical Water Oxidation System. The SCWO system was installed in Building 4165 at DPG. The system consists of four skids: hydrolysate (liquid feed), hydropulper (dunnage slurry feed), reactor, and compressor/cooling tower. The skids, which had been assembled at General Atomics, arrived in November and December 1998. The installation was completed at the end of January 1999, approximately seven weeks behind schedule. The delay was caused by the late arrival of the platinum-lined reactor and pre-heaters.

Systemization of the SCWO system ran from mid-December 1998 until the beginning of March 1999. The end date was delayed approximately five weeks primarily due to problems with the platinum-lined reactor, the computer controls system, and various mechanical components. General Atomics opted to send an unlined Inconel™ 718 reactor to continue with systemization, because of the problems associated with the platinum lined reactor. Despite these problems, the two systemization runs that were performed before launching into the workup and validation runs proceeded efficiently and smoothly. There were no major problems associated with SOP development or operator training. Findings from pre-operational surveys were few and easily correctable.

b. Demonstration Operations

Energetics Rotary Hydrolyzer. The ERH was demonstrated to determine its effects on the physical and chemical properties of the munitions and liquid effluent. The objectives of the demonstration testing included the following:

- ☐ Demonstrate effective dissolution of aluminum and energetics in fuzes and bursters, and propellant in rocket motors, to allow downstream processing in the continuously stirred tank reactor (CSTR), SCWO, and heated discharge conveyor (HDC).
- ☐ Determine the deactivation of the energetics in fuzes and bursters, and the propellant in rocket motors.
- ☐ Validate the retention times for aluminum and energetics in fuzes and bursters, and propellant in rocket motors.
- ☐ Characterize the gas, liquid, and solid process streams from the ERH.

The ERH demonstration unit was a custom designed, 4 ft diameter (1/2 of full scale) and 2 ft long cylindrical drum, filled with 8-12M sodium hydroxide, and rotated at the very slow rate of 0.1 revolutions per minute. The drum was heated with condensing steam at 212-230^{o}F to melt out the energetics and to increase the hydrolysis reaction rate.

The results of the testing clearly demonstrated the ability of the ERH to effectively deactivate and dissolve the energetics and aluminum found in the M557 fuzes and M83 bursters, and to effectively deactivate the energetics found in the M6 and M14 bursters. The test data from the validation trials for these four munitions indicate that the energetics can be dissolved (melted) and deactivated in 2-4 hours. Test data on the M28 rocket motor sections indicate that longer residence time (10 hours) at high caustic concentrations (12M) and temperatures (230^{o}F) are needed for complete hydrolysis of the propellant.

Dunnage Shredding/Hydropulping System. The shredding and hydropulper system was demonstrated to show that solid wastes (wooden dunnage, DPE suits, and butyl rubber) could be adequately size-reduced and pulped to a pumpable mixture. The objectives of the demonstration testing included the following:

- Validate the ability of the shredders and the hydropulper to adequately prepare the dunnage for downstream processing in the SCWO.
- Qualitatively evaluate the operability of the shredder/hydropulper unit operations with particular focus on material handling.
- Validate the ability of the shredders to process 1,000 lb/hr of pallets and separately, 250 lb/hr of plastics.

Several commercial shredders were used to achieve size reduction of the solid materials of interest. The demonstration shredding equipment is identical in size to the units proposed for the full-scale system. The individual components of the DSHS had been tested previously in their respective applications, but had not been used collectively in the configuration demonstrated in this test program. Because of this, the demonstration had numerous, albeit not insurmountable, problems, e.g., wood “nesting” in the hammermill and micronizer feed chutes, and inadequate magnetic separation of metal from the shredded DPE suits prior to processing in the granulator. General Atomics was able to control system and feed variables well enough to achieve their target feed processing rates and obtain the proposed size-reduction objectives (<1mm for wood and <3mm for plastics). The 3-mm plastic material product was sieved to 1-mm to ensure it could be fed to the SCWO. The full-scale system will use larger feed nozzle diameters that should be capable of accepting the dunnage material as shredded (i.e., without the need for additional processing). Metal components had to be removed from DPE suits before feeding to the DSHS. The hydropulper was not validated and did not provide size reduction, but one work up run showed that it was able to effectively blend the energetics hydrolysates with size-reduced wood to yield a uniform, pumpable slurry for processing via SCWO.

Supercritical Water Oxidation System –Agent and Energetics Hydrolysate/Dunnage. SCWO was demonstrated to validate destruction of Schedule 2 and other organic compounds from agent hydrolysis products. The objectives of the demonstration testing included the following:

- Validate the ability of the SCWO to eliminate the Schedule 2 compounds present in the agent hydrolysate feed.
- Validate the ability of the agent hydrolysis process and the SCWO to achieve a DRE of 99.9999% for HD, GB, and VX.

- Demonstrate the long-term operability of the SCWO reactor with respect to salt plugging and corrosion.
- Characterize the gas, liquid, and solid process streams from the SCWO.

Supercritical Water Oxidation System –Energetics Hydrolysate/Dunnage. SCWO was also demonstrated to validate destruction of organic compounds from energetic hydrolysis products and to demonstrate the feasibility of destroying shredded solids. The objectives of the demonstration testing included the following:

- Validate the ability of the ERH, CSTR and SCWO to achieve a DRE of 99.999% for Tetrytol, Comp B, and M28 propellant.
- Determine the impact of the aluminum from the ERH process on SCWO operation.
- Determine the extent to which the organics in the shredded dunnage are oxidized in the SCWO.
- Characterize the gas, liquid, and solid process streams from the SCWO.

The SCWO system performed reasonably well except with respect to corrosion and salt plugging, which are issues of concern for reliable long-term operation. Platinum liners may improve on corrosion resistance, but appear to be difficult to form and work with (the platinum-lined reactor proposed for demonstration was never used because of difficulties in fabrication). Operationally, the agent hydrolysate runs (all liquid feeds) proceeded smoothly except for system leaks due to corrosion. After workup runs to determine suitable operating parameters, replicate validation runs showed that energetic hydrolysate/dunnage feeds can be processed successfully provided that aluminum hydroxide is removed from the feed (it caused severe plugging) and that feed nozzle restrictions are minimized.

c. Technology Evaluation

The General Atomics process of neutralization followed by SCWO was validated during demonstration. In addition, based on input from the Dialogue, it is likely that this process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of all assembled chemical weapons. The basis for this conclusion is summarized below.

(1) Process Efficacy and Performance

The General Atomics proposed total solution uses modified baseline reverse assembly and cryofracture of projectiles for munitions access. Agent and energetics are destroyed by caustic or water hydrolysis followed by SCWO. Metal parts are washed with caustic followed by a 5X thermal treatment, and dunnage is shredded, mixed with caustic, and destroyed by SCWO.

Cryofracture and baseline reverse assembly operations are well developed and therefore were not demonstrated. During demonstration testing, the government validated that caustic or water hydrolysis is effective for the destruction of agents to 99.9999% DRE and the destruction of energetics to 99.999%. The agent hydrolysis process does, however, produce Schedule 2 compounds, which are precursors to agents and are regulated by the Chemical Weapons Convention; the SCWO effectively destroyed all Schedule 2 compounds. Three of General

Atomics' critical unit operations were demonstrated—the dunnage shredding and hydropulper system (DSHS), energetics rotary hydrolyzer (ERH), and SCWO. Characterization of tested materials and products was completed to an acceptable degree. Most of the sampling and analysis methodologies required were verified and validated, and solutions for the remaining methods appear straightforward.

In general, the unit operations demonstrated a level of maturity that lends confidence for full-scale development, although there are concerns with respect to the maturity and operability of SCWO. The demonstrated SCWO reactor (made of Inconel, a high nickel chromium steel) and titanium heat exchanger experienced corrosion, and the reactor showed susceptibility to salt plugging. As proposed by General Atomics, a platinum-lined SCWO reactor should reduce the reactor corrosion and plugging problems for full-scale. However, the proposed platinum demonstration unit could not be fabricated in time for demonstration testing. Operability problems notwithstanding, the SCWO effectively mineralized all Schedule 2 and other compounds of concern to produce an effluent essentially free of organics. The demonstrated ERH removed and hydrolyzed energetics from bursters, propellant from rocket motor sections, and the majority of energetics from fuzes. Concerns remain with the scale-up of the ERH and SCWO while maintaining stable treatment conditions.

While the total solution is complex because of the large number of unit operations, most are inherently stable and can be effectively monitored and controlled using commercially available controls and instrumentation.

(2) Safety

The General Atomics' process poses minimal risk to workers during normal operations. The process requires relatively large quantities of process chemicals. However, the process chemicals pose only moderate health hazards. Hydrolysis is a low temperature, near ambient pressure process with relatively stable reaction rates. While the overall process is inherently low risk, equipment containment and agent monitoring issues increase worker risk during normal operations. While cryofracture and SCWO operate at extreme operating conditions and pose severe physical hazards, the demonstrated engineering and administrative controls should greatly reduce both the probability and severity of an accident. Equipment redesign is expected to ensure containment of the ERH fugitive emissions and HDC fuze detonations. Although containment issues exist, the process poses manageable concerns for worker safety.

Because of the low volatility of the process chemicals and products, minimal potential for fires or explosions, and an effective process control system, potential facility accidents pose minimal public risk. The process involves relatively large quantities of process chemicals and solid waste, but none are highly volatile, flammable, or an acute inhalation hazard. Therefore, there are no unusual transportation accident response requirements, and risk to the public is minimal.

(3) Human Health and Environment

The SCWO process effectively treats agent hydrolysates, energetic hydrolysates, and dunnage, thus destroying essentially all organics and producing an effluent of low concern and impact to human health and the environment. The demonstrated liquid effluent (and subsequent dried salts in full-scale) contained significant concentrations of heavy metals from SCWO reactor corrosion and lead from some energetics. A platinum liner should eliminate much of the heavy metals from SCWO corrosion, but was not demonstrated. The solid waste stream may fail RCRA's toxic characteristic leaching procedure and require further treatment prior to disposal due to the presence of heavy metals. All effluents are well characterized. Gaseous effluents from the SCWO are expected to be of low hazard and concern. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Although details of the permitting strategy were not provided, permitting of a hydrolysis/SCWO process for the Newport Chemical Activity in Indiana indicates that an acceptable permitting strategy is possible for demilitarization of chemical weapons.

(4) Potential for Implementation (Including Cost, Schedule, and Public Acceptance)

Life Cycle Cost and Schedule: The results of the life cycle cost and schedule evaluations will be discussed in follow-on correspondence to Congress dealing with requirements set forth in PL 105-261. An Integrated Process Team has been established within the Department of Defense to determine if the demonstrated alternative technologies described within this report meet certification requirements set forth by PL 105-261. The certification requirements are as follows:

The Under Secretary of Defense must certify in writing to Congress that an alternative is

- ❑ "As safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions; and
- ❑ Is capable of completing the destruction of such munitions on or before the later of the date by which the destruction of the munitions would be completed if incineration were used or the deadline date for completing the destruction of the munitions under the Chemical Weapons Convention."

Public Acceptance: Neutralization/SCWO was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process

3. Parsons/AlliedSignal

Three primary process systems were tested separately and concurrently by the Parsons/ AlliedSignal team at the DCD and DPG to determine their viability in providing a complete destruction alternative for assembled chemical weapons. These systems include a high-pressure water jet cutting and washout system to dismantle M55 rockets, a superheated steam process to treat metal parts and miscellaneous dunnage, and bioreactors to treat neutralized VX and GB agents and energetics. The latter process was also tested at the U.S. Army ECBC in APG, Maryland with neutralized HD agent.

a. Installation and Systemization Summary

Rocket Cutter and Washout (RC&W). In general, the installation and systemization activities associated with the RC&W process went smoothly. In large part, the ease with which installation and systemization activities proceeded was due to two factors. First, the support provided by the DPG Test Facility personnel proved to be an important contribution due to their experience with conducting similar tests, as well as their expertise with munitions and related energetic material and safety issues. Second, the installation and systemization effort at DPG proved to be simplified by the design, engineering, fabrication, and systemization activities performed at the Parsons/AlliedSignal facility in Pasco, Washington prior to shipment of the equipment to DPG.

Metal Parts Treater (MPT). The MPT system was installed in the Chemical Test Facility (CTF) at the CAMDS site in Tooele, Utah. Installation of the MPT at the CTF took place during January 1999. The majority of the MPT system was pre-erected on skids prior to shipment to the CAMDS site. On-site installation consisted primarily of placement of the equipment, completion of utility connections, piping and plumbing, and installation of monitoring equipment. Although most of the installation proceeded smoothly, there were delays due to a shortage of resources and some design changes made during installation. Systemization activities occurred at the CTF throughout January 1999 and February 1999 until the commencement of testing on 1 March 1999. Systemization activities included on-site systemization of installed equipment as well as shop tests performed by Parsons/AlliedSignal prior to shipment of equipment to the site. There were some equipment problems during systemization that included air preheaters, steam superheater, process air flow meter, and induction heater. These problems were resolved and systemization was completed before the start of testing. The installation and systemization effort at CAMDS proved to be simplified by the design, engineering, fabrication, and systemization activities performed at the Parsons/AlliedSignal facility in Pasco, Washington prior to shipment of the equipment to CAMDS.

Immobilized Cell Bioreactor (ICB). The GB and VX ICB systems were installed in the CTF and the HD ICB system was installed in Building E3570 at ECBC. Installation of the GB/VX ICB systems at CAMDS was impacted by conflicts between the design and size of the ICB reactor units and the physical space limitations of the CTF. Changes to equipment configuration and design that resulted did have an impact on the installation and systemization schedule. The actual systemization activities ran relatively smooth, except for some delays due to equipment installation and some site specific delays.

b. Demonstration Operations

Rocket Cutter and Washout. The RC&W system was demonstrated to determine its effectiveness in the disassembly of the M55 rocket and the washout of energetic materials. The objectives of the demonstration included the following:

- Demonstrate the ability to perform circumferential cuts of a rocket at required locations along the rocket length;
- Demonstrate effective fluid mining and separate collection of rocket bursters, motor propellants, and residual agent simulant;
- Demonstrate the ability to maintain control of rocket metal and plastic parts from cutting and fluid mining operations;
- Determine the energetic particle size of mined rocket bursters and propellant; and
- Determine the requirements for separating used grit from the residual cutting solution.

With one major exception, the RC&W system demonstration ran smoothly. The system demonstrated the ability to remove fuzes, cut warheads to include the igniter assembly, and washout bursters. The RC&W system was unsuccessful, however, in washing out the M28 propellant. Unsuccessful attempts were also made to shred the propellant after it was extracted from the metal casing. Parsons/AlliedSignal will need to make adjustments to the process in order to present a total solution for the destruction of the M55 rocket.

Metal Parts Treater. The MPT was demonstrated to determine its effectiveness for decontaminating metal parts and miscellaneous dunnage after disassembly of munitions. The objectives of the demonstration included the following:

- ❑ Validate the ability of the MPT process to treat process wastes/dunnage;
- ❑ Validate the ability of the MPT process to achieve a 5X condition for metal parts contaminated with GB, VX, and HD;
- ❑ Identify pyrolysis products generated in the MPT during the processing of process wastes/dunnage and their impact on the downstream condenser;
- ❑ Characterize the liquid effluent form the MPT condenser to determine its suitability for treatment by hydrolysis;
- ❑ Validate the ability of the MPT condenser and the catalytic treater to eliminate chemical agents and Schedule 2 compounds from process gas streams;
- ❑ Determine the potential for fouling and plugging of the CatOx as a result of MPT operation; and
- ❑ Characterize gas, liquid, and solid process streams from the MPT and CatOx unit operations for selected chemical constituents and physical parameters. Characterize these streams with respect to the presence/absence of hazardous, toxic, and Schedule 2 compounds (including chemical agent).

The MPT demonstration was conducted with feeds that consisted of process wastes, (to include, carbon, fiberglass firing tubes, wood pallets spiked with PCP, and DPE), and M2A1 mortar bodies spiked with GB, VX, and HD agents. In general, the MPT system performed well throughout the validation tests with no major problems related to system integrity, reliability, and maintainability. Most of the complexities of the system operation involved the preparation of feeds containing chemical agents, which required DPE entries to the system by specially-trained personnel. This operation would be automated for full-scale.

Immobilized Cell Bioreactor. The ICB was demonstrated to determine its effectiveness for treating the secondary waste products from the hydrolysis of agent and energetics. The objectives of the demonstration include the following:

- ❑ Validate the ability of the ICB process to eliminate Schedule 2 compounds present in the hydrolysate feeds;
- ❑ Confirm the absence of agent in the effluents of the ICB system;
- ❑ Validate the ability of the ICB systems (and the separately-tested agent hydrolysis systems) to achieve a DRE of 99.9999% for VX, GB, and HD;
- ❑ Validate the ability of the ICB systems (and the separately-tested energetic hydrolysis systems) to achieve a DRE of 99.999% for energetics including;

  - For the VX ICB system—Trinitrotoluene (TNT), Royal Demolition Explosive (RDX), nitrocellulose, nitroglycerin
  - For the GB ICB system—TNT, RDX
  - For the HD ICB system—TNT, Tetrytol

- ☐ Develop mass loading and kinetic data to allow for scale-up of ICB system unit operations;
- ☐ Validate the ability of the CatOx to eliminate specified volatile organic compounds (VOCs), semi-VOCs, and Schedule 2 compounds from the ICB process gas stream;
- ☐ Determine the potential impact of operating conditions on the fouling and plugging of the CatOx; and
- ☐ Characterize gas, liquid, and solid process streams from the ICB process for selected chemical constituents and physical parameters, and the presence/absence of hazardous, toxic, agent, and Schedule 2 compounds.

Overall, the mechanical functions of the ICB systems performed as required throughout the test. Feed and treatment flows could be maintained at required rates. There were some problems experienced with the eductors, air preheater, reverse osmosis unit, CatOx and lime bed, but none significantly delayed the test program. Agent monitoring, however, proved to present a significant challenge to the operation of the VX ICB system. The complex gas streams generated by the processes caused interferences in the agent detection and monitoring systems.

c. Technology Evaluation

The Parsons/AlliedSignal process of neutralization of mustard followed by treatment in the Immobilized Cell Bioreactor (ICB) was validated during demonstration. In addition, based on input from the Dialogue, it is likely that the mustard process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of chemical weapons with mustard agent. The process for the demilitarization of chemical weapons with nerve agent was not validated during demonstration. Based on input from the Dialogue, it is unlikely that the nerve agent process will be publicly acceptable. Therefore, this process is not considered a viable total solution for the demilitarization of chemical weapons with nerve agent. The basis for these conclusions is summarized below.

(1) Process Efficacy and Performance

The Parsons/AlliedSignal process uses caustic or water hydrolysis as the primary destruction method for the agent and energetics extracted from chemical weapons. The destruction of agents was validated to 99.9999% and the destruction of energetics was validated to 99.999%, in government testing. The Parsons/AlliedSignal team’s use of this technology, along with the thermal treatment of metal parts and other solid wastes, has been validated to effectively treat the components of chemical weapons. The agent hydrolysis process does, however, produce Schedule 2 compounds, which are precursors to agents and are regulated by the Chemical Weapons Convention. For mustard type munitions, these Schedule 2 compounds were effectively treated in the ICB system. The Schedule 2 compounds from nerve agent munitions were not adequately treated by the ICB system during demonstration testing as evidenced by the steady increase in concentration of these compounds in the ICB over time. The nerve agent ICB process is therefore considered not sufficiently mature and hence unacceptable, at this time, for the disposal of munitions containing nerve agent. The process is considered mature for the processing of mustard agent, although there are concerns with the optimization of the integrated ICB system and the maturity of the metal parts treater and continuous steam treater. The process is also considered stable for processing mustard munitions although the many unit operations required contributes to its complexity. The monitoring and control of the system is straightforward and effective using commercially available controls and instrumentation.

(2) Safety

The Parsons/AlliedSignal process poses minimal risk to workers during normal operations. Although the process requires relatively large quantities of process chemicals, hydrolysis, and bio-treatment operate at low temperature and near-ambient pressure, involve slow stable reactions, and have demonstrated good equipment-level containment capability. However, there are concerns regarding VX hydrolysate agent monitoring interference and unverified MPT, continuous steam treater, and M28 shredding equipment-level containment capabilities. Because the process chemicals and intermediate products are not highly volatile, flammable, or acute inhalation hazards, and the CatOx demonstrated the ability to effectively treat process gas emissions, process accidents pose negligible public risk. Although the process involves relatively large quantities of process chemicals and solid waste, there are no unusual transportation accident response requirements, and risk to the public is minimal.

(3) Human Health and Environment

The ICB and MPT are expected to produce effluents of low hazard and concern for mustard munitions. The secondary treatment of the GB/Comp B hydrolysate and the VX/Comp B/M28 hydrolysate waste streams was incomplete and contained a complex mix of volatile organic compounds, semi-volatile organic compounds, and inorganic anions, which could not be fully quantified because some compounds were not anticipated. This poses unknown risks with respect to human health and the environment. This effluent also contained Schedule 2 compounds with unknown disposal options. The CatOx gaseous effluent is expected to be of low hazard and concern. A dewatering system based on an evaporator/crystallizer is proposed for water recycle; no water effluents are expected. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Although details of the permitting strategy were not provided, a bulk mustard hydrolysis/biological treatment process is undergoing permitting in Maryland indicating an acceptable permitting strategy is possible.

(4) Potential for Implementation (Including Cost, Schedule, and Public Acceptance)

Life Cycle Cost and Schedule: The results of the life cycle cost and schedule evaluations will be discussed in follow-on correspondence to Congress dealing with requirements set forth PL 105-261. An Integrated Process Team has been established within the Department of Defense to determine if the demonstrated alternative technologies described within this report meet certification requirements set forth by PL 105-261. The certification requirements are as follows:

The Under Secretary of Defense must certify in writing to Congress that an alternative is

- "As safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions; and
- Is capable of completing the destruction of such munitions on or before the later of the date by which the destruction of the munitions would be completed if incineration were used or the deadline date for completing the destruction of the munitions under the Chemical Weapons Convention."

Public Acceptance: Neutralization/biotreatment for nerve agents was deemed unlikely to obtain public acceptability due to the inability to validate the biotreatment process in demonstration. Neutralization/biotreatment for mustard agents was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

III. CONCLUSIONS

The following conclusions are provided in accordance with direction in the implementing legislation (Public Law 104-208). These conclusions rely on the demonstrations of critical unit operations and proposed total system solutions by Burns and Roe, General Atomics, and Parsons/AlliedSignal, and take into account the input from the Dialogue, especially concerning the likelihood for public acceptability.

The following conclusions are made:

- Based on the technical findings summarized in Section II.C.1 of this report and in Section B.5.1.1 of the Technical Evaluation Report (Appendix B), the Burns & Roe PWC process for demilitarization of chemical weapons can not be considered a viable total solution at this time.
- Based on the technical findings summarized in Section II.C.2 of this report and in Section B.5.1.2 of the Technical Evaluation Report (Appendix B), the General Atomics process of neutralization followed by SCWO is considered a viable total solution for the demilitarization of all assembled chemical weapons.
- Based on the technical findings summarized in Section II.C.3 of this report and in Section B.5.1.3 of the Technical Evaluation Report (Appendix B), the Parsons/AlliedSignal process of neutralization followed by treatment in the ICB is considered a viable total solution for the demilitarization of chemical weapons with mustard agent. The process for the demilitarization of chemical weapons with nerve agent is not considered a viable total solution at this time.

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Appendix A

Dialogue Participants and Alternates

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Appendix A
Assembled Chemical Weapons Assessment Program
Dialogue Participants and Alternates
(1 September 1999)

Dan Bauer
State Science Advisor
Governor's Office of Planning & Budget
116 State Capitol
Salt Lake City, UT 84114
801-538-1569 (telephone)
801-538-1547 (fax)
dbauer@gov.state.ut.us

James Bryant
(Alternate for G. Hardy)
Chief, Government Facilities Section
Alabama Department of Environmental Management
1751 Congress W.L. Dickinson Drive
Montgomery, AL 36109-2608
334-271-7738 (telephone)
334-279-3050 (fax)
jlb@adem.state.al.us

Pua'Ena Burgess
Pacific & Asia Council of Indigenous People
86-649 Puuhulu Road
Wai'nae, HI 96792
808-696-5157 (telephone)
808-696-7774 (fax)
plaenui@pixi.com

Kathryn Cain
Director of Operations
U.S. Army
Pueblo Chemical Depot
45825 Highway 96 East
Pueblo, CO 81006-9330
719-549-4060 (telephone)
719-549-4318 (fax)
krcain@pcd-emh1.army.mil

David Christian
Serving Alabama's Future Environment
1302 Noble Street, Suite 3A
Lyric Square
Anniston, AL 36201
256-237-0317 (telephone)
256-237-0325 (fax)
dxian@wwisp.com

Daniel Clanton
Engineering Supervisor
Active Sites Branch
Arkansas Department of Environmental Quality
Hazardous Waste Division
8001 National Drive
Little Rock, AR 72219-8913
501-682-0834 (telephone)
501-682-0565 (fax)
clanton@adeq.state.ar.us

Ralph Collins
Deputy Commissioner
Natural Resources
Kentucky Department for Environmental Protection
14 Reilly Road
Frankfort, KY 40601
502-564-2150 (telephone)
502-564-4245 (fax)
collins_r@nrdep.nr.state.ky.us

Elizabeth Cotsworth
Acting Director, Office of Solid Waste
U.S. Environmental Protection Agency
2800 Crystal Drive
Crystal Section—9th Floor
Arlington, VA 22202
703-308-8895 (telephone)
703-308-0513 (fax)
Cotsworth.Elizabeth@EPAMAIL.EPA.GOV

Carl Daly
(Alternate for EPA)
Environmental Engineer
U.S. Environmental Protection Agency
Region VIII
999 18th Street—Suite 500
Denver, CO 80202-2466
303-312-6416 (telephone)
303-312-6064 (fax)
daly.carl@EPAMAIL.EPA.GOV

Dennis Downs
Director
Division of Solid and Hazardous Waste
Utah Department of Environmental Quality
288 North 1460 West
Salt Lake City, UT 84114-4880
801-538-6170 (telephone)
801-538-6715 (fax)
eqshw.ddowns@email.state.ut.us

Joe Elliott
(Alternate for D. Maddox)
Project Engineer
Blue Grass Army Depot
ATTN: SIOBG-MO (Bldg. 219/Elliott)
2091 Kingston Highway
Richmond, KY 40475-5070
606-625-6021 (telephone)
606-625-6409 (fax)
ElliottJ@bgad-exch1.army.mil

Pamela Ferguson
Indiana Citizens’ Advisory Commission
RR#4, Box 292 B
Rockville, IN 47872
765-569-3440 (telephone)
765-569-3362 (fax)
JAAP@jobax.net

Wm. Gerald Hardy
Chief
Land Division
Alabama Department of Environmental
Management
1751 Congress W.L. Dickinson Drive
Montgomery, AL 36109-2608
334-271-7974 (telephone)
334-279-3050 (fax)
wgh@adem.state.al.us

Kay Harker
(Alternate for R. Collins)
Manager of Planning & Program
Coordination Branch
Commissioner’s Office
Department of Environmental Protection
14 Reilly Road
Frankfort, KY 40601
502-564-2150 (telephone)
502-564-4245 (fax)
harker@nrdep.nr.state.ky.us

Hugh Hazen
(Alternate for EPA)
Environmental Engineer
U.S. Environmental Protection Agency
Region IV
61 Forsyth Street
Atlanta, GA 30303
404-562-8499 (telephone)
404-562-8439 (fax)
hazen.hugh@EPAMAIL.EPA.GOV

Douglas Hindman
Co-Chair
Kentucky Citizens’ Advisory Commission
300 Center Street
Berea, KY 40403
606-623-5035 (telephone)
606-625-9006 (fax)
psyhindm@acs.eku.edu

Worley Johnson
Co-Chair
Kentucky Citizens’ Advisory Commission
Department of Environmental Science
Eastern Kentucky University
219 Disney Building
Richmond, KY 40475-3135
606-622-1940 (telephone)
606-625-1502 (fax)
evhjohns@acs.eku.edu

Karyn Jones
Chairperson
G.A.S.P.
1010 West Highland Avenue
Hermiston, OR 97838
541-567-6581 (telephone)
541-567-6581 (fax)
karynj@oregontrail.net

Cindy King
Utah Chapter Sierra Club
2963 South 2300 East
Salt Lake City, UT 84109
801-486-9848 (telephone)
801-467-9296 (fax)
cindy.king@sierraclub.org

Irene Kornelly
President
Kornelly and Associates
4015 Loring Circle South
Colorado Springs, CO 80909
719-591-5157 (telephone)
719-591-1305 (fax)
ikornelly@pcisys.net

Thomas Linson
Branch Chief
Indiana Department of Environmental Management
100 North Senate Avenue
P.O. Box 6015
Indianapolis, IN 46206-6015
317-232-3292 (telephone)
317-232-3403 (fax)

Dane Maddox
Director, Business Management
Blue Grass Army Depot
2091 Kingston Highway (Bldg. 219/Maddox)
Richmond, KY 40475-5070
606-625-6021 (telephone)
606-625-6409 (fax)
MaddoxD@bgad-exch1.army.mil

Catherine Massimino
(Alternate for EPA)
Senior RCRA/Superfund Technical Specialist
Region X
U.S. Environmental Protection Agency
1200 Sixth Avenue—WCM-127
Seattle, WA 98270
206-553-4153 (telephone)
206-553-8509 (fax)
massimino.catherine@epamail.epa.gov

Brett McKnight
(Alternate for W. Thomas)
Manager of Regional Hazardous Materials Program
Eastern Region—Bend Office
Oregon Department of Environmental Quality
2146 N.E. 4th St.—Suite #104
Bend, OR 97701
541-388-6146 x-236 (telephone)
541-388-8283 (fax)
mcknight.brett@deq.state.or.us

James Michael
(Alternate for EPA)
Senior Permit Advisor, Office of Solid Waste
Environmental Protection Agency
Mail Code 5303W
401 M Street, S.W.
Washington, DC 20460
703-308-8610 (telephone)
703-308-8609 (fax)
michael.james@epamail.epa.gov

Sara Morgan
Citizens Against Incineration at Newport
Rt. 1, Box 159
Montezuma, IN 47862
317-498-4472 (telephone)
317-569-3325 (fax)
MORGANS@roxi.rockville.k12.in.us

John Nunn
Co-Chair Person
Maryland Citizens' Advisory Commission
P.O. Box 141
Worton, MD 21678
410-778-5968 (telephone)
410-778-0809 (telephone)
410-778-6004 (fax)

Bob Palzer
Chair
Sierra Club Air Committee
501 Euclid Street
Ashland, OR 97520
541-482-2492 (telephone)
541-482-0152 (fax)
bob.palzer@sierraclub.org
palzer@mind.net

Joe Schieffelin
(Alternate to J. Sowinski)
Unit Leader
Permits & Compliance Unit
Hazardous Materials & Waste
Management Division
CO Department of Public Health and
Environment
4300 Cherry Creek Drive South
Denver, CO 80246
303-692-3356 (telephone)
303-759-5355 (fax)
joe.schieffelin@state.co.us

Charles Schindler
(Alternate for D. Hindman)
Common Ground
311 Forest Street
Berea, KY 40403
606-986-9341 (telephone)
606-986-4506 (fax)
charly_schindler@berea.edu

George Smith
Alabama Citizens' Advisory Commission
1031 Quintard Avenue
P.O. Box 2128
Anniston, AL 36202
256-231-1279 (telephone)
256-231-1355 (fax)

Joan Sowinski
Federal Facilities Program Manager
Hazardous Materials and Waste Management
Division
CO Department of Public Health &
Environment
4300 Cherry Creek Drive South
Denver, CO 80246-1530
303-692-3359 (telephone)
303-759-5355 (fax)
joan.sowinski@state.co.us

Wesley Stites
Arkansas CAC Member
Associate Professor of Biochemistry
University of Arkansas
Department of Chemistry & Biochemistry
Fayetteville, AR 72701-1201
501-575-7478 (telephone)
501-575-4049 (fax)
wstites@comp.uark.edu

Debra Strait
(Alternate to K. Cain)
Chemist
Team Leader, Lab and Monitoring
U.S. Army
Pueblo Chemical Depot
45825 Highway 96 East
Pueblo, Colorado 81006-930
719-549-4273/4357 (telephone)
719-549-4582 (fax)
dastrait@pcd-emh1.army.mil

Wayne Thomas
Program Manager
Umatilla Chemical Agent Disposal Program
Oregon Department of Environmental Quality
256 NE Hurlburt
Suite 105
Hermiston, OR 97838
541-567-8297 (telephone)
541-567-4741 (fax)
THOMAS.Wayne@deq.state.or.us

Ross Vincent
Chair
Environmental Quality Strategy Team
Sierra Club
1829 South Pueblo Boulevard
PMB 300
Pueblo, CO 81005-2105
719-561-3117 (telephone)
719-561-1149 (fax)
ross.vincent@sierraclub.org

Paul Walker
Director
Global Green USA Legacy Program
1025 Vermont Avenue, N.W.
Suite 300
Washington, DC 20005-6303
202-879-3181 (telephone)
202-879-3182 (fax)
ipis@igc.apc.org

Chip Ward
(Alternate for C. King)
West Desert HEAL
P. O. Box 1005
Grantsville, UT 84029
801-715-6740 (telephone)
801-715-6767 (fax)
cward@inter.state.lib.ut.us

Lisa Weers
(Alternate for J. Sowinski)
Hazardous Waste Permit Writer
CO Department of Public Health &
Environment
4300 Cherry Creek Drive South
Denver, CO 80246-1530
303-692-3359 (telephone)
303-759-5355 (fax)
lisa.weers@state.co.us

J.R. Wilkinson
Director
Special Sciences Resources Program
Confederated Tribes of Umatilla
P.O. Box 638
Pendleton, OR 97801
541-276-0105 (telephone)
541-278-5380 (fax)
jrw@ucinet.com

Craig Williams
Spokesperson
The Chemical Weapons Working Group
Kentucky Environmental Foundation
P.O. Box 467
Berea, KY 40403
606-986-7565 (telephone)
606-986-2695 (fax)
kefwilli@acs.eku.edu

Evelyn Yates
Pine Bluff for Safe Disposal
5613 West Jones
Pine Bluff, AR 71602-4467
870-247-9484 (telephone)
870-543-8440 (fax)
yates_e@yahoo.com

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Appendix B

Program Evaluation Team
Technical Evaluation Report

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Program Evaluation Team

Final Technical Evaluation:

Burns and Roe Plasma Arc
General Atomics Neutralization/SCWO
Parsons/AlliedSignal Neutralization/Biotreatment

Program Evaluation Team (PET) Chair: Joseph J. Novad 14 Sep 99
Joe Novad Date

Technical Evaluation Committee (TEC) Chair: Jim Richmond 14 Sep 99
Jim Richmond Date

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Executive Summary

The ACWA Evaluation Process

In accordance with Public Law (PL) 104-208, the Under Secretary of Defense for Acquisition and Technology appointed the Program Manager for Assembled Chemical Weapons Assessment (PMACWA) with the mission to identify and demonstrate at least two alternative technologies to baseline incineration for the disposal of assembled chemical weapons (ACWs). ACWs for this purpose represent the chemical weapons stockpile configured with fuzes, explosives, propellant, chemical agents, shipping and firing containers, and packaging materials.

The PMACWA established four teams (Technical Team, Environmental Team, Business Team, and Public Outreach Team) to accomplish the mission of the program. In addition, the Dialogue on Assembled Chemical Weapons Assessment (DACWA or the "Dialogue") was formed in an effort to effectively address the charge of PL 104-208. The Dialogue included representatives from affected communities, state and/or tribal representatives, federal representatives, and other concerned entities. This group and the PMACWA interacted throughout the program.

The ACWA program was organized in three phases—Phase 1, Criteria Development; Phase 2, Technology Assessment; and Phase 3, Demonstration Testing. Since resource constraints prevented the testing of all technologies that had technically passed the evaluation using Demonstration Selection Criteria developed in Phase 1, a Best Value Decision (BVD) was incorporated into Phase 2 to determine the appropriate technologies to demonstrate. The BVD was based on the technical merit of each proposed technology and on resource considerations, such as cost and availability of facilities.

The evaluation and recommendations described in this report were developed by the Program Evaluation Team (PET). The PET consists of members of the Technical Evaluation Team (TET), the Demonstration Working Group (DWG), the Environmental Team (ET), personnel from support contractors, and personnel from other government agencies. The evaluation was conducted in close association with the Citizens Advisory Technical Team (CATT), appointed by the Dialogue to represent the public's interest in the evaluation. Members of the CATT participated in all of the PET meetings and maintained lines of communication among the CATT and PET members. The CATT and PET also met at several milestones throughout the process to discuss results, gain consensus, and develop recommendations.

In accordance with the Congressional mandate, alternative technologies from three technology providers were demonstrated. The three technology providers and their corresponding processes are:

- ❑ Burns and Roe—primary destruction: plasma arc process
- ❑ General Atomics—primary destruction: agent and energetics neutralization; secondary destruction: supercritical water oxidation (SCWO)
- ❑ Parsons/AlliedSignal—primary destruction: agent and energetics neutralization, secondary destruction: biological treatment.

Findings

Burns and Roe Plasma Arc Process

The Burns and Roe team's proposed total solution uses a Plasma Waste Converter (PWC) as the sole destruction mechanism. The PWC represents a robust, indiscriminate thermal treatment technology capable of destroying organic materials. The proposed process uses multiple PWCs, with similar configurations, to destroy all ACWs. The demonstration utilized a single, multipurpose PWC for the objective of testing several different feeds.

The demonstration results indicate a lack of process maturity for the PWC—this translates into a need for significant redesign, development, and testing before full-scale implementation of the system. Problems with PWC operation and reliability during systemization and operation of the equipment led to changes in test configuration and schedule delays resulting in an inability to complete all of the planned tests. The most significant impact of the operational and reliability problems experienced during systemization and operations was the Army's decision to cancel the planned campaigns with chemical agent. Other planned demonstration tests were completed and provided valuable data for the evaluation of the technology. The ability of the process to destroy energetics, metal parts, and secondary wastes of ACWs was validated, and additional operations were successfully conducted with an agent simulant and an agent hydrolysate.

The plasma arc process poses moderate, but manageable risk to workers during normal operations. The PWC process chemicals and intermediates are low-to-moderate health hazards. The PWCs rely on negative pressure to achieve equipment-level containment. The observation of fugitive gaseous emissions during demonstration leads to concern over the PWC containment capability. This indicates the potential for worker exposure and will necessitate a significant increased use and reliance on personal protective equipment to provide worker protection. While severe physical hazards such as extreme temperature during PWC operations are present, the demonstrated use of engineering and administrative controls should greatly reduce both the probability and severity of an accident. Secondary facility containment, administration procedures, automated process controls, and hold, test, and release/rework capability mitigate the hazards posed by potential facility accidents and result in negligible public risk. The process involves low volumes of process chemicals and solid waste products that are not highly volatile, flammable, or an acute inhalation hazard. Therefore, there are no unusual transportation accident response requirements and minimal public risk.

Optimal operating parameters were not established during demonstration and are not well defined. Concerns and impacts to human health and the environment cannot be properly assessed without effluent characterization data from standardized demonstration runs. Air infiltration to the PWC during demonstration and the lack of agent derived data prevented complete characterization of the effluents. The plasma-converted gas sampling for energetics and dunnage runs indicated an absence of hazardous constituents; however, predicted conversion of feed materials to a synthesis gas was not demonstrated. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Effluents appear to be treatable and disposable; however, Burns and Roe's permit strategy is dependent on the Resource Conservation and Recovery Act (RCRA) synthesis gas exemption. Data in demonstration, however, indicates this exemption may not be achieved. There is no history of permitting a PWC for treatment of agent waste and it is unclear how regulatory agencies will evaluate the process.

In the area of potential for implementation, the plasma arc process's total capital cost may be approximately equal to that of baseline incineration. It is likely that the total operations and maintenance (O&M) costs for the plasma arc process may be slightly greater than baseline. The schedule estimates developed for the demilitarization of ACWs utilizing the Burns and Roe plasma arc process indicate completion of operations for Pueblo in January 2012 and Blue Grass in April 2012. This schedule is essentially equivalent to that for baseline incineration, given the uncertainty inherent in the schedule estimates, particularly for permitting. Based on the input from the Dialogue, the plasma arc process was deemed unlikely to obtain public acceptability due to the incomplete demonstration and the perceived similarity to incineration.

In summary, the Burns and Roe process, using a PWC to demilitarize ACWs, was not validated for agent destruction during demonstration testing due to the lack of maturity. In addition, based on input from the Dialogue, it is unlikely that this process will be publicly acceptable. Therefore, this process cannot be considered a viable total solution for the demilitarization of ACWs.

General Atomics Neutralization/SCWO

The General Atomics proposed total solution uses modified baseline reverse assembly and cryofracture of projectiles for munitions access. Agent and energetics are destroyed by caustic or water hydrolysis followed by supercritical water oxidation. Metal parts are washed with caustic followed by a 5X thermal treatment, and dunnage is shredded, mixed with caustic, and destroyed by SCWO.

Cryofracture and baseline reverse assembly are well developed and therefore were not demonstrated. During demonstration testing, the government validated that caustic or water hydrolysis is effective for the destruction of agents and energetics. The agent hydrolysis process does, however, produce Schedule 2 compounds, which are precursors to agents and are regulated by the Chemical Weapons Convention; the SCWO effectively destroyed all Schedule 2 compounds. Three of General Atomics' critical unit operations were demonstrated. In general, the unit operations demonstrated a level of maturity that lends confidence for full-scale development, although there are concerns with respect to the maturity and operability (salt plugging and corrosion) of SCWO.

Neutralization/SCWO poses minimal risk to workers during normal operations. Hydrolysis is a low temperature, near ambient pressure process with relatively stable reaction rates. Because of the minimal potential for fires or explosions, and an effective process control system, potential facility accidents pose minimal worker and public risk. The process involves relatively large quantities of process chemicals and solid waste, but none are highly volatile, flammable, or an acute inhalation hazard. Therefore, there are no unusual transportation accident response requirements, and risk to the public is minimal.

The SCWO process effectively treats agent hydrolysates, energetic hydrolysates, and dunnage, thus destroying essentially all organics and producing an effluent of low concern and impact to human health and the environment. A qualitative assessment of resource requirements indicate no expected exceptional energy or water demands. Permitting of a hydrolysis/SCWO process for the Newport Chemical Activity in Indiana indicates that an acceptable permitting strategy is possible for demilitarization of ACWs.

In the area of potential for implementation, neutralization/SCWO's total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M costs for neutralization/SCWO will be comparable to baseline. The schedule estimates developed for the demilitarization of ACWs utilizing neutralization/SCWO indicates completion of operations for Pueblo in September 2011 and Blue Grass in July 2011. This schedule is essentially equivalent to that for baseline incineration, given the uncertainty inherent in the schedule estimates, particularly for permitting. Based on the input from the Dialogue, the neutralization/SCWO technology was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

In summary, the General Atomics process of neutralization followed by SCWO was validated during demonstration. In addition, based on input from the Dialogue, it is likely that this process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of all ACWs.

Parsons/AlliedSignal Neutralization/Biotreatment

The Parsons/AlliedSignal process uses caustic or water hydrolysis as the primary destruction method for the agent and energetics extracted from ACWs. The destruction of agents and energetics was validated in government testing. The Parsons/AlliedSignal team's use of this technology, along with the thermal treatment of metal parts and other solid wastes, has been validated to effectively treat the components of ACWs. The agent hydrolysis process does, however, produce Schedule 2 compounds, which are precursors to agents and are regulated by the Chemical Weapons Convention. For mustard type munitions, these Schedule 2 compounds were effectively treated in the Immobilized Cell Bioreactor (ICB™) system. The Schedule 2 compounds from nerve agent munitions were not adequately treated by the ICB system during demonstration testing as evidenced by the steady increase in concentration of these compounds in the ICB over time. The nerve agent ICB process is therefore considered not sufficiently mature and hence unacceptable for the disposal of munitions containing nerve agent. The process is considered mature for the processing of mustard agent, although there are concerns with the optimization of the integrated ICB system and the maturity of the metal parts treater and continuous steam treater.

The Parsons/AlliedSignal process poses minimal risk to workers during normal operations. Although the process requires relatively large quantities of process chemicals, hydrolysis and biotreatment operate at low temperature and near-ambient pressure, involve slow stable reactions, and have demonstrated good equipment-level containment capability. However, there are concerns regarding VX hydrolysate agent monitoring interference and unverified metal parts treater (MPT), continuous steam treater, and propellant shredding equipment-level containment capabilities. Because the process chemicals and intermediate products are not highly volatile, flammable, or acute inhalation hazards, and because the Catalytic Oxidation (CatOx) demonstrated the ability to effectively treat process gas emissions, process accidents pose minimal worker and public risk. Although the process involves relatively large quantities of process chemicals and solid waste, there are no unusual transportation accident response requirements, and risk to the public is minimal.

The ICB and MPT are expected to produce effluents of low hazard and concern for mustard munitions. The secondary treatment of the two specific nerve agent/energetics hydrolysate waste streams could not be fully quantified because some compounds were not anticipated. This poses unknown risks with respect to human health and the environment. This effluent also contained Schedule 2 compounds with unknown disposal options. A qualitative assessment of resource requirements indicate no expected exceptional energy or water demands. A bulk mustard hydrolysis/biological treatment process was permitted in Maryland indicating an acceptable permitting strategy is possible.

In the area of potential for implementation, the neutralization/biotreatment total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M costs for neutralization/biotreatment will be comparable to baseline. The schedule estimates developed for the demilitarization of ACWs utilizing Parsons/AlliedSignal's neutralization/biotreatment indicates completion of operations for Pueblo in April 2011 and Blue Grass in April 2012. This schedule is essentially equivalent to that for baseline incineration, given the uncertainty inherent in the schedule estimates, particularly for permitting. Based on the input from the Dialogue, neutralization/biotreatment for nerve agents was deemed unlikely to obtain public acceptability due to the inability to validate the biotreatment process in demonstration. Neutralization/biotreatment for mustards was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

In summary, Parsons/AlliedSignal process of neutralization followed by biotreatment in the ICB for the demilitarization of ACWs with nerve agent was not validated during demonstration. In addition, based on input from the Dialogue, it is unlikely that the nerve agent process will be publicly acceptable. Therefore, this process is not considered a viable total solution for the demilitarization of ACWs with nerve agent.

The Parsons/AlliedSignal process of neutralization followed by biotreatment for the demilitarization of ACWs with mustard agent was validated during demonstration. In addition, based on input from the Dialogue, it is likely that the mustard process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of ACWs with mustard agent.

Recommendations

The following recommendations to the PMACWA are based on the technical findings whose details are documented in this report.

The Burns and Roe plasma arc process for demilitarization of ACWs cannot be considered a viable total solution at this time. Therefore, the PET recommends that PMACWA not consider this process for future pilot testing.

The General Atomics process of neutralization followed by SCWO is considered a viable total solution for the demilitarization of all ACWs. Therefore, the PET recommends that PMACWA consider this process for future pilot testing at any stockpile site with ACWs. As part of those piloting activities, and in preparation for the development of a pilot plant design, the PET recommends that the maturation testing focus on optimization of: bulk energetics hydrolysis, the platinum-lined SCWO reactor, rocket motor processing, and general waste disposal practices.

The Parsons/AlliedSignal process of neutralization followed by biotreatment in the ICB is not considered a viable total solution for the demilitarization of ACWs with nerve agents at this time. The process for the demilitarization of ACWs with mustard agents is considered a viable total solution. Therefore, the PET recommends that PMACWA consider this process for future pilot testing at any stockpile site with ACWs containing mustard agents. As part of those piloting activities, and in preparation for the development of a pilot plant design, the PET recommends that the maturation testing focus on optimization of: the hydrolysis of bulk energetics, the MPT CatOx system, the HD hydrolysate biotreatment, and general waste disposal practices.

B.1 Introduction

In accordance with Public Law (PL) 104-208, the Under Secretary of Defense for Acquisition and Technology has appointed the Program Manager for Assembled Chemical Weapons Assessment (PMACWA) with the mission to identify and demonstrate at least two alternative technologies to "baseline" incineration for the disposal of ACWs. ACWs for this purpose represent the chemical weapons stockpile configured with fuzes, explosives, propellant, chemical agents, shipping and firing tubes, and packaging materials.

The PMACWA established four teams (Technical Team, Environmental Team, Business Team, and Public Outreach Team) to accomplish the mission of the program. In addition, the Dialogue on Assembled Chemical Weapons Assessment (DACWA) was formed in an effort to effectively address the charge of PL 104-208. The Dialogue included representatives from affected communities, state and/or tribal representatives, federal representatives, and other concerned entities. This group and the PMACWA interacted throughout the program.

The Assembled Chemical Weapons Assessment (ACWA) program was organized in three phases—Phase 1, Criteria Development; Phase 2, Technology Assessment; and Phase 3, Demonstration. In Phase 1, criteria were developed by PMACWA and the Dialogue to conduct an evaluation of technologies for selection for demonstration and for the evaluation of results from demonstration. The Go/No-Go Screening Criteria provided an initial screening of proposals, and the Demonstration Selection Criteria were used to select technologies for demonstration testing. The Demonstration Selection Criteria were then expanded into Program Implementation Criteria, which were used to evaluate the technologies following the completion of demonstration testing. All three sets of criteria were incorporated into the ACWA Request for Proposal (RFP) and were reflected in the proposals received from industry in September 1997. Each set of criteria can be found in Attachment B-B. Phase 2, Technology Assessment, was divided into four steps and is discussed in Section B.2. The purpose of Phase 2 was to select technologies for Phase 3, Demonstration Testing.

Since resource constraints prevented the testing of all technologies that had technically passed the evaluation using Demonstration Selection Criteria developed in Phase 1, a Best Value Decision (BVD) was incorporated into Phase 2 to determine the appropriate technologies to demonstrate. The BVD was based on the technical merit of each proposed technology and on resource considerations, such as cost and availability of facilities. The three technology providers selected to perform demonstration testing are:

- Burns and Roe
  800 Kinderkamack Road
  Oradell, New Jersey 07649
  Point of Contact: Ralph DeChiaro
  (201) 986-4058

- General Atomics
  3483 Dunhill Street
  San Diego, California 92121
  Point of Contact: Michael Spritzer
  (619) 455-2337

Parsons/AlliedSignal
100 West Walnut Street
Pasadena, California 91124
Point of Contact: Jack Scott
(626) 440-4966

The total technology solutions proposed by the three teams chosen for demonstration are summarized in Table B.1-1. The unit processes that were selected for demonstration are identified and described in Section B.4.

Table B.1-1. Technology Descriptions for the Three Offerors Awarded Demonstration Task Orders

Offeror	Munitions Access	Agent Treatment	Energetics Treatment	Metal Parts Treatment	Dunnage Treatment
Burns and Roe Foster-Miller STARTECH	Minor modifications to baseline reverse assembly	Plasma arc	Thermally initiated explosives detonation followed by plasma arc	Plasma arc	Size reduction followed by plasma arc
General Atomics	Parts of baseline reverse assembly, cryofracture	Caustic or water hydrolysis followed by supercritical water oxidation (SCWO)	Caustic hydrolysis followed by SCWO	Caustic hydrolysis followed by thermal treatment with steam	Size reduction/ pulping followed by SCWO
Parsons/ AlliedSignal	Modified baseline reverse assembly (fluid-abrasive cutting and fluid mining	Caustic or water hydrolysis followed by biotreatment	Caustic hydrolysis followed by biotreatment	Thermal treatment with steam	Thermal treatment with steam

The evaluation and recommendations described in Sections B.4 and B.5 of this report were developed by the Program Evaluation Team (PET). The PET consists of members of the Technical Evaluation Team (TET), the Demonstration Working Group (DWG), the Environmental Team (ET), personnel from support contractors, and personnel from other government agencies. The list of the current PET members is included as Attachment B-A. The evaluation was conducted in close association with the Citizens Advisory Technical Team (CATT), appointed by the Dialogue to represent the public's interest in the evaluation. Members of the CATT participated in all PET meetings and maintained lines of communication among the CATT and PET members. The CATT and PET also met at several milestones throughout the process to discuss results, gain consensus, and develop recommendations.

The evaluation in this report is driven by the Program Implementation Criteria and is based upon the data and information acquired throughout the program, including the results of the demonstration tests. Additional details regarding the assessment process are discussed in Section B.2, ACWA Technical Assessment.

Section B.3 of this report discusses the Demonstration Preparations and Testing. Section B.4 contains the Technical Evaluation of each technology. Technical Conclusions and Recommendations are presented in Section B.5.

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B.2 ACWA Technical Assessment

The ACWA technical assessment is based on demonstration data, as well as historical data relevant to the demonstration of each technology. This section provides an overview of the process that led to demonstration testing and identifies sources of data and information that were used to assess the technologies in the final evaluation. This section concludes with a brief description of the overall process used in the final evaluation.

B.2.1 Phase 2: Technology Assessment Process and Information Sources

The purpose of the Phase 2 assessment, conducted between September 1997 and July 1998 was to select technologies for demonstration. The following summary of the four-step process (shown in Figure B.2-1) shows how, where, and what type of data and information were obtained throughout the program prior to demonstration testing. Items in italics indicate information and data sources.

Step 1—Go/No-Go. The Technology Proposals were assessed as to overall responsiveness and evaluated against the Go/No-Go Screening Criteria. As a result of the evaluation, a basic task-order contract was awarded to all offerors determined to be responsive to the solicitation requirements and whose technology met the Go/No-Go Screening Criteria.[1]

Step 2—Initial Assessment/Data Gap Resolution. The initial assessment of each technology against the Demonstration Selection Criteria identified data gaps in describing the technology or demonstration and targeted data gap resolution. The technologies for all technology providers receiving a task order contract were evaluated by the PET against the Demonstration Selection Criteria shown in Attachment B-B to identify data or information missing from the proposal. The missing data and information were identified as data gaps. Data Gap Identification Reports (DGIRs) were provided to the technology providers.

Using the appropriate DGIR, each contractor prepared a Data Gap Work Plan (DGWP) and submitted it to the government by December 10, 1997. The DGWP provided a detailed description of how the contractor would resolve the data gaps (including any testing) and included a milestone schedule for completion of the work. With the approval of the DGWP, the technology provider was authorized to proceed with the approach presented in the DGWP and prepare the Data Gap Resolution Report (DGRR). This completed the initial assessment of the proposals.

Step 3—Final Assessment/Technology Ranking. The PET conducted a final assessment of each technology using all provided information (Technology Proposal and DGRR) against the Demonstration Selection Criteria. The CATT participated throughout this process. Six technology providers were recommended for demonstration testing: AEA Technology, Burns and Roe, General Atomics, Lockheed Martin, Parsons/AlliedSignal, and Teledyne-Commodore.[2] Each of these technology providers received a task order to prepare a Demonstration Work Plan.

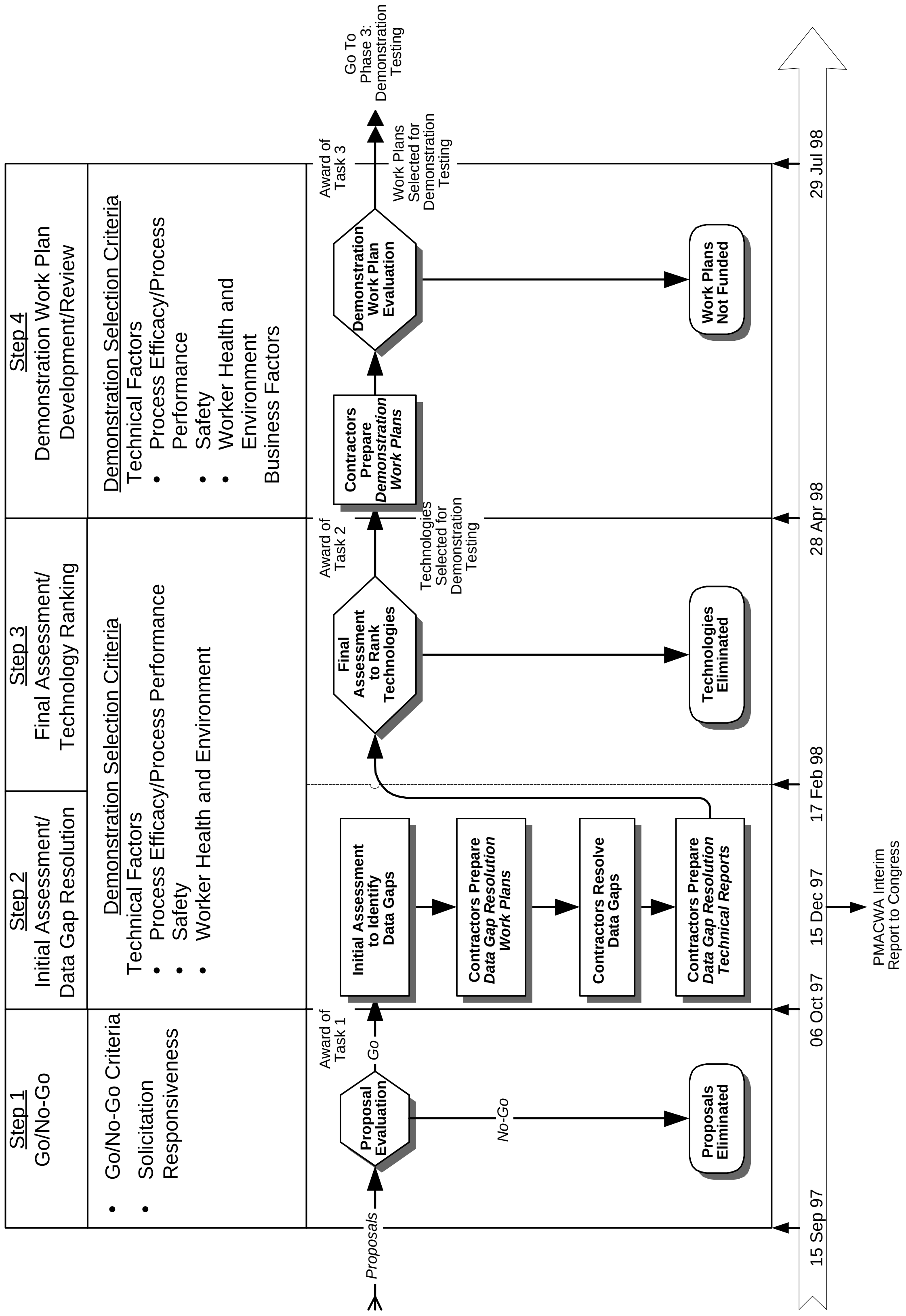

Figure B.2-1. The Four Steps of the ACWA Phase 2 Technology Assessment

Step 4—Demonstration Work Plan Development/Review. Each of the six technology providers that were awarded task orders prepared a detailed Demonstration Work Plan that was evaluated by the PET against the full set of Demonstration Selection Criteria: technical factors (process efficacy; worker health and safety; human health and environment); and business factors. Besides the likelihood of conducting a successful demonstration based on the evaluation, the constraint of program resources also was used to determine which technologies continued into the demonstration phase. Based on the evaluation of each of the Demonstration Work Plans and a determination of best value to the government, three technology providers were awarded task order contracts to conduct demonstration testing: Burns and Roe, General Atomics, and Parsons/AlliedSignal.[3] Descriptions of the three technologies are provided in Section B.4.

B.2.2 Information Sources and Final Evaluation Process

B.2.2.1 Information Sources

This evaluation report is based on data and information from a variety of sources, including the results of the demonstration tests. Figure B.2-2 depicts the information sources used to conduct the evaluation. Information sources were available prior to demonstration and following demonstration. The results of the demonstration tests were captured in several documents from the DWG, the technology providers, and organizations that provided some of the government furnished material for demonstration. Citations for all these reports can be found in the References section.

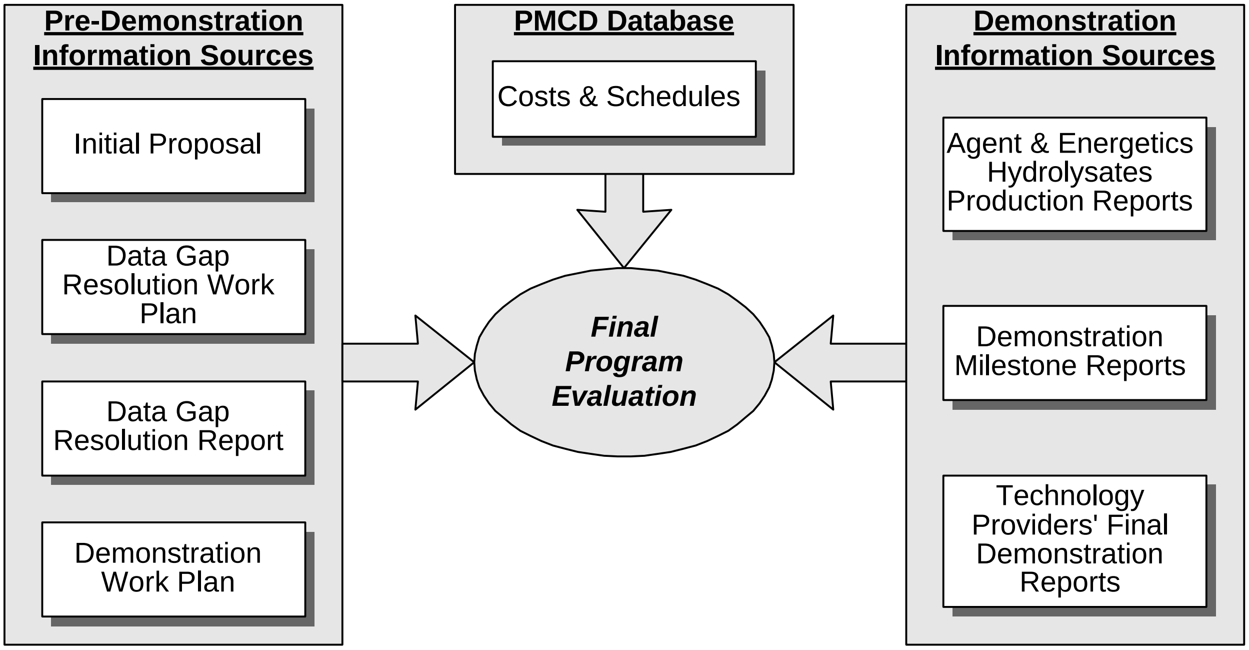

Figure B.2-2. Sources of Information for the ACWA Evaluation Process

The DWG provided two sets of Milestone Reports capturing detailed demonstration information for each technology provider. The first set of milestone reports described activities related to the equipment installation and systemization, and the second set of milestone reports described the demonstration test activities and the results of the demonstration tests. The DWG also maintained a master database of all analytical chemistry results obtained from demonstration. Each technology provider also prepared a Final Technical Report that incorporated the results of the demonstration tests with other information generated throughout the program. The government organizations that provided the hydrolysates for chemical agent and energetics feeds also provided reports documenting their efforts and results.

B.2.2.2 Final Evaluation Process

For the Final Evaluation, the PMACWA continued the process that was used successfully during Phase 2 (see Figure B.2-3). The PET (see Attachment B-A), consisting of members of the TET, the DWG, and the ET, worked with the CATT to conduct and obtain consensus for the Final Evaluation against the Program Implementation Criteria. Each group was responsible for a portion of the nineteen factors that comprised the Program Implementation Criteria (see Attachment B-B). The TET developed, coordinated, and reached consensus with the CATT, DWG, and ET on the input for factors 1-16 relating to Process Efficacy, Worker Health and Safety, and Human Health and Environment. The DWG developed and coordinated input for factors 17-18 regarding Cost and Schedule, and reached consensus with the CATT and TET. Meeting with the PET during essential portions of the evaluation process, the CATT worked in close coordination with the PET throughout the evaluation process. The Dialogue provided input for factor 19 regarding Public Acceptability on a site-specific basis during the Dialogue meeting in Washington, DC on August 25-28, 1999.

For each of the nineteen factors, a set of guidelines was developed and mutually agreed upon by the CATT and PET. For the purpose of assessing the three technologies in the current evaluation, these guidelines were applied to both the historical and demonstration data.

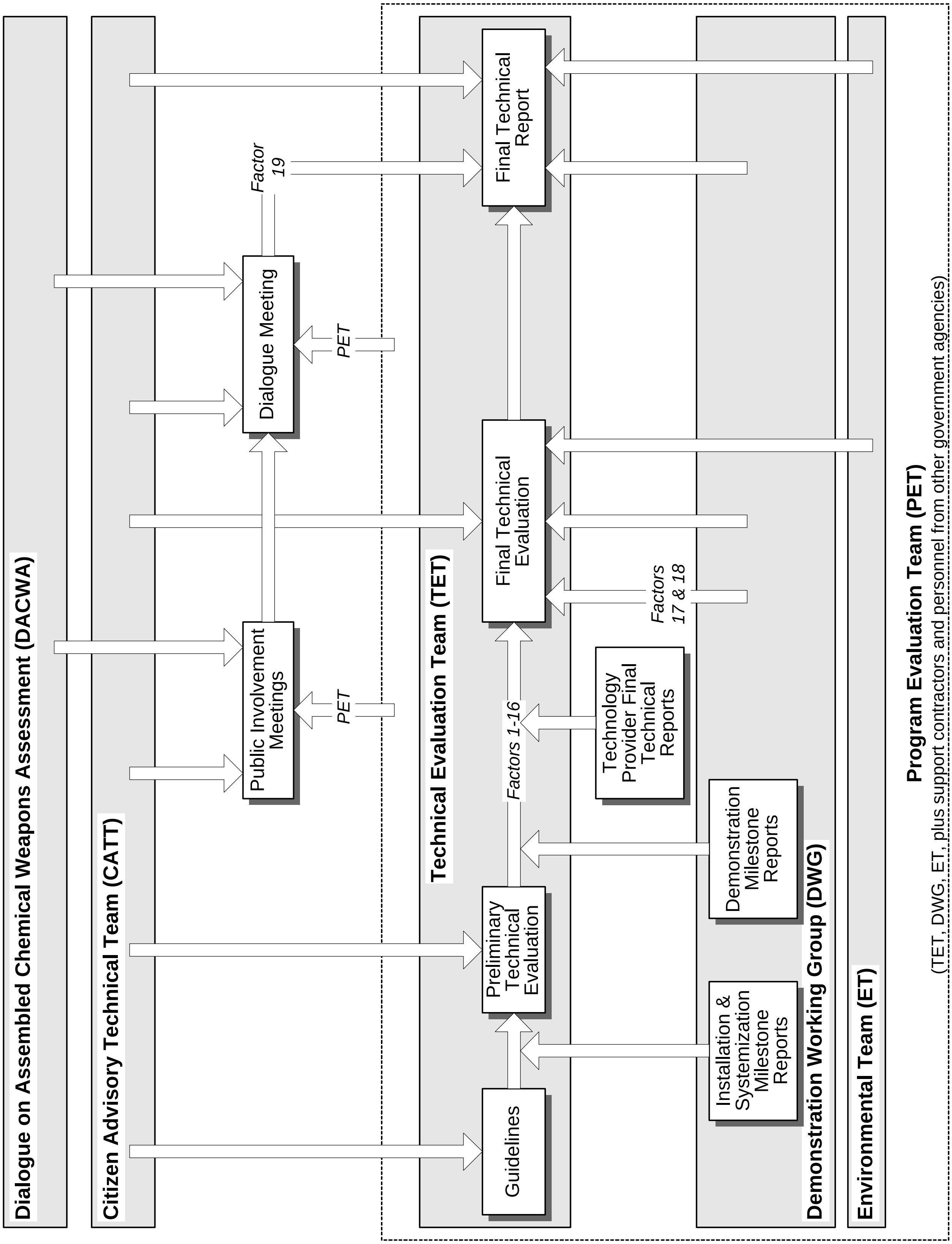

Figure B.2-3. Final Evaluation Process for ACWA Technologies Selected for Demonstration

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B.3 Demonstration Preparations and Testing

The demonstration testing phase of the ACWA program began with the award of tasks to teams led by Burns and Roe, General Atomics, and Parsons/AlliedSignal on July 29, 1998. Because of the constrained program schedule, the demonstration planning activities were conducted concurrently with the technology evaluation process and continued after the award of task order 3. Equipment installation began in the fall of 1998 at the three demonstration test sites: the Dugway Proving Ground (DPG), UT; the Chemical Agent Munitions Disposal System (CAMDS), Deseret Chemical Depot (DCD), UT; and the Edgewood Chemical and Biological Center (ECBC), Aberdeen Proving Ground (APG), MD. Demonstration testing started in early February 1999 and was completed on May 12, 1999.

B.3.1 Demonstration Goals

It is important to note how ACWA defined technology demonstrations. PMACWA determined that testing of a fully integrated system, from start to finish, was unnecessary because many of the technologies proposed to incorporate proven unit operations. PMACWA also decided that the tests would be conducted independently by government personnel in government test facilities. This meant that existing facilities had to be used because the aggressive ACWA schedule and budgetary constraints precluded the construction of any new test facilities. The ACWA technology demonstrations, then, were designated to be a series of tests on critical, less proven unit operations to show their effectiveness and repeatability and to establish confidence that they could be incorporated into an overall system or "total system solution." The purpose of this phase was technology demonstration, not development testing. The unit operation selections were based on information (test scale size, use of readily available equipment, prior test data, technology maturity, etc.) in the technology providers' original proposals and in their DGRRs.

Based on this definition of demonstration, the following goals were established for the demonstration tests:

- Independent validation of selected unit operations needed to achieve the stated performance objectives for a technology;
- Characterization of major feed materials, intermediates, and final products/effluents;
- Independent validation of analytical detection methods for agents and energetics used during demonstration testing; and
- Verification of the maturity and operability of the tested unit processes.

B.3.2 Demonstration Planning

The PMACWA staff worked in an iterative process with test installation representatives, PMACWA contractors, members of the CATT, and the technology providers in performing detailed planning activities.

The primary product of the demonstration planning process was a Demonstration Test Matrix (test matrices) for each technology provider. These matrices were carefully developed so that the technology demonstrations could meet requirements of PL 104-208 and be responsive to the Program Implementation Criteria. Specific elements of the test matrices included the following:

- Unit operations to be demonstrated,
- Feed materials (type and quantity),
- Test location(s),
- Number/duration of test runs,
- Process monitoring parameters,
- Utility requirements,
- Operating personnel requirements,
- Sampling locations/methodologies/frequency,
- Analytical methodologies/validation,
- Quality Assurance/Quality Control (QA/QC) program,
- Data requirements/reduction, and
- Final report requirements.

B.3.3 Global Demonstration Issues

In addition to the goals and constraints described above, several considerations were identified during the demonstration planning process and that were generic to all the technologies to be demonstrated. The major issues and considerations are summarized below:

- Facilities. Due to the nature of the demonstration program requiring use of agent and energetics, and the need to maintain government control in conducting the testing, there were a limited number of qualified facilities. The units to be tested were therefore constrained by the capacity of these available facilities. The demonstration equipment needed to be configured so that tests could be carried out in the designated facility and meet all requirements associated with that facility.

- Analytical Methods and Procedures. The technology providers were responsible for providing all analytical methods and procedures for the constituents in each test. Any nonstandard method needed to be validated in an independent laboratory designated by the government prior to its use in the analysis of any demonstration samples. In some cases, samples were not able to be analyzed because standard methods did not exist, and new methods were not validated.

- Hydrolysate Production. The government provided methods for and preparation of all agent and energetic hydrolysis reactions. Two of the three technologies chosen for demonstration involved hydrolysis of both agent and energetics. Agent hydrolysis was a government technology offered as part of a total solution. Because of this, the government provided these feeds. The energetic hydrolysate was also provided by the government due to the expertise within the government, the limited availability of demonstration site facilities, and the duplicate cost if demonstrations were conducted separately by both technology providers.

- Polychlorinated biphenyls (PCBs). PCBs were not tested as part of the demonstration because this would have triggered regulatory requirements under the Toxic Substances Control Act that would have added considerably to the cost and difficulty of the demonstration. It was anticipated that testing with pentachlorophenol (PCP) would provide information that could be extrapolated to the ability of treating PCBs. Therefore, PCP was used to simulate PCB-contaminated material for each technology tested.

- ☐ Baseline Operations. Processes used in the baseline operations such as reverse assembly, brine reduction, condensers, gas scrubbers, and carbon filtration are well established. PMACWA determined that it was not necessary to demonstrate these processes due to the extensive Army experience with these systems. Feed material was provided in the configuration anticipated from baseline or modified baseline reverse assembly.
- ☐ Environmental and Regulatory Compliance. Compliance was achieved at each demonstration site following all Federal, State, Army, local, and facility environmental regulations. The safety Standing Operating Procedure and the pre-operational survey ensured the application of environmental regulations. Operational activities, chemical method development, and waste storage and disposal followed all applicable environmental guidelines. In addition, the demonstrations were conducted as treatability studies coordinated with the states of Utah and Maryland to increase the amount of material that could be treated, in accordance with the Resource Conservation and Recovery Act (RCRA) treatability study regulation.
- ☐ There were several examples where environmental and regulatory compliance impacted the demonstration tests. As discussed above, PCBs were not tested. Another example concerned the method for producing the M28 propellant hydrolysate. The lead stearate from the M28 had to be added to the hydrolysate at the test site rather than at the site where the M28 hydrolysate was produced because EPA considers the lead stearate a hazardous material and restricts the quantities that can be shipped between test sites.
- ☐ Treaty Compliance. All related testing conducted under the ACWA Demonstration Program was done in compliance with the *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction*, referred to as the Chemical Weapons Convention or CWC and witnessed by Treaty Inspectors. The Organization for the Prohibition of Chemical Weapons (OPCW) Executive Council approved transparency measures to verify and document the fate of Schedule 2 compounds generated in the neutralization processes. In addition, a modification to an existing Facility Agreement was approved for the agent related testing that was planned for one of the technology providers.

B.3.4 Demonstration Testing

Equipment installation and systemization began at each of the test sites in the fall of 1998. The actual demonstration tests were conducted from early February 1999 to May 12, 1999. Figure B.3-1 contains an overview of the activities that occurred during demonstration testing, as well as the documentation corresponding to each activity.

Throughout demonstration testing, issues surfaced that required modifications to the test matrices for each technology provider. Changes to the test matrices were developed by the technology provider, reviewed by the PMACWA staff and support contractors, and then discussed with the CATT prior to the change being approved and incorporated.

Because the demonstration tests involved technologies that, to varying degrees, are new to chemical demilitarization, there were modifications made to the test matrices to accommodate schedule slippage, operational issues, and equipment failures. Although these types of modifications were made throughout demonstration, all planned unit operations were tested. In addition, most of the planned analytical samples were taken. In all, the demonstration test resulted in:

- The collection of approximately 2,300 samples for chemical characterization,
- Approximately 11,500 sample analyses, and about 210,000 analytical data results.

Analytical samples were sent to one of nineteen laboratories to support the demonstration test results. As discussed previously, details regarding the demonstration test activities are described in the second set of Milestone Reports.

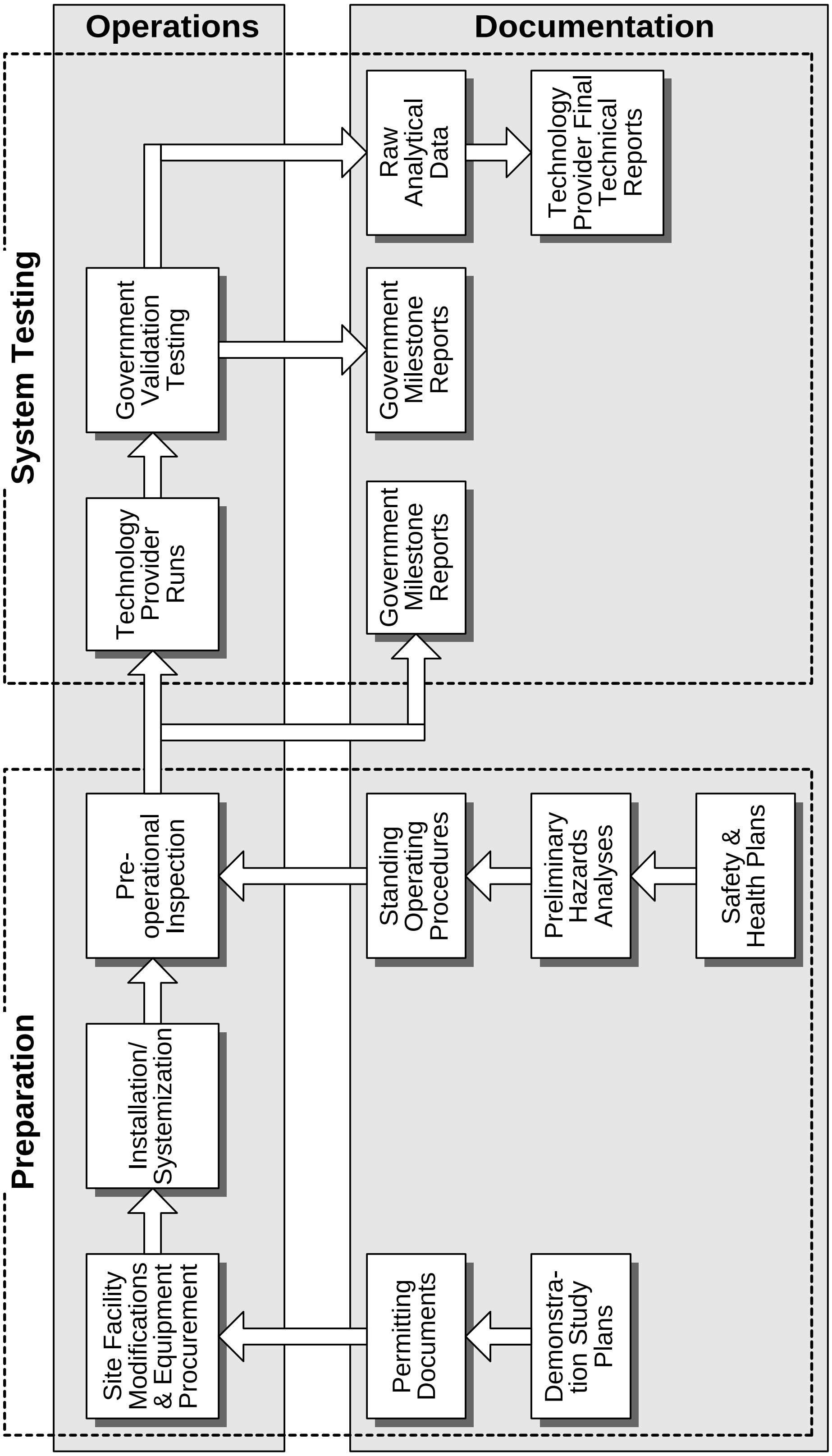

Figure B.3-1. Demonstration Testing Activities and Documentation Included in Evaluation

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B.4 Technical Evaluations

The final evaluation process is based on the process used successfully for Phase 2 of the ACWA Program. The principal differences from the previous evaluations are:

- The use of the Program Implementation Criteria (see Attachment B-B), which expanded the Demonstration Selection Criteria by reorienting them to include issues related to implementation of the technologies
- The availability and use of actual data from the demonstration testing—the primary source of information for these evaluations

The following discussion describes important points relative to the Program Implementation Criteria.

Process Efficacy/Process Performance. Many of the demonstration test objectives were selected to specifically address the criteria found in the Process Efficacy/Process Performance section of the Program Implementation Criteria. This allowed for a direct evaluation of many of these criteria with quantifiable data. Some extrapolation was required for the evaluation of the Process Maturity and Process Operability criteria. The Sampling and Analysis evaluation (see Attachment B-C) is based on whether or not the various sampling and analysis methodologies and techniques required to characterize the chemical substances in the process are verified and validated. During the ACWA demonstration, each non-standard sampling and analysis method was subject to validation testing prior to any use of the method on actual test samples. In addition, all data obtained during demonstration was subject to quality control (QC) validation. The performance of the ACWA samples during QC validation verifies whether or not the method worked in practice.

Worker Health and Safety. The evaluation of the criteria found in the Worker Health and Safety section focused on the hazards inherent to the process and the technology providers' engineering design attributes and operational strategy that mitigate or eliminate potential exposure or accidents. Since the demonstrations were only short-term representations of the critical processes and not full-scale, completely integrated technologies, the data generated from demonstration were, as expected, insufficient to support quantitative assessments of safety criteria. As such, guidelines were previously developed to provide a qualitative assessment. In industry, secondary containment (that provided by the facility) design and administrative procedures are used to mitigate or eliminate most hazards associated with process systems. Since the RFP did not identify a specific facility or provide theoretical facility design characteristics, the technology providers' design and process control attributes were paramount. The main discriminators among the technologies were innate containment capabilities; inherent physical hazards; potential health and physical hazard exposures associated with process chemicals, intermediates, and products; process monitoring and control responsiveness and sensitivity; reaction stability; and scope of required operator interfacing. Intrinsically safe technologies eliminate or greatly reduce the need for secondary containment or personal protective equipment (PPE) and therefore received evaluations that are more favorable.

Human Health and Environment. The evaluation of criteria in the Human Health and Environment section involved the use of characterization data from demonstration, as well as the technology providers' proposed plans for the implementation of their technology at a particular site. The effluent characterization and its impact on human health and environment were addressed using effluent characterization data from demonstration. For each of the constituents found in the effluent, regulatory standards were used as indicators for the hazard assessment. Demonstration data and the technology provider's Final Technical Reports were used to evaluate the completeness of the material balance, the effluent waste management plan, and environmental compliance and permitting experience. Some of the evaluations were made using historical data along with a level of understanding of the proposed process for handling waste. The resource requirements were evaluated using data for each unit operation, appropriately scaled-up for full system operations. The projections of water and fuel use are approximate and allow only a qualitative evaluation.

Potential for Implementation. The evaluation of criteria in the Potential for Implementation section was based on the technology providers' proposed plans for implementation, including cost and schedule projections, and the feedback from the public at the sites of concern. For implementation of alternatives to baseline incineration at Pueblo, Colorado and Blue Grass, Kentucky, an independent cost and schedule analysis was performed. An independent analysis was developed because the cost and schedule information provided by the technology providers was not of sufficient detail to conduct a reliable and consistent evaluation. This analysis applied a consistent set of assumptions and ground rules to the alternative technologies, as well as to the baseline plants for those sites (see Attachment B-D). Site specific feedback on the potential public acceptability of each of the technologies was gathered in a series of public meetings held at each of the ACW stockpile sites at the conclusion of the demonstration tests. Dialogue members used feedback from the public meetings, as well as information from the August 1999 Dialogue meeting, to provide site specific input regarding the public acceptability of each technology.

The discussion above provides the focus and framework for the final evaluation for each of the technologies in the following sections.

B.4.1 Burns and Roe Plasma Arc Process

This section of the technical evaluation report covers the description and evaluation of the technology proposed to PMACWA by the team headed by Burns and Roe.[4] The team includes Burns and Roe (engineering design and construction), STARTECH Environmental Corporation (plasma arc provider), Foster-Miller (mechanical feed system design), and The Ensign-Bickford Company[5] (process engineering and testing).

B.4.1.1 Description of the Proposed Technology

The plasma arc process uses modified baseline reverse assembly for munitions access. Agent, energetics, metal parts, and shredded dunnage are all treated in plasma waste converters (PWCs). The PWCs use a plasma arc technology—electrically driven torches that produce an intense field of radiant energy causing the dissociation of chemical compounds.[6]

B.4.1.1.1 ACWA Total Solution

As shown in Figure B.4-1, the plasma arc process includes operations from the unpack area to effluent management. The process is a combination of the Army's baseline reverse assembly process, a thermally initiated, controlled detonation chamber, and PWCs to access and destroy all components of ACWs. Multiple PWCs operate in parallel to destroy the different components of the ACWs. The gaseous products of the PWCs are treated in a pollution abatement system and then made available for reuse as a cleaned synthesis gas. The solid products from the process are landfilled or recycled from molten metal ingots.

Munitions access uses baseline reverse assembly followed by thermal initiation of the energetics. Reverse assembly is incorporated in its entirety for all munitions. High-explosive components (fuzes, bursters, supplemental charges, and landmine components) are first segregated from other hardware and the M28 rocket propellant and are then thermally initiated in the Explosive Detonation Chamber (EDC), a controlled detonation chamber. Wooden pallets are first shredded. PWCs treat four, separate waste streams. PWCs are refractory-lined vessels that are heated with one or two plasma arc torches operating in the transferred arc mode. Nitrogen, the plasma gas medium, serves also to purge the PWC vessels during operations. Organic material is vaporized and inorganic solids are melted or evaporated. Steam is added to the PWCs to reform disassociated elements into Plasma-Converted Gas (PCG), a flammable synthesis gas. Drained chemical agent and spent decontamination solution are fed through a port in the side of the Agent/Decon Demil System (PWC A). Sheared rocket motors containing the M28 propellant as well as hardware/shrapnel and off-gas from the EDC are fed to the Energetic Demil System (PWC B) via an inclined ram feed chute. Offgas from the EDC is fed directly to PWC B. Drained projectile bodies are fed to the Projectile Demil System (PWC C) via a horizontal ram feed chute. A screw conveyor transfers shredded dunnage to a ram feed chute where solid processing wastes are added and fed to the Solid/Dunnage Demil System (PWC D).

A dedicated PCG Collection and Utilization System processes PCG from each PWC. Each system consists of particulate removal, caustic scrubbing, and a scrubber system for removing oxides of nitrogen (NOx) with a hold and test capability. PCG, a flammable synthesis gas (consisting largely of carbon monoxide, hydrogen, and traces of methane), can be reworked through the respective PWC if necessary; but typically it is stored and used as fuel for heating (combustion in a boiler). Combustion gases from the boiler are scrubbed before release to the atmosphere. Metals are precipitated from the scrubber brine with the remaining water evaporated to the atmosphere in the Brine Reduction Area (BRA). Precipitated metals and particulates are vitrified in sand in a PWC. Molten material continuously flows from PWC C (to offset projectile feed) and is periodically removed from PWC B and PWC D. Molten material is collected in ladles and allowed to cool, forming 5X slag and/or metal ingots. Vitrified slag is landfilled, and metal is commercially recycled.

The deviations from the original design include the following:

- Plasma gas medium changed from argon, temporarily to carbon dioxide, and finally to nitrogen
- Plasma arc torch operated in the transferred, instead of non-transferred, mode
- PWC liquid feed via side port instead of through the plasma torch itself

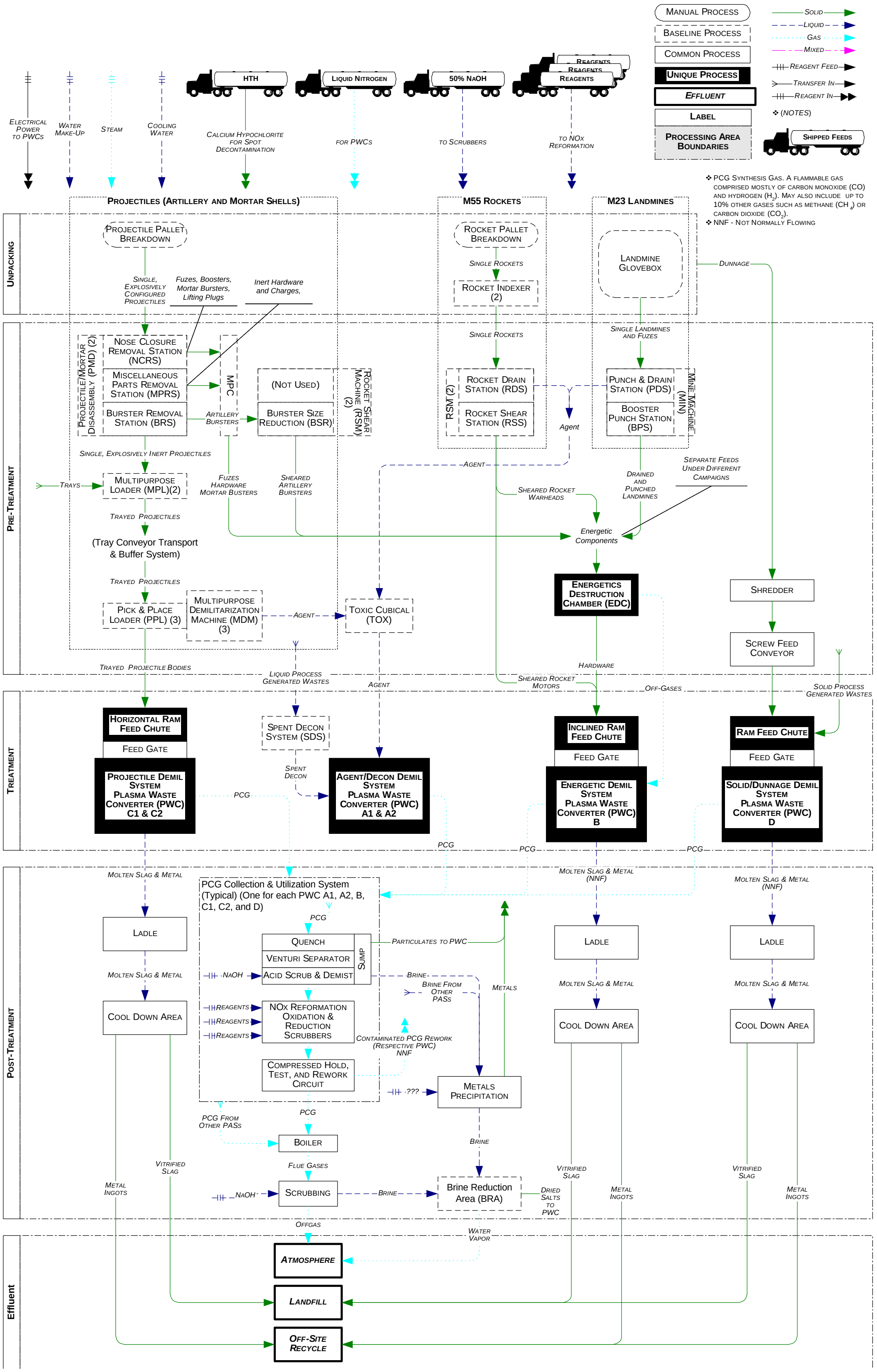

Figure B.4-1. Burns and Roe Plasma Arc Process Flow Diagram

- PWC automatic control strategy refined
- NOx reduction scrubber system added
- Metals precipitated from scrubber brine by chemical reagent treatment

B.4.1.1.2 Unit Operations Not Demonstrated

As previously discussed, baseline reverse assembly, carbon filtration, and the BRA were not demonstrated. Some unit operations proposed by Burns and Roe were not selected for demonstration. The reasons PMACWA elected to not demonstrate these units are as follows:

- **Size-Reduction (Shredder).** This is common commercial equipment used for marginal size reduction of material simply to transfer through the PWC feed gates. Although size reduction was not demonstrated, material was shredded off-site as a feedstock for demonstration.
- **Screw Transport/Feed Unit.** This is common commercial equipment. Materials transport of the proposed feeds is not expected to be particularly challenging.
- **Energetics Destruction Chamber (EDC).** The Bofors-Dynasafe SK1200 Static Kiln is a commercially available system with a fairly basic design premise. Although this particular unit was not demonstrated, characterization of the off gas expected from this unit was conducted during demonstration using an explosives initiated, controlled detonation chamber, the Energetics Deactivation Chamber (also referred to as an EDC).
- **NOx Reduction System.** This commercially available system was added as part of the final design in response to results from demonstration testing and was not demonstrated.
- **Brine Metals Precipitation.** This is a common operation using chemical reagents. It was added as part of the final design and was not demonstrated.

B.4.1.1.3 Unit Operations Demonstrated

This section explains the rationale for selecting the unit operations for demonstration of the plasma arc system, the objectives of testing, and significant deviations from the planned testing.

The PWC demonstration system, shown in Figure B.4-2, is an integrated system consisting of the following:

- **PWC.** One, multipurpose 300-kW PWC was used to demonstrate the four, separate units proposed. This unit had a horizontal ram feed for solids, as proposed, but liquids were fed through the steam injection system rather than being fed through the torch, as originally proposed. The arc system was capable of both non-transferred (arcing from electrode to electrode on the torch) and transferred modes (arcing from torch electrode to an electrode in the melt) of operation.
- **Gas Polishing System (GPS).** The PWC exhausted to the GPS, a typical pollution abatement system consisting of a venturi quench/scrub tower and an acid gas scrubber using a common caustic sump. Scrubbed gases are passed through a high efficiency particulate air (HEPA) filter, with the addition of a hold, test, and release/rework (HT&R) tank, before being transferred to the thermal oxidizers for combustion.

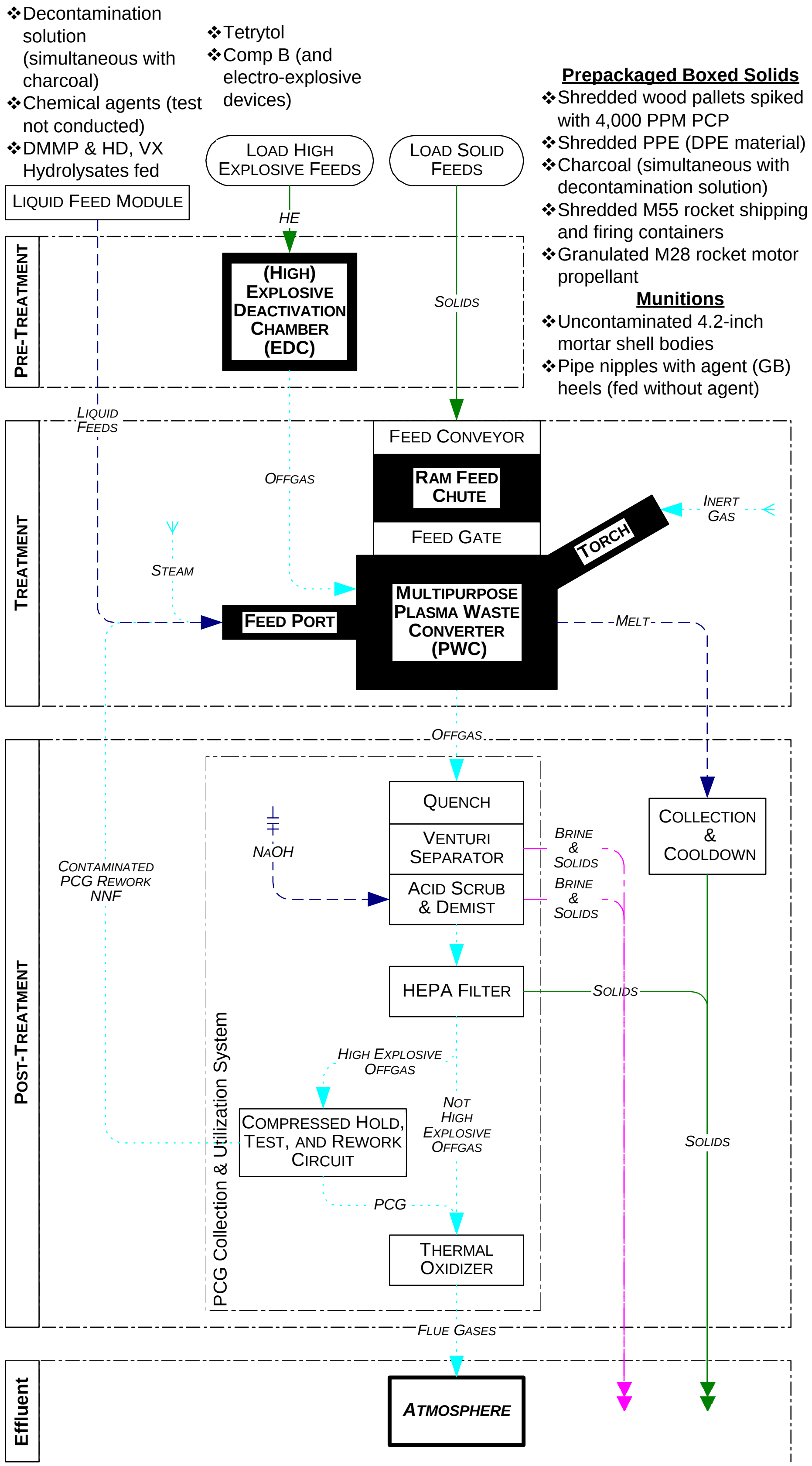

Figure B.4-2. Plasma Arc System Demonstration Process Flow Diagram

- **Liquid Feed Module.** This system supplied only liquid feed to the PWC and was not intended to demonstrate a specific unit operation.
- **Box Feed Module.** This system consists of, and represents, the feed chain conveyor, ram feed chute, and feed gates. Boxes are manually loaded on the conveyor for automatic feed to the PWC. This process varies slightly from the screw feed system proposed. Air and nitrogen purge/cooling were added to the box feed module during demonstration.
- **Thermal Oxidizers (TO).** These systems were used only during demonstration to burn the PCG for characterization of the effluent and were not intended to demonstrate a specific unit operation (such as plant boilers). The inside thermal oxidizer (ITO) was in the test chamber and the outside thermal oxidizer (OTO) was outside the facility.
- **Energetics Deactivation Chamber (EDC) (EDC Offgas Feed Simulator).** This system only generated and supplied the expected energetics offgas feed to the PWC and was not intended to demonstrate a specific unit operation. This device is an explosives-supplemented, controlled detonation chamber that generates explosive offgas for feed to the PWC. Explosives representative of ACWA feeds are detonated in the chamber using supplementary electroexplosive devices. The gases produced are vented to the PWC.

The unit operations described above functioned as an integrated process with an automated control and data acquisition system. The EDC and the HT&R systems were used only for high-explosive energetics (i.e., Composition B (Comp B) and Tetrytol) runs. Instrumentation consisted of two Analyzers and two Automated Gas Sampling Systems each for the PCG and the Thermal Oxidizers.

The Burns and Roe team was required to demonstrate the ability of the PWC system to irreversibly destroy ACWA feeds. The demonstration campaigns were divided into two classes: nontoxic campaigns and toxic campaigns. For all campaigns, the primary objective was steady state conditions of a duration long enough to obtain the required data. One confirmation, or “work-up”, run was allowed at the beginning of each campaign followed by three validation runs (four runs total). Initial confirmation runs were required for characterization of the energetics. Nontoxic campaigns were scheduled before toxic campaigns. The four demonstration campaigns were planned to run as follows:

Energetics Campaign. This campaign was required to validate that the PWC can destroy offgas from the proposed EDC, which is used for thermal initiation of high explosive components (bursters and fuzes). The test objectives for this campaign were as follows:

- Demonstrate the feasibility of the proposed energetics destruction strategy using the integrated EDC demo unit and PWC system for high explosives and the PWC system for M28 propellant.
- Validate the ability of the integrated EDC and PWC unit operations to achieve a destruction removal efficiency (DRE) of 99.999% (five 9s) for energetics Comp B and Tetrytol.
- Validate the ability of the PWC unit operations to achieve a DRE of 99.999% (five 9s) for M28 propellant.
- Characterize the detonation gases and residues from Comp B and Tetrytol from the EDC

demo unit for suitability to be processed in the PWC.

- Characterize the deflagration gases from the M28 propellant feed to the PWC system.
- Compare the detonation gases from the EDC demo unit to the deflagration gases from the M28 propellant in the PWC system.

These runs required that each high explosive (Comp B and Tetrytol) be detonated in the EDC at 16 gram (gm) per shot (20 shots for 320 gm total). The M28 propellant runs required boxed, 0.25-lb lots of granular feed delivered automatically to the PWC at set intervals at a rate of 5 lb/hr for 2 hours (10 pounds total).

Significant deviations from the planned demonstration testing included the following:

- The plasma torch medium was changed during this campaign from carbon dioxide to nitrogen, which was used for the remainder of the demonstration.
- The plasma torch anode was changed from copper to silver, also retained for the rest of the demonstration.

Dunnage and Secondary Waste Campaign. This campaign was required to validate destruction of solid and liquid secondary wastes and the decontamination dunnage to a 5X level. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters.

The objectives of the demonstration testing included the following:

- Demonstrate the ability of the PWC unit operation to process carbon filter media, PPE (Demilitarization Protective Ensemble [DPE] material), wooden pallets spiked with 4,000 parts per million (PPM) PCP, decontamination solution with carbon filter media, and M55 rocket shipping and firing containers.
- Characterize the process gases, liquids, and solids.
- Validate the ability of the PWC unit operation to meet a 5X condition of solid residues from these feeds.

These runs required feed of 100 lb/hr for 2 hours (800 pounds total for one workup and three validation runs). Demonstration required solid feeds to be size-reduced (shredded) where necessary and subdivided into cardboard boxes (off site by the vendor) for automatic feed to the PWC at set intervals (126 boxes/hr).

Significant deviations from the planned demonstration testing included the following:

Solid and liquid wastes were combined for simultaneous feed to expedite the process. Individual boxes of materials were fed in a specified sequence to the PWC simultaneously with spent decontamination solution.

Agent Campaign. This campaign was required to validate destruction of chemical agents. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives for this campaign included the following:

- Validate the ability of the PWC process to achieve a DRE of 99.9999% (six 9s) for chemical agents HD, GB, and VX.
- Characterize the process gases, liquids, and solids.
- Balance the elemental carbon and heteroatoms from each agent to the extent possible.

These runs required GB and HD agents to be separately fed at 50 lb/hr for 2 hours per run (400 lb total) and VX be fed at 17 lb/hr for 2 hours per run (136 lb total).

Significant deviations from the planned demonstration testing included the following:

- Chemical agents were not processed.
- GB chemical agent simulant DMMP was processed.
- Hydrolysate from VX caustic neutralization was processed.
- Hydrolysate from HD water neutralization was processed.
- The plasma arc torch was changed from non-transferred mode to transferred mode during this campaign and for the rest of demonstration. The change was made for the Projectile Heel Campaign (discussed below), which was conducted midway through the HD hydrolysate runs.

Projectile Heel Campaign. This campaign was required to validate destruction of chemical agent adhered to metal parts and demonstrate removal of the melt from the PWC. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives for this campaign included the following:

- Validate the ability of the PWC process to achieve a DRE of 99.9999% (six 9s) for chemical agent GB heels in simulated projectile shells.
- Demonstrate the ability of the PWC to process simulated projectile shell heels using chemical agent in pipe nipples.
- Demonstrate melting of uncontaminated 4.2-inch mortar shells.
- Validate the ability of the PWC unit operation to meet a 5X condition for solid residues from this feed.
- Characterize the gases, liquids, and solids.
- Demonstrate the ability to remove the melt from the PWC; however, samples of the melt were manually removed.

These runs required that 15 simulated mortars with 0.15-lb GB heels be fed in 2 hours. Uncontaminated mortars were to be placed into cardboard supports and fed to the PWC. Following this campaign, automatic pouring of the melt was to be demonstrated. The purpose of this test was to ensure that rapidly volatilized chemical agent will be destroyed by the PWC and not blown through to the PAS.

Significant deviations from the planned demonstration testing included the following:

- Only uncontaminated material was processed.

- The melt was not removed by pouring from the PWC; however, samples of the melt were manually removed.

General Objectives. The following represent general requirements of the PWC demonstration. These were used for scale-up for the proposed full-scale system.

- Evaluate the impact of operations on refractory life.
- Characterize the gas, liquid, and solid process streams from the PWC for selected chemical constituents and physical parameters and for the presence/absence of hazardous, toxic, agent, and Schedule 2 compounds.
- Data Collection. Parameters to be studied included a variety of analytes in both the gas and solid effluents. Process parameters for demonstration include power, plasma medium, steam, neutralizer, PCG quantity, etc.

There were no significant deviations from the planned demonstration general objectives.

B.4.1.1.4 Demonstration Testing

Throughout the demonstration, there was equipment and operational redesign of the PWC system. As stated earlier, these redesigns included (1) a change in the plasma gas to nitrogen, (2) a change in the materials of construction for the torch anode to a silver alloy, and (3) a change in the operating mode of the system from the non-transfer to the transfer mode of operation. These redesigns were necessary because of equipment failures.

Delays throughout the test program were attributed to these equipment failures, system redesigns, and an inadequate design of the GPS, which required frequent modifications. The result was a shortened test window, which had a significant impact on the demonstration test objectives. The first major change to the test objectives was to the dunnage campaign. The solids and liquids for the dunnage and secondary waste runs were combined for simultaneous feed to the PWC (instead of processing each dunnage feed separately) to recover from some of the lost time.

The second major change to the test objectives was the elimination of the agent campaigns and addition of agent simulant and agent hydrolysates. This change was made for two reasons. First, by the scheduled start of the agent campaign the operability, reliability, and repeatability of the system had not been demonstrated due to equipment failures, system redesigns, and operational modifications. It was determined that this operational data was critical and should be demonstrated. Second, any failure occurring during agent testing would very likely jeopardize the brief remaining test period, forfeiting any remaining testing and losing the opportunity for collection of valuable operational data. This is because the test facility and equipment would require time consuming agent decontamination and higher levels of PPE for workers conducting the repairs. It was therefore determined that testing should continue using only simulant and agent hydrolysate and no chemical agent.

In summary, major redesign of equipment caused notable delays that, in turn, shortened the available test window and required modifications to the test objectives. Many of the delays were demonstration specific and are not applicable to full-scale operations. The problems that occurred during demonstration mostly related to equipment failures. The consequence of the setbacks prevented completion of a number of demonstration objectives and some that were completed are questionable due to frequent modification to operating conditions between and during tests. Consequently, there was insufficient time in the schedule to conduct toxic campaigns, although agent simulants and hydrolysates were processed.

B.4.1.2 Technical Evaluation

B.4.1.2.1 Process Efficacy/Process Performance

B.4.1.2.1.1 Effectiveness

The effectiveness of the PWC has not been fully tested with representative materials from ACWs. While successful demonstration testing of energetics, metal parts, and dunnage were performed, no chemical agent testing was conducted.[7] There were no validation data for the agents of concern.

Agent simulant and hydrolysate testing provided limited data to indicate that the process should be capable of destroying agent. In agent simulant testing, dimethyl methylphosphonate (DMMP) was not detected in the PCG, scrubber solution, or moisture knock-out trap sample with detection limits of 35 $\mu g/m^3$ or lower, 0.014 mg/L, and 14.6 ng/L respectively.[8] This indicates a destruction efficacy of greater than 99.99997% for DMMP, which is a simulant for GB. This DRE and the similarity between GB and DMMP with respect to the vapor pressure and chemical bonds to be thermally broken are an indication of the ability of the PWC to destroy GB. HD and VX hydrolysate were also processed through the PWC. Trace levels of thiodiglycol (TDG) were detected in PCG samples in two of the six HD hydrolysate runs. However, the concentrations are significantly below the method detection limit where the measurement errors are the greatest; and there is evidence that the TDG in the liquid knockout trap may be the result of field contamination of the gas samples. At the conclusion of the HD hydrolysate testing campaign, no TDG was detected in the scrubber solution (at a detection limit of 9.8 mg/L) or the scrubber solids (at a detection limit of 10 μg/g). No destruction efficacy has been reported for TDG, but this provides support to indicate that the PWC could destroy HD. In VX hydrolysate testing, ethyl methylphosphonic acid (EMPA) was not detected at levels of 14 mg/m^3 or lower. Methylphosphonic acid (MPA) was not detected at levels of 32 mg/m^3 or lower.[9] No EMPA was detected in the scrubber solution (at 9.4 mg/L) or the scrubber solids (at 100 μg/g) at the conclusion of the campaign. No MPA was detected in the scrubber solution (at 21.5 mg/L) at the conclusion of the campaign. No destruction efficacy could be calculated for EMPA or MPA, but this provides limited support to indicate that the PWC could destroy VX.

The results of the energetics testing validated greater than 99.9998% destruction with energetics Comp B and Tetrytol. In Comp B testing, RDX was not detected in scrubber solution at a detection limit of 0.0005 mg/L and was detected in scrubber solids at a level of 0.44 μg/g. This indicates a destruction efficacy of greater than 99.99987% for RDX. TNT was not detected in scrubber solution at a detection limit of 0.0005 mg/L. However, TNT was detected in scrubber solids at a level of 0.3 μg/g, but may be an artifact of analytical interference. This indicates a destruction efficacy of greater than 99.9998% for TNT.[10] In Tetrytol testing, tetryl was not detected in scrubber solution at a detection limit of 0.0005 mg/L or in scrubber solids at a detection limit of 0.13 µg/g. This indicates a destruction efficacy of greater than 99.99991% for tetryl. TNT was not detected in scrubber solution at a detection limit of 0.0005 mg/L or in scrubber solids at a detection limit of 0.13 µg/g. This indicates a destruction efficacy of greater than 99.9998% for TNT.[11] Propellant testing also showed that nitrocellulose was not detected in scrubber solution at a detection limit of 5 mg/L or in scrubber solids at a detection limit of 50 mg/kg. Nitroglycerin was not detected in scrubber solution at a detection limit of 0.0005 mg/L or in scrubber solids at a detection limit of 0.12 µg/g. These results validated greater than 99.97% destruction with M28 propellant for nitrocellulose, and greater than 99.99998% destruction for nitroglycerin.[12] The nitrocellulose portion of the M28 did not achieve greater than 99.999% destruction due to a high detection limit.

The results of the metal parts testing performed with 4.2-inch mortar shells validated effective 5X decontamination of metal parts. Mortar shells were fed into the PWC at 6- to 15-minute intervals and were visually observed to melt.[13] Fiberglass shipping and firing containers from rockets were destroyed in the PWC during the dunnage test.[14] Although no metal parts contaminated with agent or energetics were tested (as planned), the fact these parts were melted at a temperature exceeding 1,000°F and held as molten metal within the PWC for over 15 minutes indicate that a 5X level of decontamination occurs. This supports the conclusion that the PWC is effective for the decontamination of chemical weapons hardware.

The results of the dunnage testing validated effective 5X decontamination with all selected materials. PCP-spiked oak pallet material, activated charcoal, fiberglass shipping and firing containers, and material from DPE were destroyed in the PWC during the dunnage test.[15] There was no agent-contaminated dunnage tested for demonstration, as planned.

The results of the testing validated that there was no sensitivity of the process with PCP-contaminated wood, nor with the impurities in energetics and HD and VX hydrolysates.[16] The robust nature of a thermal process should be insensitive to impurities. However, because no agent testing was performed insufficient data was obtained with agent impurities, additives, or mixtures of agents and energetics.

In summary, the EDC and PWC processes are effective in destroying energetics and effectively processing metal parts and dunnage; however, the lack of any agent data prohibits the complete validation of the system. Although agents have not been demonstrated, greater than 99.9999% destruction of simulant can be extrapolated to indicate the likely effectiveness with agent.

B.4.1.2.1.2 Products

Although only partially validated during demonstration, the proposed plasma arc process converts organic materials and steam into a plasma-converted gas (PCG), the major constituents of which are carbon monoxide, nitrogen, carbon dioxide, and hydrogen; the plasma-converted gas is then burned, giving predominantly carbon dioxide, nitrogen, and water. Chlorine, fluorine, sulfur, and phosphorus in the feed materials are converted into mineral acids, which are removed in the pollution abatement system as sodium chloride, sodium fluoride, sodium sulfide, and sodium phosphate.[17]

There was good characterization of the process for the demonstrated streams. Due to the omission of agent testing during demonstration, however, validation of products from agent runs was not possible. In addition, leakage of air into the PWC during demonstration caused an excess of oxygen over the desired level, which affected the chemical composition of the PCG.[18] Therefore, the entire process characterization can not be validated.

Although it is not known if Schedule 2 compounds are produced during the processing of agent, demonstration did provide validated data with respect to destruction of Schedule 2 compounds. DMMP, HD hydrolysate containing thiodiglycol (TDG), and VX hydrolysate containing EMPA and MPA were successfully treated to below detection limits.[19]

Hazardous intermediates for agent treatment were not characterized; however, other feeds did result in some hazardous intermediates. Although full-scale correlations are difficult to make, data from demonstration testing shows that the following hazardous substances were produced:[20]

- Formaldehyde—formed in the PWC at levels up to tens of µg/m^3 for most campaigns. The thermal oxidizer does not significantly reduce off-gas concentrations (hundreds of µg/m^3 to single-digit mg/m^3). These concentrations will need to be addressed for full-scale because of treatment and fugitive emissions.
- Carbonyl sulfide—produced in the PWC at up to hundreds of part per billion (PPB) levels during dunnage, HD hydrolysate, and VX hydrolysate processing. There were instances during demonstration where these levels were reduced to below detectable limits in the thermal oxidizer, however in certain instances the levels increased in the thermal oxidizer. This compound is a hazardous air pollutant.[21]
- Cyanide—produced in the EDC during energetics detonation at mg/m^3 levels which are decreased to hundreds of µg/m^3 in the PWC, but then increased in the thermal oxidizer to mg/m^3 levels. These levels are comparable to the lowest adverse chronic effect levels for occupational cyanide exposure.[22]
- Dioxins/Furans—produced in the PWC at up to single-digit ng/m^3 total dioxin levels (approximately 100 pg/m^3 toxic equivalency [TEQ] factor) during dunnage and HD hydrolysate processing, with levels increasing in the thermal oxidizer. Dioxins and furans can also accumulate to hundreds of ng/L levels in the GPS scrubber solution. These concentrations exceed concentrations associated with health effects,[23,24] although they are lower than typical incinerator effluent limits.[25,26]

In general, there was good characterization of process effluents for demonstrated streams. However, unavailability of any data from agent runs using the PWC prohibits validation of the process for this major feed. For other processed materials, hazardous intermediates were formed, but most are at acceptable levels at the demonstration scale. Some compounds may require further treatment to ensure acceptable levels for release at full scale.

B.4.1.2.1.3 Sampling and Analysis

Prior to the start of PWC testing, Schedule 2 compounds analysis methods were validated using a simulated scrubber solution. The proposed EDC and PWC operations use the following standard sampling and analysis methodologies:

- Standard on-site process monitoring instrumentation for high-level gas composition.
- Standard gas sample collection and analysis techniques for low-level agent, energetics, and other hazardous compounds in PCG.
- Standard liquid sample collection and analysis techniques for GPS solutions.
- Standard solid sample collection and analysis techniques for the PWC melt and other solid products.

During the PWC demonstration, most of the data generated has been deemed usable for evaluation of the technology and characterization of the process effluents. The level of verification for each type of analysis is given in Table B.4-1.

Table B.4-1. Level of Verification for Burns and Roe Analyses

Type of Analysis	Amount of Usable Data
Feed and Product Composition	Not validated for hydrogen, carbon monoxide, carbon dioxide, and oxygen
Low Level Agent	Not validated
Low Level Energetics	Acceptable
Hazardous Substances	Acceptable for scrubber solutions Less for PCG and thermal oxidizer gas

Several standard sampling and analysis methodologies did not perform acceptably during demonstration. For this reason, the ACWA demonstration was unable to validate or verify methodologies for the analysis of the following types of chemical substances:

- No agent testing was conducted during demonstration, so there is no indication of how the standard methods would have worked with the PWC matrices.
- Poor configuration of the gas sample collection equipment resulted in samples of questionable quality from the PWC. However, modification to the configuration to increase the quality of the samples collected is relatively straightforward.
- Due to unknown interferences, PCG and thermal oxidizer samples being analyzed for hydrogen cyanide by EPA SW-846 method 9014 and for hydrogen sulfide by EPA SW-846 method 9034 required additional sample preparation. This potentially causes the samples to be biased low.[27] Method 9034 for analysis of sulfides in scrubber solution could not be analyzed for energetic feeds due to the color of the matrix.[28]
- Zero percent recovery of the matrix spikes were reported for the analysis of the scrubber solution by Method 8315A for aldehydes and ketones are likely biased low.[29] The results of the analyses indicate that the matrix likely reacts with the carbonyl compounds. Further investigation of this issue is warranted.
- Low recoveries of surrogates and internal standards were reported for the volatile analyses of some gas and liquid samples. In addition, numerous matrix issues were reported for the semi-volatile organic analyses of gas and liquid samples. Review of the data indicated that there were some cases where laboratory performance rather than matrix issues was the source of the problem.[30]

- Difficulties with implementation of the measurement techniques used during demonstration were observed, particularly with the on-site instruments for the measurement of hydrogen, carbon monoxide, carbon dioxide, and oxygen. Therefore, the sampling and analysis methodologies and techniques were not verified for all constituents used in the mass balance; some method optimization will be required.

In summary, the sampling and analysis methodologies used during demonstration for the mass balance and for determining residual levels of energetics and other compounds of concern in the process matrices were in general acceptable, but some methods did not provide adequate levels of usable data. No agent testing was conducted during demonstration, so there is no indication of how the standard agent methods would have worked with the PWC matrices. Overcoming the analytical difficulties may require a method optimization effort.

B.4.1.2.1.4 Process Maturity

Pre-Treatment

The baseline reverse assembly system is fully developed for full-scale and requires only programming modifications. The EDC, a thermally initiated, controlled detonation chamber, will be the SK1200 detonation kiln, a commercially available unit from Bofors-Dynasafe. However, only one of the proposed SK1200 units has ever been built and operated and it has never processed feed representative of that proposed.[31] Little information was provided on how the EDC interfaces with the PWC or its compatibility with material transports (e.g., sheared munition hardware and resulting shrapnel).

Treatment

Plasma arc technologies and principles are mature and used in commercial/industrial applications.[32,33,34] Non-PWC components are common industrial equipment readily made-to-order or available off-the-shelf. A number of plasma arc furnaces have been built and tested and plasma arc torches are commonly used in the metallurgical industry. The principles of plasma arc have been tested on some materials that are representative of ACWA feeds (e.g., polymers and metals) at smaller scales.[35,36] The PWC components *represent* a mature technology, but the ACWA demonstration indicates that the proposed PWC configurations are not as mature as or comparable to their industrial counterparts.

The demonstration PWC was identical in size to the unit proposed for energetics and operated with approximately 1/13th to 1/2 of the feed rate proposed for full-scale feed of metals. However, demonstration indicates that the GPS was improperly designed for the demonstration PWC. As shown from the demonstration test matrix, mixed secondary wastes were decreased by 20% to prevent the offgas production from exceeding the capacity of the GPS.[37] The PWC itself may be capable of higher feed rates, but it was limited by the GPS throughput.

Although high explosives will be sent to the EDC, the process proposes sending propellant (sheared rocket motors) directly to the PWC. There is a lack of historical or industrial experience with processing explosive components in refractory-lined furnaces. This lowers the confidence in the technology provider’s analysis[38] showing that the propellant sections will deflagrate without any tendency to explode. Although the PWC successfully demonstrated destruction of granulated propellant, it should be noted that an explosive event, however unlikely, is still possible. The unknown probability of such an event is of concern. The conditions in the PWC (high temperature and high heating rate) and the explosion temperature of the propellant indicate an event is possible although none has yet occurred. Therefore, the PWC must meet explosion containment requirements. However, it is not apparent how this can be achieved since the high temperature exhaust of the PWC requires a refractory brick lined duct, which may preclude the use of attenuation ducts to mediate any explosive overpressure.

Post-Treatment

Gas and solid effluents are treated by common, commercial, emissions control systems. PCG is treated with the GPS (quench, scrub, filter, etc.) that is similar to the baseline including the BRA. Molten material tapping, collection, and cooldown are common foundry operations. The throughput limitations demonstrated by the PAS are not expected to adversely affect the full-scale system.

Scalability and Availability

Materials of construction are mostly common and components are commercial off-the-shelf or made-to-order. Proprietary designs include the liquid feed configuration, the refractory formulation, and the positioning of the plasma torch, all for the PWC. Scaling of the PWC to larger units appears straightforward, but it is unknown how many PWCs of various sizes have actually been manufactured by the provider. In addition, the PWC was not tested in the proposed configuration or with proposed feed materials and there is insufficient information to extrapolate applicability to a full-scale, integrated system. No suppliers for other equipment were provided and only generalized availability statements were made. Demonstration units were successfully assembled, but only with notable delays and complications.

Summary

Even though the PWC/GPS appears to be straightforward in design and operation, the lack of a sound technical basis for design and operations, the marginal operational performance to date, and the very limited industrial use of the proposed PWC configuration reduce the confidence that this process can be made to work as proposed.

The proposed process incorporates mature equipment with a substantial base of industrial and commercial use. Although not all demonstration objectives met, the ACWA demonstration provided the majority of the experience for processing secondary wastes and the sole experience for ACW configurations. There appears to be very little other historical information with feeds or configurations representative of those expected with ACWs.

Demonstration of the integrated PWC process raises serious concerns about the maturity of this system as proposed. Although a wide variety of materials were fed to the PWC (but not all that were required), the continual systemization, modifications, and redesign of the process during demonstration by the provider leaves some doubt about the applicability of the test data and the capability of the demonstrated system to represent full-scale operations. Changes to operating conditions raise questions about whether or not the data were representative of the proposed process and what actual operating conditions are required; the design basis is lacking. The lack of agent data in any amount or at any level creates significant uncertainty. For the most part, the physical configuration of the equipment remained the same, but a number of changes were made to the materials of construction and operating conditions in response to unanticipated failures, a sign of poor maturity. Most notable are the troubles encountered with the plasma arc torch and soot generation, indicators that the reactor did not have the proper reformation environment during some of the tests. The PWC was not tested in the proposed configuration or with proposed feed materials and there is insufficient information to extrapolate applicability to a full-scale, integrated system.

The remaining design and development needed for the PWC are unknown but is considered significant. The proposed PWC has not demonstrated a level of maturity to proceed with full-scale implementation without significant additional testing.

B.4.1.2.1.5 Process Operability

The PWC is a robust, indiscriminate thermal treatment process capable of destroying organic feeds if operated at high enough temperatures with sufficient residence time and appropriate feed rates. Stability is enhanced by the ability to HT&R the PCG. However, the limits for stable operation of the system are presently unknown for all four classes of feed (agent, energetics, metals, and dunnage) and a convincing rationale was not provided to assure stable operation at the full-scale feed rates. The stability of the system is of concern especially with regard to the consistency and quality of syngas production and the minimization of soot when processing dunnage and other high organic content feeds. The demonstration testing did not demonstrate these features[39] and there is concern that as the organic feeds approach maximum loading, the soot formation problem will reoccur. The PWC will need to be pushed to its processing feed limits with all materials to determine maximum capacities.

Stability of energetics processing is of particular concern for the EDC and the propellant-fed PWC. There remains some technical risk associated with the proposed processing of M28 propellant from the M55 rocket motor. There is concern that deflagration of rocket motor sections in the high temperature environment will generate large and transient variations in pressure, temperature, and gas production.[40] Assuming deflagration without explosion, the frequent variations in these parameters within the PWC should make their control strategy difficult to establish and maintain. There is some chance that the motor sections may explode and damage components of the PWC (e.g., anode, refractory, etc.). While the PWC processed propellant during demonstration, the feed was only in 0.25-lb quantities, which is equivalent to only 20% by mass of the size proposed for full-scale destruction.[41] The consistency of the propellant was also different; the Army was only able to provide granulated material for demonstration while the 1.25-lb rocket propellant pieces, which will be difficult to feed in repeatable quantities at full scale, are solid slices of the rocket motor. The stability of the full-scale EDC is unknown when processing sheared rocket and projectile burster feeds. Both of these operations would need to be further studied and demonstrated prior to any implementation phase.

The PWC demonstrated poor reliability, availability, and maintainability (RAM) characteristics with insufficient information to extrapolate acceptability to full-scale. The many changes in operating conditions (e.g., plasma gas, electrode materials, arc transfer mode) resulted in the

PWC only being operated in its final configuration for 14 hours of testing. Because of the simplicity of the system, the potential exists for substantial improvement in PWC RAM characteristics. The Bofors-Dynasafe EDC has never been tested with the proposed feeds and has had little historical use; thus, its RAM characteristics remain unknown. The EDC would need to be further studied and demonstrated prior to any implementation phase.

The proposed plasma arc process is generically simple because it has so few unit operations. An advantage of the process is that one unit, the PWC, is used for complete destruction of agents and agent contaminated materials. Due to the robust nature of the technology and the relatively few unit operations, it is expected that the system will require relatively few operators with relatively low skill levels.[42] Simple demands are expected for idle, upset recovery, and campaign changeover, and the overall system has the potential for relatively short preventive and routine maintenance requirements. Complex interfaces include the feeding and extracting of solids to and from the EDC and processing dunnage for feeding to the PWC.

B.4.1.2.1.6 Process Monitoring and Control

The process uses many commercially available controls and instrumentation (e.g., temperature, pressure, flow rate, and level sensors). Process control relies heavily on temperature, pressure, and gas composition sensors,[43] which are well-developed technologies. Deviation from acceptable operating ranges for any of the critical parameters will result in automatic PWC shutdown.

There are a number of major concerns with respect to monitoring and control. In general, monitoring and control systems for exceptionally high temperature environments are more difficult to construct and maintain and are prone to failure. No method was proposed to monitor erosion of the plasma torch anode during PWC operation. As was observed during demonstration, excessive erosion of the electrodes can cause catastrophic structural failure, releasing cooling water into the PWC. This indicates that the control system must be able to shut off the power and the cooling water supply before steam generation and resulting overpressure become severe enough to breach the reactor vessel or downstream GPS. In some runs, there were overpressures in the bag filter unit, and many leaks and operating difficulties in the GPS. Agent monitoring and sampling were not tested, and there is a concern that interferents may create false positive readings during agent monitoring. Monitoring and control to prevent or minimize energetics (M28 propellant) initiation has not been established. There may be unmanageable control problems related to rapid pressure excursions and insufficient residence time even if the propellant sections burn rapidly (deflagrate) without exploding. Development of a method for PWC melt level and discharge control is also needed.[44]

For the full-scale facility, steam flow to the PWC will be controlled by the CO/CO_2 ratio (syngas quality).[45] To prevent carbon soot formation in the syngas and to maintain the desired PCG quality, CO/CO_2 ratio, BTU analyzers, and temperatures will be used to sense overly lean or rich gas and adjust the ratio of feed streams (especially solids), steam, and nitrogen to the PWC. However, the unknown and potentially lengthy lag time involved in the feedback of control information makes the control effectiveness questionable. The batch operation for dunnage and energetics with variable feed to the PWC adds additional complexity to the proposed control strategy. These complex procedures and the underlying control strategy were not demonstrated and remain a major source of uncertainty.

The temperature-based energy control of the plasma arc minimizes the occurrence of process upsets because the thermal inertia of the PWC tends to reduce the possibility of unreacted organics leaving the reactor. However, thermal inertia could also continue to volatilize organics (potentially undesirable) and/or generate hazardous compounds (undesirable) in case of a process upset or sudden shutdown. The use of HT&R tanks minimizes the probability of any process upset resulting in a release of contaminated gas to the atmosphere.[46]

In summary, the monitoring and control equipment for the PWC is available, which is an advantage of the system. However, the frequent variations in PWC feeds (especially during batch feeding of solids) could make the plasma arc system control strategy difficult to establish and maintain. The automatic control features proposed for the full-scale plant were not demonstrated, and further, demonstration data were not used to support the feasibility of the monitoring and control concepts proposed for the full-scale design.

B.4.1.2.1.7 Applicability

This process was not validated for any chemical munition because of lack of agent data. The PWC destruction process has been shown feasible for all other munition feeds (e.g., dunnage, metal parts, and energetics) and for agent simulants.

B.4.1.2.2 Safety/Worker Health and Safety

B.4.1.2.2.1 Design or Normal Facility Occupational Impacts

Workers are protected during normal operations by a number of administrative measures/controls and by some design features. The primary destruction processes (PWCs) and the GPS are remote operations that minimize worker exposure. However, dunnage shredding operations and molten metal recovery may require limited worker intervention. The fully automated process control system takes advantage of the fact that shutoff of the feed and energy supply immediately stops the processes.

The process uses seven major process chemicals in low quantities.[47] Only three process chemicals (nickel, nitrogen, and calcium oxide)[48] are used in the critical destruction unit. The others (sodium hydroxide, sodium chlorate, sulfuric acid, and sodium sulfide)[49] are used in the GPS. All are low-to-moderate inhalation hazards, but sodium hydroxide and sulfuric acid are acute dermal hazards. The nickel used to maintain the melt in the bottom of the PWC[50] poses the most serious hazard because it is the source of nickel-containing particulates found in the PWC output; nickel in particulate form is a human carcinogen,[51] and has the lowest workplace inhalation permissible exposure limit (1 mg/m^3) of the proposed process materials.[52] All process chemicals are commonly used in industry, and can be handled in accordance with well-established industrial safety practices. The flammable PCG will contain a large number of byproducts of varying degree of hazard and quantity (see Section B.4.1.2.1.2).

Equipment containment issues identified during demonstration need to be resolved. The PWC reactors are designed to operate at slightly negative operating pressure, preventing any leakage of toxic contents into the worker environment during normal operations. Nevertheless, the potential of the PWC and GPS to release fugitive gaseous emissions during normal and upset operations was observed several times during demonstration. Also during demonstration, the ram feeder caused blowback of the PWC reactants into the feed chute as it was being withdrawn, and flames appeared around the feed ram. Design changes (including reduced ram travel before gate closure and purging with plasma feed gas) eliminated the visible flame, but did not necessarily eliminate other emissions. The long-term effectiveness of the proposed final solution remains to be demonstrated. Although PWC operations are isolated, maintenance operations around the PWC could cause unnecessary exposure to hazardous intermediates, especially nickel particulates. This demonstrated unreliable PWC containment capability increases the potential for worker exposure and will necessitate a significant increased use and reliance on PPE.

Fugitive emissions (haze) from the GPS were observed many times during demonstration. It was concluded that the GPS was undersized and therefore unable to reliably handle the PWC gaseous effluents. Therefore, the GPS emissions could be a demonstration related anomaly that may be eliminated by correctly sizing the GPS to the PWC effluent flow and constituents. However, until validated, there is a significant increased potential for worker exposure. The proposed use of double-walled piping, with continuous monitoring to detect leaks, may eliminate emissions and enhance worker safety.

The projected physical workplace environment generates few but manageable risks. While the scope of the manual operations associated with dunnage shredding and molten metal handling is not well defined in the final proposal,[53] there is a possibility of continuous, awkward, repetitive motions and moderate lifting associated with these operations that pose some potential for soft tissue skeletal injuries. Potential thermal dermal hazards associated with the hot surfaces of the PWC, the PWC ducts, the molten metal, and the GPS are effectively mitigated by the prudent use of insulation and barricades.[54] The process generates moderate noise and minimal vibration hazards. The need for PPE during dunnage processing and torch maintenance or changeover can be expected to generate high but manageable worker thermal stress. While some maintenance may be required during operations, the need for PPE is expected to be minimal. Because of the very high internal temperature of the PWC and exit piping, the PWC units and exit ducts are projected to self-decontaminate to the 5X level after normal, forced, or emergency shutdowns.[55]

Worker protection is enhanced during maintenance by administrative measures. PWC maintenance activities are restricted to ambient, decontaminated, and fully shutdown conditions.[56] Thermally reflective garments, similar to those used in foundry-like operations, are used (as necessary) near molten material operations.[57] Insulation is expected to keep outside skin temperature of the reactors and ducts at safe levels,[58] reducing the need for special thermally protecting PPE.

Remote control of major unit operations (PWCs, transport and feed systems, shredders, molten metal recovery, etc.)[59] minimizes worker exposure to high temperature, high voltage, fugitive emissions, and moving machinery. The proposed use of continuous leak detection[60] will enhance worker safety.

PCG monitoring for chemical agent relies on standard Army methods (MINICAMS™, DAAMS).[61] No process interference is anticipated but the necessary verification testing remains to be done.

In summary, the plasma arc process poses moderate risk to workers during normal operations because of the potential for vapor containment failure of the PWC and the GPS. Although containment issues exist, administrative and operational controls should manage these concerns.

B.4.1.2.2.2 Facility Accidents with Worker Impact

The process requires seven major process chemicals to achieve complete destruction of both the agent and explosives. The critical destruction unit requires only a plasma medium gas (nitrogen) and the melt material (nickel). The process chemicals are projected to be used in relatively low volumes and are of low-to-moderate toxicity and persistency. These chemical hazards are typical of light industrial operations. While no acute inhalation or dermal hazards were identified in the final products,[62] the process generates a large volume of flammable gas products (the PCG) that contain nickel, a human carcinogen when present in particulate form, and other hazardous intermediates (i.e., formaldehyde, cyanide) at concentrations that are above their permissible exposure limits. These gas products would increase the severity of any process leaks.

The severity of potential accidents is minimal because the most hazardous operations (PWC, EDC) are performed remotely with fully automated process control, which can effectively stop the process by shutdown of electric power.[63] The process has not demonstrated a potential for cascading out of control but failed to detect anomalies (e.g., cathode failure/steam overpressure incident) and safely shut down prior to PWC torch leakage. However, the demonstrated PWC did not have the proposed fully automated control system. It is expected that a fully automated control system would significantly mitigate the severity or the probability of occurrence of the steam incident. Early HT&R points follow agent and energetic destruction and gas polishing, enhancing worker safety.

Production of hot ingots from molten metal and PWC slag removal are proposed as a fully automated robotic operation with unspecified worker interaction.[64] These operations, together with the PWC's extremely high internal operating temperatures (up to 26,000°F for plasma[65] and ~2,000°F at the refractory wall[66]), surface temperature, and effluent gas stream temperature, represent a significant potential for operator burns and workplace heat stress. While the PWC operates at extreme temperature and poses severe physical hazards, the demonstrated prudent use of engineering and administrative controls should greatly reduce both the probability and severity of an accident.

While PWCs are designed to operate at negative pressure, demonstration documented failures to maintain negative (sub-atmospheric) pressure during workup and validation runs. This inability to maintain negative pressure significantly increases the severity and probability of routine operator and facility exposure.

The demonstration data provided tentative support for the provider's contention that the maximum credible event from the processing of M28 propellant would be a deflagration.[67] However, the data do not conclusively preclude the potential for a explosion because the proposed full-scale feed configuration (1.25-lb solid sections[68]) was not demonstrated; ¼-lb boxes of shredded propellant were tested, instead. Additional testing, beyond the scope of the ACWA program, is still required to demonstrate safe processing of M28 propellant as proposed. While the provider proposes to construct the PWC-B as a total containment "explosion proof" vessel,[69] a significant design and validation testing effort would be required before the potential for overpressure or fragmentation exposure during M28 processing is eliminated.

The process generates a large volume of flammable PCG,[70] which poses a moderate risk of fire or explosion. The PCG is held, tested, and reworked if necessary before release to the steam boiler as a supplemental fuel. Any plant accident that ruptures the PCG system has the potential for causing a fire or an explosion in the plant work areas.

PCG monitoring for chemical agent relies on standard Army methods (MINICAMS, DAAMS). No process interference is anticipate but the necessary verification testing remains to be done.

In summary, although containment issues exist, the process poses manageable concerns regarding worker safety. The PWC poses moderate, but manageable, risk of a facility accident with the potential to affect workers. The major safety concern is the demonstrated lack of vapor containment at the equipment (i.e., PWC and GPS) level. Other factors affecting the risk of a facility accident include the large amount of flammable PCG, the high operating and surface temperatures, corrosive processing chemicals, and the unproven processing of larger amounts of M28 propellant.

B.4.1.2.2.3 Facility Accidents with Public Impact

The entire process requires seven major process chemicals, which are not highly volatile. The chemical used in the largest volume will be the plasma medium gas (nitrogen), which poses no threat to the public. These chemicals are used in low volumes, and are of low-to-moderate toxicity and persistency. The process generates a large volume of flammable gaseous product (PCG).

Public impact of any facility accident is minimized by use of low-to-moderate quantities of process chemicals, and by low concentrations of hazardous intermediates (see Section B.4.1.2.1.2). The proposed HT&R of PCG significantly reduces the potential for public exposure. The process has not demonstrated a potential for cascading out of control. While the process design calls for limited agent accumulation,[71] early HT&R points within the critical process streams enhance public safety.[72] Since agent destruction is achieved quickly in the process, the probability and severity of potential agent leaks is minimal.

The process generates a large volume of flammable PCG, which poses a minor fire and explosion risk. The PCG is held, tested, and reworked if necessary before release to the steam boiler as a supplemental fuel. Any plant accident that ruptures the PCG system has the potential for causing a fire or an explosion in the plant work areas.

In summary, the plasma arc process poses minimal risk to the public, primarily because there is no large inventory of hazardous chemical, including neat agent, that could be released to the public. While there is a moderate amount of flammable product, prudent application of known industrial safety practices and procedures should effectively minimize the risk.

B.4.1.2.2.4 Off-Site Transportation Accidents

Few process chemicals would have to be transported on-site; hence, the process poses relatively low health hazard to nearby populations in the event of a transportation accident. The Department of Transportation (DOT) has classified the process chemicals as corrosives (sodium hydroxide, sulfuric acid)[73] and non-flammable gases (nitrogen).[74]

Waste materials that would have to be transported off-site have been identified and characterized for all feeds except for chemical agents, which were never tested. The waste products will be solids of two types: dried salts from the GPS; and, solid metal ingots drawn from the PWC melt pool. Of the waste materials identified to date, none are classified by DOT as a poison or a hazardous material.

Standard hazardous materials (HAZMAT) and fire department PPE, containment equipment, and techniques are sufficient to contain any potential spills. However, standard fire department PPE is not adequate for sulfuric acid spills. Evacuation zones would be less than 300 yards.[75] No special training beyond Occupational Safety and Health Administration (OSHA) HAZMAT and DOT requirements is needed.

In summary, this technology poses very little risk of a serious transportation accident affecting the public. Standard HAZMAT responses are adequate, and needed only for the common industrial chemicals sulfuric acid and sodium hydroxide. The transported chemicals are all low in volume, not highly hazardous, and well within common industrial experience. There is minimal risk associated with transportation issues.

B.4.1.2.3 Human Health and Environment

B.4.1.2.3.1 Effluent Characterization and Impact on Human Health and Environment

Consistent operating conditions were not established during demonstration. Human health and environment cannot be properly assessed without effluent and resource characterization data from standardized demonstration runs. Examples of operational problems that impacted effluent characterization include:

- Operation of the PWC resulted in positive pressure excursions that caused release to secondary containment.
- Operation during initial test runs had a failure of the GPS causing acid gas release and condensate leaks at various points.
- The thermal oxidizers experienced excessive high temperatures and acidic condensate during operation.
- There were difficulties in collecting all expected sampling data due to high moisture content of the gaseous effluent from the PWC resulting in condensation in the sampling lines (see Section B.4.1.2.1.3).

Agent testing was not conducted; therefore, the sampling of the PCG and other effluent streams could not determine if they would contain agents or other compounds of concern. The PCG sampling for energetics and dunnage runs indicated an absence of hazardous constituents, however predicted conversion of feed materials to a synthesis gas was not demonstrated. A significant unknown for effluent characterization is the management strategy for PCBs, because the treatment of these compounds was not demonstrated (see Section B.3.3). Although the PWC system should adequately treat these compounds the accountability and management of this pollutant was not addressed in the final report. Because of these problems and limitations, it is not possible to reliably determine the quantity of effluents, rates of emissions and discharges, constituents and concentrations of effluents, and potential for internal releases.

B.4.1.2.3.2 Completeness of Effluent Characterization

The characterization with validated material balance for all demonstrated effluents was incomplete. No agent derived effluent data is available. Leakage of air into the PWC during demonstration caused an excess of oxygen over the desired level, which affected the chemical composition of the PCG. Low recoveries and interferences were noted for analysis of semivolatile organic compounds. The provider's final report does not adequately address nickel particulates in the air effluent stream when the PWC is operated in the transferred arc mode.[76]

B.4.1.2.3.3 Effluent Management Strategy

A general effluent waste management plan outline with stated goals and proposed disposal options of RCRA brine salts was provided.[77] The process does include HT&R of the PCG. The proposed plan proposes the baseline BRA operation as a model for water recovery and salts disposal. The baseline brine reduction operation as proposed by the provider, is not employed at TOCDF. Disposal of scrubber liquid at an off-site location was found to be more cost effective than on-site drying and disposal. This raises concerns about the ability of the provider to recycle scrubber brine as proposed, reducing off-site waste disposal. This could require significant changes to the proposed water effluent and reuse plans, since the technology provider indicates in their final report that there will be no liquid effluents.[78] However, other available solids drying technologies should be able to dewater the scrubber brines.

PCG may not meet the RCRA hazardous waste derived fuel requirements (proposed synthesis gas exemption[79] or other regulatory options (e.g. the Boiler and Industrial Furnace [BIF] requirements[80]) or may contain unacceptable concentrations of nickel, formaldehyde, or other pollutants. No viable disposal option is provided for this exigency. Only the dunnage waste stream produced PCG with any appreciable (albeit highly variable) heating value. Minimal discussion was provided in the final report on how the PCG from the agent, energetics, or metal parts PWCs would achieve a higher heating value than was obtained during demonstration (when these feed streams produced a gas effluent stream with little or no heating value).[81,82]

The technology provider did not list any prior experience in managing similar waste streams. The proposed waste management plan is dependent on two processes that were not demonstrated—vitrification of precipitated heavy metals and a syngas exemption for PCG. Overall, analysis indicates that effluents appear treatable and disposable.

B.4.1.2.3.4 Resource Requirements

Specific water and energy requirements could not be quantitatively verified from the information in the technology provider's final report,[83] however, a qualitative assessment has determined that there are no unusual resource requirements. Water recovery and recycle may further reduce water use.

B.4.1.2.3.5 Environmental Compliance and Permitting

The proposed permitting strategy primarily depends on the baseline permitting strategy.[84] The proposed ability to use the PCG as a RCRA-exempt synthesis gas would eliminate significant permit issues from the baseline strategy. However, the ability to meet this exemption was not demonstrated. If the PCG either fails to achieve an exemption as proposed by the provider or other regulatory options (i.e., BIF rule cannot be used), then the PCG will require a RCRA combustion technology permit similar to baseline. Reaction chemistry was not verified for agent destruction processes and insufficient information on the permitting history of the PWC was provided. It is unclear how regulatory agencies will evaluate this process.

The strategy to ensure compliance with all environmental laws and regulations, including permits, is not described; however, the strategy is dependant on a RCRA exemption for the PCG. The process is not known to have been permitted in a similar application.

B.4.1.2.4 Potential for Implementation

B.4.1.2.4.1 Life Cycle Cost

Based upon the information provided in Burns and Roe's final technical report,[85] it was possible to develop total capital cost estimates for both Pueblo and Blue Grass. These estimates, presented in Table B.4-2, are expressed in constant dollars with no inclusion for either escalation, de-escalation, productivity gains/losses in labor or material supply, or cost growth in materials. The accuracy of the cost estimate is within the +20/-10% range. The analytical approach used to develop these estimates is presented in Attachment B-D.

Table B.4-2. Total Capital Cost Estimate for Burns and Roe's Plasma Arc Process

Burns and Roe Plasma Arc Process	Pueblo Total Capital Cost ($Millions)	Blue Grass Total Capital Cost ($Millions)
Installed Core Process Equipment	155	123
Installed Baseline Equipment Additions	45	47
Total Installed Equipment Cost	**200**	**170**
Buildings and Support Facilities	225	230
Total Capital Cost	**425**	**400**
Comparison to Baseline	**About 5% Greater**	**About the Same**

As indicated in this table, the total capital cost for the proposed plasma arc process for the destruction of ACWs at both Pueblo and Blue Grass is comparable to that for the baseline incineration process. At Pueblo, the total capital cost may be approximately 5% greater than or equal to that of baseline incineration, whereas at Blue Grass the total capital cost may be approximately equal to that of baseline incineration. The cost analysis showed that nearly 55% of the total capital cost for the plasma arc process is attributed to equipment and buildings common to baseline incineration and the two other alternative technologies tested.

Sufficient information currently does not exist to make a reasonable estimate of the operating and maintenance (O&M) costs for the plasma arc process. However, based upon a review of the proposed process, it was independently estimated that the O&M labor requirements may be 15 to 20% higher than those for baseline incineration. Furthermore, since O&M labor requirements account for 65 to 70% of the total O&M costs for baseline, it is likely that the total O&M costs for the plasma arc process may be slightly (10 to 15%) greater than baseline. This is also because no extraordinary chemical usage or utility requirements are anticipated for the plasma arc process.

B.4.1.2.4.2 Schedule

The basic schedule assumptions, key milestone activities, and key activity duration periods used to develop an implementation schedule are summarized in Attachment B-D. The following key points are unique to the implementation of the proposed plasma arc process:

- ❑ Completion of the Environmental Impact Statement (EIS) and Record of Decision (ROD) approval takes a total of 19 months. Relative to the other technologies in this evaluation, a longer Maturation Testing period is required.
- ❑ Duration of Maturation Testing for both Pueblo and Blue Grass is 15 months; a longer maturation test period is required due to lack of maturity in the demonstrated systems' equipment design and operating philosophy.
- ❑ Operations, based on information provided by Burns and Roe, is 28 months for both Pueblo and Blue Grass.

Based on these durations and those specified in Attachment B-D, the key milestones and corresponding dates to implement the plasma arc process on a full-scale basis were developed. These are summarized in Table B.4-3 for both Pueblo and Blue Grass.

As indicated in the table, the schedule estimates developed for the demilitarization of ACWs utilizing the Burns and Roe plasma arc process indicate the following dates for completion of operations:

- ❑ Pueblo: January 2012
- ❑ Blue Grass: April 2012

Applying the same analytical approach to the schedule for baseline incineration (see Attachment B-D), the schedule for implementing the plasma arc process is comparable to that for baseline incineration. Using similar key milestone start dates and assumptions, the completion dates for the baseline plants at Pueblo and Blue Grass are:

- ☐ Pueblo: December 2009
- ☐ Blue Grass: May 2010

Table B.4-3. Implementation Schedule for Burns and Roe's Plasma Arc Process

Key Milestones	Dates for Pueblo	Dates for Blue Grass
EIS Start	31 October 1999	31 October 1999
Maturation Testing Start	1 January 2000	1 January 2000
RFP Release	31 May 2001	31 August 2001
Final EIS/ROD	31 May 2001	31 May 2001
Contract Award	30 November 2001	28 February 2002
Final Design (65% Completion)	31 May 2002	31 August 2002
RCRA Part B Issued	31 August 2003	30 November 2003
MDB Construction Start	31 August 2003	30 November 2003
MDB Construction Finish	30 April 2006	31 July 2006
Systemization Start (Pilot Train)	1 October 2006	1 January 2007
Systemization Start (All Trains)	1 April 2009	1 July 2009
Operations Start	1 October 2009	1 January 2010
Operations Finish	30 January 2012	30 April 2012

Although these implementation schedules are not completed until after the CWC date of 29 April 2007, demilitarization operations for the plasma arc process and baseline incineration are estimated to likely be completed within the possible 5-year CWC extension. Within the confidence level (75% likelihood of success) of these schedules, the implementation schedules of the plasma arc process and baseline incineration are comparable. The most significant uncertainty with the baseline incineration's estimated schedule is with respect to permitting. It is assumed that there is no difference in the time required for the RCRA Part B approval process between the plasma arc process and baseline incineration. However, this assumption does not necessarily reflect the history of public opposition to baseline incineration. It is believed that the program completion dates for the plasma arc process and baseline incineration are essentially the same for either Pueblo or Blue Grass.

B.4.1.2.4.3 Public Acceptance

Based on input from the Dialogue, the plasma arc process was deemed unlikely to obtain public acceptability due to the incomplete demonstration and the perceived similarity to incineration.

B.4.2 General Atomics Neutralization/SCWO

This section of the technical evaluation report covers the description and evaluation of the technology proposed to PMACWA by General Atomics.

B.4.2.1 Description of the Proposed Technology

The General Atomics process uses modified baseline reverse assembly and cryofracture of projectiles for munitions access. Agent and energetics are destroyed by caustic or water hydrolysis followed by supercritical water oxidation (SCWO). Metal parts are subjected to the caustic hydrolysis processing followed by 5X thermal treatment. Dunnage is shredded, mixed with caustic, and destroyed by SCWO.

B.4.2.1.1 ACWA Total Solution

Munitions access uses baseline reverse assembly and cryofracture. Reverse assembly is incorporated in its entirety for all M55 rockets and M23 landmines with additional high-pressure spray washout of agent reservoirs. For projectiles (artillery shells and mortars), only the explosives-removal operations of the baseline reverse assembly are used; the projectile bodies are then cryofractured (embrittled by cryocooling in liquid nitrogen and fractured with a hydraulic press) for agent access. Figure B.4-3 illustrates the process flow diagram for General Atomics' neutralization/SCWO process.

Caustic hydrolysis using sodium hydroxide neutralizes the nerve agents and the energetics and water hydrolysis neutralizes the mustard agents. Munition hardware is treated with caustic in rotary hydrolyzers (rotating vessels with a helical transport flight[1]): the Projectile Rotary Hydrolyzer (PRH) is used for agent-contaminated, cryofractured projectiles; and, the Energetics Rotary Hydrolyzer (ERH) is used for all other munition components. Drained agents are neutralized with caustic (for GB and VX) or with water (for mustards) in continuous stirred tank reactors (CSTRs) (the Army's Alternative Technology Program (ATP) process). ERH effluent liquids are treated in similar CSTRs. Dunnage and other organic solid wastes are shredded, pulverized, and water/caustic pulped (with tramp solids removal) into a slurry hydrolysate. Thermal treatment is used for decontamination of solids not pulped. Solid effluents from the PRH and ERH pass to modified (inert atmosphere) baseline Heated Discharge Conveyers (HDCs) for 5X thermal decontamination. Non-shreddable solid wastes (metals, glass, etc.) receive 5X thermal decontamination in a induction-heated, inert atmosphere Metal Parts Furnace (MPF). 5X decontaminated munition bodies are commercially recycled and 5X solid waste is landfilled.

Agent hydrolysates, energetics hydrolysates from the ERH, and dunnage slurry hydrolysates undergo secondary treatment in solid-wall Supercritical Water Oxidation (SCWO) units. The agent hydrolysates are treated in a separate SCWO processing train. Brine from the SCWO units is evaporated, the water being condensed and recycled to the hydrolysis units, and the salts sent to a RCRA landfill. Off-gases from the HDCs vent to their respective rotary hydrolyzers. Off-

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[1] A continuous, flat plate (or "flight") attached to the inner wall of the vessel, forming a corkscrew from one end to the other. Material is moved along the bottom of the vessel by the helical transport as the vessel rotates.

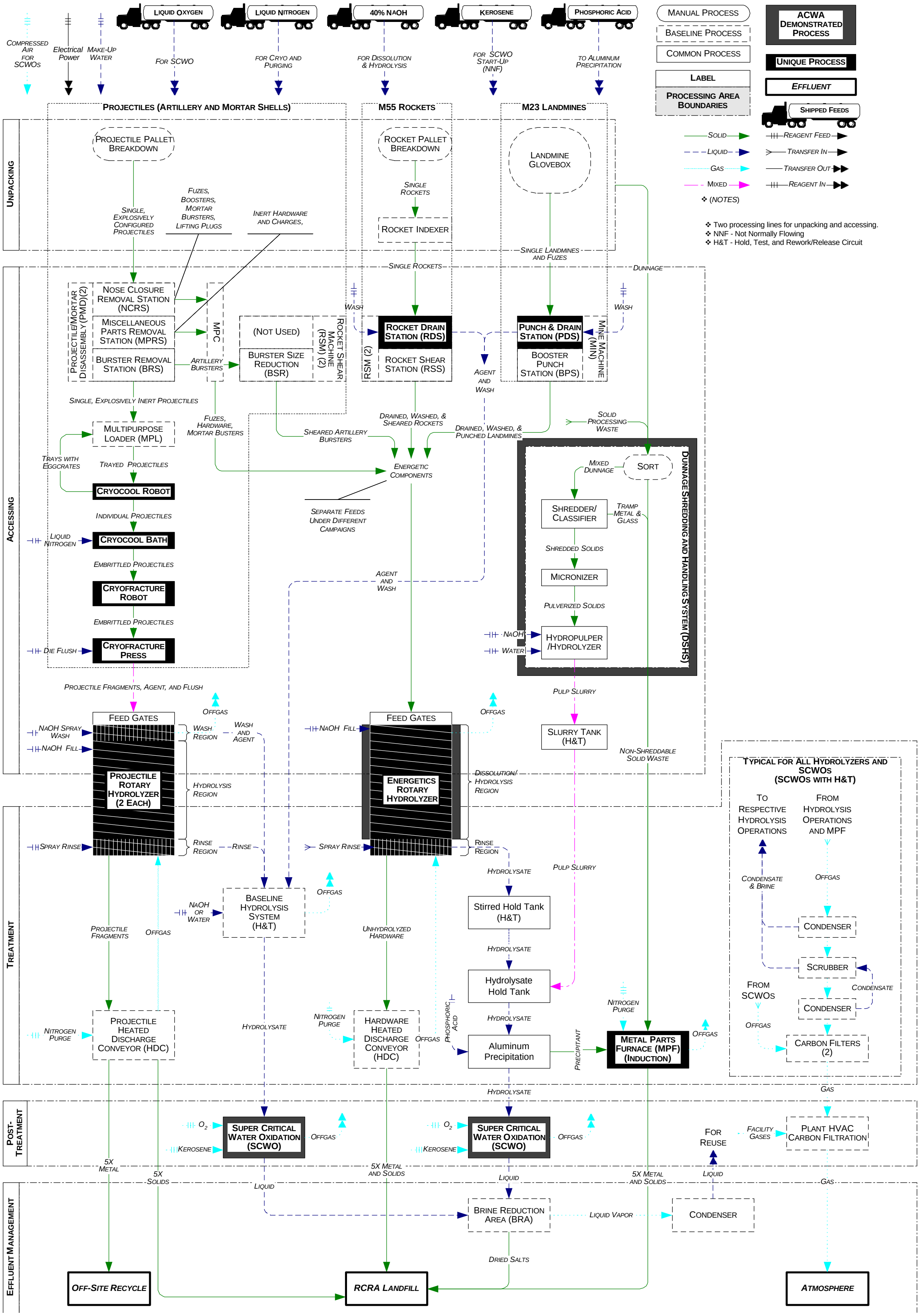

Figure B.4-3. General Atomics Neutralization/SCWO Process Flow Diagram gases from the hydrolyzers and the MPF pass through condensers, scrubbers, and carbon filters before being released to the atmosphere. Liquid from condensers and scrubbers returns to the rotary hydrolyzers for eventual treatment by SCWO. SCWO off-gas passes through carbon filters and is released to the atmosphere.

B.4.2.1.2 Unit Operations Not Demonstrated

As discussed previously in Section B.3.3, baseline reverse assembly, carbon filtration, and the BRA were not demonstrated. The reasons PMACWA elected not to demonstrate certain unit operations proposed by General Atomics are as follows:

Cryofracture System (bath, robotic transport, and press). This is a well-developed system that has been demonstrated at full scale at DPG. For this program, the only required changes to the demonstrated equipment are scaling down the press and instituting conveyor transport of individual munitions through the liquid nitrogen bath. Demonstration of this unit was therefore, not required.

Projectile Rotary Hydrolyzer (PRH). Drum-dryers, the basis of the PRH, are well developed and demonstrated commercially. The PRH is essentially a batch process with a slow tumbling action (identical in principle to the ERH). Therefore, demonstration of this unit was not seen as critical at this time.

Heated Discharge Conveyer (HDC). The proposed unit is essentially identical in design to the baseline HDC (used at JACADS and TOCDF), but would operate in a nitrogen atmosphere. Heated bucket conveyors are well developed and demonstrated commercially. While demonstration of the HDC was viewed originally as desirable, the discontinuation of PCB testing (see Section B.3.3) made an HDC demonstration less essential at this stage in the program.

Metal Parts Furnace (MPF). This batch furnace is similar to the baseline MPF structure except that induction heaters will be used instead of gas-fired heaters. Operationally, the MPF differs from the baseline version by using an inert atmosphere for the processing of solid wastes. Demonstration of this unit was not required since the MPF is proposed to treat only a very small portion of stockpile and plant materiel.

B.4.2.1.3 Unit Operations Demonstrated

This section explains the rationale for selecting the General Atomics demonstration unit operations, the objectives of testing, and the significant deviations from the planned testing.

Agent Hydrolysis. The Army has previously demonstrated agent hydrolysis extensively. PMACWA ran agent hydrolysis units primarily to provide representative feedstock for SCWO and to characterize the intermediate product stream for residual agent, Schedule 2 compounds, and other substances required to verify the mass balance.

The specific test objectives of these demonstration units included the following:

- ☐ Design, fabricate, and deliver GB and VX Hydrolysate Production Systems with the production capacity of 100 gallons of hydrolysate per run.

- Use the hydrolysate recipes developed and tested by the ECBC.
- Demonstrate that the agent concentration in the hydrolysate solution is less than the Waste Control Limit by using the analytical methods developed and approved by ECBC.
- Characterize solid, liquid, and gas process streams.
- Provide agent hydrolysate in support of demonstration testing.

GB and VX hydrolysates were produced in a newly constructed 100-gallon stirred tank reactor system at CAMDS. The design and manufacture of a hydrolysis system provided information on equipment and operational parameters that can be used for scale-up to a full-scale facility. Approximately 225 gallons of each hydrolysate were shipped to DPG for use in the General Atomics SCWO demonstration.

Approximately 4,200 gallons of HD hydrolysate were produced in a campaign of 120 batch runs. The equipment used was not intended to be a model for scale-up to a full-scale facility, but was an expedient design suitable for use in the contained environment of the Chemical Transfer Facility at Aberdeen Proving Ground. Approximately 245 gallons of the HD hydrolysate were shipped to DPG for use in the General Atomics SCWO demonstration.

Energetics Hydrolysis. Other government agencies have previously demonstrated energetics hydrolysis; however, further knowledge of the process was needed for evaluation, feedstock for SCWO was required, and the characterization of the intermediate product streams for residual energetics and other substances were required to verify the mass balance.

The specific test objectives of these demonstration units included the following:

- Produce energetics hydrolysate for use as feed material in subsequent demonstration testing.
- Characterize solid, liquid, and gas process streams.
- Gather process operation information to support the ACWA program and future scale-up.

Eighty-three (83) pounds of M28 propellant were hydrolyzed with 12% sodium hydroxide to produce approximately 45 gallons of hydrolysate in two production runs at the Radford Army Ammunition Plant, Radford, Virginia. Thirty (30) pounds of Comp B and 121 pounds of Tetrytol were also hydrolyzed using 12% sodium hydroxide in single production runs at the Pantex Plant, Amarillo, Texas. All of the hydrolysates were transported to DPG, Utah and used as feedstock for the SCWO.

Dunnage Shredder/Hydropulper System (DSHS). The shredding and hydropulper system was demonstrated to show that solid wastes (wooden dunnage, DPE suits, and butyl rubber) could be adequately size-reduced and pulped to a pumpable mixture. Shredded material was used for the SCWO pulped dunnage testing.

The objectives of the demonstration testing included the following:

- Validate the ability of the shredders and the hydropulper to adequately prepare the dunnage for downstream processing in the SCWO.

- ❑ Qualitatively evaluate the operability of the shredder/hydropulper unit operations with particular focus on material handling.
- ❑ Validate the ability of the shredders to process 1,000 lb/hr of pallets and, separately, 250 lb/hr of plastics.

Several commercial shredders were used to achieve size reduction of the solid materials of interest. A low-speed shredder was used to break up wooden pallets. The rough-shredded wood was size-reduced to small chunks in a hammer mill and then further reduced in a micronizer to the consistency of flour. Three belt conveyors were used to transport feeds to the low-speed shredder, from the low-speed shredder to the hammer mill, and from the hammer mill to the micronizer. A baghouse was used to collect dust generated by the shredding equipment. DPE suits (plastic material) with metal parts removed, and butyl rubber (the material of boots and gloves) were rough shredded in the low-speed shredder, cryo-cooled in a bath of liquid nitrogen, and size reduced in a granulator. The size-reduced wood, plastic, and rubber, along with activated carbon (air filter material) and energetics hydrolysate, were combined to produce a pumpable slurry to feed to the SCWO. The demonstration shredding equipment is identical in size to the units proposed for the full-scale system.

Significant deviations from the planned demonstration testing included the following:

- ❑ Metal pieces were removed from DPE suits prior to shredding because removal by magnets after shredding was ineffective, resulting in damaged granulator blades.
- ❑ DPE suit plastic was successfully shredded to <3 mm, a test objective, but this size proved to be too large to be fed to the demonstration SCWO unit without plugging the feed system. Alternatives for further size reduction were explored, but ultimately the plastic was sieved to 1 mm or less for use as feed for the SCWO dunnage validation runs.
- ❑ The hydropulper operation was not validated. Systemization and the single work-up run indicated that the unit provided no size-reduction benefit.

Energetics Rotary Hydrolyzer (ERH). The ERH was demonstrated to determine its effects on the physical and chemical properties of the munitions and liquid effluent.

The objectives of the demonstration testing included the following:

- ❑ Demonstrate effective dissolution of aluminum and energetics in fuzes and bursters, and propellant in rocket motors to allow downstream processing in the CSTR, SCWO, and HDC.
- ❑ Determine the deactivation of the energetics in fuzes and bursters and the propellant in rocket motors.
- ❑ Validate the retention times for aluminum and energetics in fuzes and bursters and propellant in rocket motors.
- ❑ Characterize the gas, liquid, and solid process streams from the ERH.

Fuzes, bursters, and rocket motor propellant were tested with the ERH, demonstrating aluminum and energetics dissolution and energetics hydrolysis for a full-scale ERH. The ERH demonstration unit was a custom designed, 4-ft diameter (½ of full scale) and 2-ft wide cylindrical drum, filled with 8-12 molar sodium hydroxide, and rotated at the very slow rate of 0.1 revolutions per minute. The drum was heated with condensing steam at 212-230°F to melt out the energetics and to increase the hydrolysis reaction rate. In the ERH tests, munition pieces were placed into the caustic filled drum, and rotation was initiated for periods up to 10 hours. Lifting flights in the drum were tilted at an angle to ensure the energetics rolled off the flight as the flight rotated out of the sodium hydroxide solution, thus minimizing the time the energetics were out of solution. Aluminum metal dissolved to form aluminum salts and hydrogen, and the energetics dissolved and reacted with the sodium hydroxide to form an energetics hydrolysate.

There were no significant deviations from the planned demonstration testing.

SCWO – Agent Hydrolysate. SCWO was demonstrated to validate destruction of Schedule 2 and other organic compounds from agent hydrolysis products. Destruction of Schedule 2 compounds is a CWC requirement and thus demonstration of the SCWO technology was essential. Testing had previously been performed with VX/sodium hydroxide hydrolysate during the ATP but had not been performed with HD/water or GB/sodium hydroxide hydrolysates.

The objectives of the demonstration testing included the following:

- ❑ Validate the ability of the SCWO to eliminate the Schedule 2 compounds present in the agent hydrolysate feeds.
- ❑ Validate the ability of the agent hydrolysis process and the SCWO to achieve a DRE of 99.9999% for HD, GB, and VX.
- ❑ Demonstrate the long-term operability of the SCWO reactor with respect to salt plugging and corrosion.
- ❑ Characterize the gas, liquid, and solid process streams from the SCWO.

For the SCWO agent hydrolysate tests, mixtures of agent hydrolysate, water, and/or auxiliary fuel along with air were fed to the SCWO reactor—a tubular continuous flow reactor operated at approximately 3,400 PSI and 1,200°F. In SCWO, the injected feed mixture is rapidly heated to supercritical conditions and oxidized to carbon dioxide, water, and inorganic salts. Quench water is injected at the bottom of the reactor to cool the effluent and to dissolve the salts that are insoluble above the critical point of water. The effluent is further cooled in water-cooled heat exchangers and passed through a liquid/gas separator and pressure letdown system. Gaseous effluents were scrubbed in carbon filters and released to the atmosphere. Liquid effluents containing soluble and insoluble salts and metal oxides were collected and analyzed. The demonstrated SCWO system operated with a hydrolysate feed rate of approximately 0.1 gal/minute,[86] which is 1/10th to 1/20th the throughput cited for the full-scale unit.

Significant deviations from the planned demonstration testing included the following:

- ❑ SCWO treatment of VX hydrolysate was not demonstrated because of schedule constraints.
- ❑ The proposed platinum-lined reactor was not used because of difficulties in fabrication.

SCWO—Energetics/Dunnage Hydrolysate. SCWO was demonstrated to validate destruction of organic compounds from energetic hydrolysis products and to demonstrate the feasibility of destroying shredded solids. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters.

The objectives of the demonstration testing included the following:

- Validate the ability of the ERH, CSTR, and SCWO to achieve a DRE of 99.999% for Tetrytol, Comp B, and M28 propellant.
- Determine the impact of the aluminum from the ERH process on SCWO operation.
- Determine the extent to which the organics in the shredded dunnage are oxidized in the SCWO.
- Characterize the gas, liquid, and solid process streams from the SCWO.

Energetics hydrolysate and shredded/slurried dunnage (wood, DPE material, and fresh granulated carbon) were blended and processed through SCWO. In this test, organic products, water, and/or auxiliary fuel along with air were fed to a SCWO reactor operated at approximately 3,400 PSI and 1,200°F. Because of the low heating value of the slurry, electric preheaters were used to heat the slurry prior to injection. In SCWO, the injected feed mixture is rapidly heated to supercritical conditions and oxidized to carbon dioxide, water, and inorganic salts. Quench water is injected at the bottom of the reactor to cool the effluent and to dissolve the salts that are insoluble above the critical point of water. The effluent is further cooled in water-cooled heat exchangers and passed through a liquid/gas separator and pressure letdown system. Gaseous effluents are scrubbed in carbon filters and released to the atmosphere. Liquid effluents containing soluble and insoluble salts and metal oxides were collected and analyzed. The demonstrated SCWO system operated with a feed rate of up to 0.1 gal/minute,[87] which is 1/10th to 1/20th the throughput cited for the full-scale unit.

Significant deviations from the planned demonstration testing included the following:

- The proposed platinum-lined reactor was not used because of difficulties in fabrication.
- During some of the SCWO testing, energetics hydrolysates and slurried dunnage were treated in separate runs because of differing effects of feed pre-heating. During the last week of testing, however, three validation runs were conducted using a mixed feed of Tetrytol hydrolysate and slurried dunnage.
- Aluminum hydroxide was either removed from, or not added to, energetics hydrolysates prior to SCWO treatment. Reactor plugging occurred while processing energetics hydrolysate feeds containing aluminum hydroxide.

B.4.2.2 Technical Evaluation

B.4.2.2.1 Process Efficacy/Process Performance

B.4.2.2.1.1 Effectiveness

The effectiveness of the aqueous neutralization of chemical agents was demonstrated previously by the Army, and was confirmed for HD, GB, and VX during this demonstration. HD was not detected in the hydrolysate product at levels as low as 11.4 µg/L,[88] indicating a destruction efficacy of greater than 99.99997% for HD. GB was not detected in the hydrolysate product, with a detection limit of 7.4 µg/L, indicating a destruction efficacy of greater than 99.999989% for GB. VX was not detected in the hydrolysate product with a detection limit of 16 µg/L or lower, indicating a destruction efficacy of greater than 99.99991% for VX. The destruction of vesicants H and HT was not part of the planned demonstration test program. However, based on the results of the HD testing and earlier laboratory data[89] there is a high degree of confidence that both of these agents can be adequately destroyed using this process. The provider proposes processing HD using a 9% concentration rather than the 3.8% concentration demonstrated.[90] This change is not expected to pose any operational problems or alter the effectiveness of the process.

The effectiveness of bulk caustic neutralization of energetic constituents was demonstrated for Comp B, Tetrytol, and M28. For neutralization of Comp B, RDX was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit of 0.5 PPM. This indicates a destruction efficacy of greater than 99.99985% for RDX. TNT was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit of 0.5 PPM. This indicates a destruction efficacy of greater than 99.9998% for TNT.[91] For neutralization of Tetrytol, tetryl was not detected in hydrolysate at a detection limit of 0.1 mg/L and was detected in filtered solids at a level of 0.76 PPM. This indicates a destruction efficacy of greater than 99.9992% for tetryl. TNT was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit of 0.5 PPM. This indicates a destruction efficacy of greater than 99.9997% for TNT.[92] For neutralization of M28, nitrocellulose was not detected in hydrolysate at a detection limit of 5 mg/L. This indicates a destruction efficacy of greater than 99.988% for nitrocellulose.[93] Nitroglycerin was not detected in hydrolysate at a detection limit of 0.1 mg/L. This indicates a destruction efficacy of greater than 99.9994% for nitroglycerin.[94] The destruction efficacy for these energetic constituents was calculated to be greater than 99.999% for all but the nitrocellulose component of the M28. The nitrocellulose portion of the M28 was not proven to have undergone a 99.999% destruction due to a high analytical detection limit. The process for the destruction of fuze energetics was also demonstrated through hydrolysis of the aluminum booster cup and tetryl booster in the ERH and initiation of the detonator in the muffle furnace. Based on all available data the process for deactivating energetics appears to be effective for the destruction of the energetics of concern.

The effectiveness of the process to decontaminate chemical weapons hardware has been partially validated. Cryofracture of projectiles after removal of energetics has been previously validated to provide effective access to the agent within.[95] The process thermally decontaminates munition components such as metals and fiberglass to 5X in HDCs, a baseline unit operation. The dissolution of the appropriate materials and destruction of the energetics in fuzes and bursters in the ERH have been validated. Destruction of tetryl in M557 fuzes was validated to 99.8%;[96] the remaining energetics were validated to be destroyed by thermal treatment. Destruction of energetics in M83, M6, and M14 bursters was validated to greater than 99% in the ERH.[97] Propellant in M28 rocket motors was validated as destroyed to greater than 99%.[98] In all cases, no visible traces of energetics remained on the hardware. The dissolution times are approximately 3 hours for fuzes, 2-4 hours for bursters, and 10 hours for the propellant.[99] Although no agent contaminated hardware testing was included in the demonstration test program, the validation of the ERH and the agent neutralization process support the effectiveness of the PRH.

Non-shreddable solid waste such as tramp metal, glass, and processing equipment will be thermally treated in an induction-heated batch furnace to 5X condition. Shredding of dunnage, DPE with metal parts removed, and sheets of butyl rubber were validated to be effective.[100] Although further size reduction was not achieved in the hydropulper,[101] SCWO destruction of shredded plastic (sieved to less than 1 mm) and dunnage from the shredder demonstration, mixed with carbon and energetics hydrolysate was validated to be effective.[102] Total Organic Carbon in energetic and dunnage slurries was destroyed by SCWO to below detection limits, with a destruction efficacy ranging from greater than 99.87% to greater than 99.95%.[103] Insufficient data was provided to determine the actual destruction mechanism of the resin/fiberglass of the M55 rocket tubes. VOC backflow to the ERH should condense there, be removed in a condenser or scrubber, or be adsorbed in the carbon filtration system. Testing of agent-contaminated dunnage was also not included in the demonstration test program.

The effectiveness of the process in the presence of known impurities or additives has also been validated in part. Testing with munitions grade agent and energetics validates the effectiveness of the process in the presence of impurities and additives associated with these compounds. Based on all available data the confidence in the effectiveness of the process in the presence of impurities and additives is high.

In summary, the proposed processes for agent detoxification and deactivation of energetics have been validated as part of this demonstration. Treatment of contaminated processing wastes was also validated. Processes used for decontamination of chemical weapons hardware have been validated elsewhere. The overall process is considered very effective for the destruction of agent, energetics, and contaminated wastes.

B.4.2.2.1.2 Products

The overall characterization of the proposed neutralization/SCWO process is well defined based on data obtained during demonstration. In general, the major products from hydrolysis and SCWO of organic materials are carbon dioxide, water, nitrogen, and mineral salts including sodium chloride, sodium fluoride, sodium sulfate, and sodium phosphate. However, some areas were not explicitly addressed during demonstration, including SCWO processing of VX hydrolysate and effluent characterization of the HDC and MPF. Although not validated during demonstration, previous VX SCWO testing for the ATP provides characterization of products and indicates that any associated hazardous compounds are destroyed in the SCWO. Information provided on anticipated major effluents from the HDC and MPF, with scrubbed effluents being treated by SCWO, provide some confidence that this portion of the system is also sufficiently characterized for the main anticipated feeds. However, minor constituents from the HDC and MPF have not been validated.

Agent reformation was validated not to occur for GB and HD, and although it was not validated, due to lack of VX hydrolysate testing, reformation of VX in the SCWO is not anticipated. VX reformation in caustic hydrolysate was shown not to occur at detectable levels.[104]

Neutralization/SCWO uses hydrolysis as the primary destruction mechanism for both energetics and agent. Data from demonstration testing confirm that Schedule 2 compounds are produced as a result of agent hydrolysis. Ethyl methylphosphonic acid (EMPA), methylphosphonic acid

(MPA), and diisopropylaminoethanethiol (VX-thiol) were generated as a result of hydrolysis of VX; isopropyl methylphosphonic acid (IMPA), diisopropylmethylphosphonate (DIMP), and MPA are generated from the hydrolysis of GB; and thiodiglycol (TDG) is generated from the hydrolysis of HD. The effectiveness of the SCWO process to destroy HD and GB chemical agent hydrolysates was validated. The Schedule 2 compounds thiodiglycol (from HD) and methylphosphonic acid (from GB) were destroyed to below detection limits. Similarly, TOC in the agent hydrolysate feeds was destroyed to below detection limits.

No EA2192 was detected at the completion of the VX hydrolysis; however, other hazardous intermediates are produced. Data from demonstration testing shows that HD hydrolysis resulted in sulfonium ions, 1,4-dithiane, 1,2-dichloroethane, and up to 7.4 µg/L dioxins/furans being fed to the SCWO. SCWO reduced dioxins/furans levels to a maximum of 10.38 pg/L, which is below EPA drinking water standards,[105] and reduced all other compounds of concern to below detection limits. Hydrolysis of energetics can produce large amounts of NOx, especially for the Tetrytol, which can be treated with commercial equipment if necessary. Propellant hydrolysis resulted in volatilization of *N*-nitrosodiphenylamine (NDPA), which will require containment in the ERH system. Energetic hydrolysis also produced cyanide, dioxins and furans, and (in the case of Tetrytol) picric acid at 30 mg/L, which were fed to the SCWO. The SCWO reduced all of these hazardous compounds to below detection limits. SCWO also treats the dunnage slurry generated from pallets and DPE. Although no information was available for PCBs, PCP was added to the dunnage slurry during demonstration testing and the results from the SCWO treatment of this slurry showed no PCPs above the detection limit.

In summary, there was good characterization of the process effluents for the demonstrated streams. Neutralization/SCWO does produce hazardous intermediates but effectively eliminates or treats these compounds to acceptable levels.

B.4.2.2.1.3 Sampling and Analysis

Prior to the start of neutralization/SCWO unit operations testing, most non-standard sampling and analysis methodologies passed validation testing, these included analysis for the following types of chemical substances:

- High-level: acetates and formates and anions in all matrices; cyanide in energetics hydrolysates
- GB and VX low-level analyses for caustic neutralization matrices.[106,107]
- HD low-level analyses for the neutralization matrix[108]
- Nitrocellulose analysis for the propellant hydrolysate matrix
- Low level energetics for neutralization matrices[109]
- Hazardous substances: acetates and formates, volatile organic compounds, anions, metals, and mercury in all matrices; cyanide and energetics in energetics hydrolysates; semivolatile organic compounds in all matrices except VX hydrolysate

The neutralization/SCWO process will use the following standard sampling and analysis methodologies:

- Gas sampling methods for energetics followed the US Army's Center for Health Promotion and Preventive Medicine (CHPPM)-developed and EPA-accepted Sampling Train for Energetic Materials protocol
- Modified standard gas sampling techniques for other hazardous substances
- All sampling and analysis techniques for SCWO liquid effluent.

These standard methodologies required no further validation as part of the ACWA demonstration. Although some results may have been biased low due to higher than expected moisture in the effluent gas stream, this is readily accommodated for subsequent sampling by use of a modified approach.

Several non-standard sampling and analysis methodologies failed validation testing or experienced relatively minor problems during demonstration. For this reason, the ACWA demonstration was unable to completely validate or verify methodologies for the analysis of the following types of chemical substances:

- Residual semivolatile organic compounds for VX hydrolysis failed validation because of the high levels of dilution required to avoid matrix interferences.
- Headspace gas from GB hydrolysis failed to provide usable samples due to the high moisture content and high pH of the headspace.
- Validation was unsuccessful only for carbonyl compounds in ERH samples (SW-846 method 8315C) because of unacceptable laboratory control spike recoveries. The results of the validation effort indicate that the matrix likely reacts with the carbonyl compounds and, if so, the concentrations of these constituents are likely to be low. Further investigation of this issue is warranted.
- Nitroglycerin results for ERH M28 runs had high (190 to 210%) spike recoveries. Better understanding of the cause of the high recovery is of interest but given that a high bias in the results is conservative from the standpoint of verifying destruction, this is not considered a high priority.[110]

During the neutralization/SCWO demonstration, most of the data generated has been deemed usable for evaluation of the technology and characterization of the process effluents. For those methodologies where minor problems were encountered, straightforward solutions appear to be feasible; future sampling and analysis should be possible. The level of verification for each type of analysis is given in Table B.4-4. Available documentation is insufficient to properly evaluate the performance of non-standard analytical methods used for characterizing non-demonstrated operations.

In summary, demonstration showed that sampling and analysis methodologies and techniques for the mass balance and for determining residual levels of agent, energetics, and other compounds of concern in the process matrices are for the most part verified and validated. For those methodologies where problems were encountered, straightforward solutions appear to be feasible; future sampling and analysis should be possible.

Table B.4-4. Level of Verification for General Atomics Analyses

Type of Analysis	Amount of Usable data
Feed and Product Composition	Acceptable
Low Level Agent	Acceptable
Low Level Energetics	Acceptable
Hazardous Substances	Acceptable

B.4.2.2.1.4 Process Maturity

In general, the unit operations that comprise the neutralization/SCWO total solution have a level of maturity adequate for timely implementation of the proposed total solution.

Pre-Treatment

The mature baseline reverse assembly process is used with minor modifications. These include adaptation of the PMD and RSM/RSS for mortar burster shearing and adaptation of the RSM/RDS for high-pressure water spray washing of the agent reservoirs. These modifications are only conceptual[111] and have never been built or tested but do not require major changes to the reverse assembly equipment and are not expected to be difficult to incorporate. Reprogramming of the RSM to shear shorter rocket sections is expected to be simple and will only increase maintenance (mostly from increased shear blade wear), as will the new rocket spray wash mechanism. The proposed changes to the baseline reverse assembly equipment should not have an adverse effect on designed (peak) throughput.

Cryofracture is well developed and has been previously demonstrated with a variety of full-scale ACWs.[112] Modifications from the demonstrated prototype relate to the basic accessing strategy. The proposed method requires cracking only explosives-free projectiles using a smaller press, not fragmenting of the entire munition. Explosive components are removed prior to cryofracture using baseline reverse assembly. Cryofracture alleviates problems noted with some reverse assembly operations such as solidified agent and pressurized agent reservoirs.

The size reduction (shredding) of dunnage and secondary wastes to sizes suitable for a slurried SCWO feed was demonstrated in full-scale equipment representative of the DSHS. In general, size reduction, classifying, and pulping are well developed and have been demonstrated commercially with waste similar to that proposed.[113] Material transport inside and between size-reduction equipment and containment of agent vapors and dust pose some operational challenges. The hydropulper was not validated and did not provide size reduction, but one work up run showed that it was able to effectively blend the energetics hydrolysates with size-reduced wood to yield a uniform, pumpable slurry for processing via SCWO. (In the proposed full-scale neutralization/SCWO facility design, no size reduction in the hydropulper is assumed). The DSHS demonstration had instances of uneven material flow between shredders and nesting/clumping of the shredded material. The materials transport problems, common to these systems, should be readily handled by the solutions incorporated into the proposed full-scale system (e.g., hoppers, screw feeders, larger feed throats).[114] The size reduction of polymeric material was demonstrated to less than 3 mm, but the 3-mm product was still sieved to 1-mm to ensure it could be fed to the SCWO. The full-scale system will use larger feed nozzle diameters that should be capable of accepting the dunnage material as shredded (i.e., without the need for additional processing).[115] Metal components must be removed from polymeric wastes before feeding to the DSHS—manual separation is proposed.

Rotary hydrolyzers are similar in design to commercial pulping equipment and to common commercial drum drying systems (e.g., rotary kiln, ball mills, etc.).[116] The ERH capability was successfully demonstrated at a representative subscale (½ diameter) using a batch tumbler configuration (no continuous helical transport). The PRH has not been built or tested, but the design and operation are very similar to that of the ERH.

Demonstration of the ERH included removal and destruction of energetics from bursters and the propellant from rocket motor sections and the majority of energetics from fuzes. During demonstration, energetics adhered to the flight and were lifted out of the caustic (flight design was such to allow removal of metal components for in-process visual inspection of hardware). In one instance, the energetic material caught fire due to the high temperature of the vessel wall. Changes to the tumbler lifts (to tumble rather than lift) and the addition of vessel wall surface spraying (which was demonstrated) are proposed for the full-scale system to mitigate this problem.[117] It is not known if these modifications will entirely alleviate the problem, and their effect on the ERH dissolution effectiveness is unknown. Explosive components within the fuzes cannot be accessed by dissolution in the ERH, and therefore will be thermally initiated in the HDC (demonstrated using a small oven).

There still remains the challenge of materials transport inside the rotary hydrolyzers and between the various unit operations. Optimization of the rotary hydrolyzers is also still required. Slow propellant dissolution extends the length of the ERH beyond the existing facility envelope of the baseline furnace system it is intended to replace. However, the use of smaller rocket motor segments is planned to help lessen this added length. In addition, it is not known what the requirements for explosive rating will be or how it will affect the equipment or facility design.

Treatment

The proposed chemical reagent hydrolysis operations for agents and energetics use common, commercial/industrial CSTR-based processing systems (vessels, fluid transport, heat exchangers, control principles, etc.). Hydrolysis is supported by extensive optimization and/or scalability testing. The agent hydrolysis process (ATP system for HD and VX) is well developed and demonstrated. Agent hydrolysis has been demonstrated for HD (55-gallon reactor) and for VX and GB (100-gallon reactor) in the ACWA program.

The hydrolysis of energetics was successfully demonstrated in equipment representative of full scale. Comp B and Tetrytol and M28 propellant were hydrolyzed in 6% and 12% caustic solutions. The caustic treatment for destruction of energetics and propellant is still in the initial development stage; therefore, processing conditions are subject to change (e.g., concentrations, loading, reaction times). The process remains unoptimized for hydrolysis of Comp B, Tetrytol, and M28 propellant. However, optimization of these simple batch processes is not considered difficult.

The HDC is a common, commercial tunnel furnace that is well developed for a variety of demilitarization applications. The induction heated MPF is also a tunnel furnace, but it is not representative of the baseline MPF. Furnaces and ovens similar to the proposed MPF (operating on principles of induction heating) are common, commercial equipment. However, incorporation of the baseline-like thermal treatment units (HDCs and MPF) as proposed was not part of the demonstration program and has not been tested. Concerns relate to the composition and condition of the feeds and the materials transport issues of the gaseous, condensed liquids, and solid waste products produced by the inert atmosphere of the system. The effects of the proposed HDC feed (consisting of cold and wet material [compared to baseline] with the possibility of trace explosives) are unknown, but are expected to require changes to the baseline HDC design. Modification of the MPF into an induction-heated system with an inert atmosphere is only conceptual. While it seems that there are many unknowns in the thermal treatment area, none are considered unsolvable. It is expected that they will consist of specially modified commercial unit operations that will effectively treat the process streams for which they are intended.

Post-Treatment

The proposed SCWO is a commercially available specialty item that is being tested at several locations internationally. SCWO has been tested at bench and pilot scale (1/10–1/20th of full-scale size) with a variety of chemical agents, simulants, and hydrolysates; energetics hydrolysates; dunnage; and secondary wastes. SCWO is to be used for post-treatment of VX hydrolysate for the Newport Chemical Demilitarization Facility. The preparation and pumping of SCWO slurry feed (solid secondary wastes with liquid energetic hydrolysate) has been demonstrated in equipment that is sub-scale compared to that proposed.[118] The increase in feed nozzle diameter (as proposed for the full-scale system) with the same particle size slurry achieved from the demonstrated DSHS should greatly reduce any prospects for plugging.[119]

The greatest concern with the maturity of the proposed total solution is the plugging[120] and corrosion minimization strategy for the SCWO system. A variety of operational and design aspects are proposed to minimize plugging and corrosion of the SCWO system, but few of these were tested or demonstrated to adequately control these particular problems. During demonstration, corrosion products from the Inconel™ reactor were prevalent in the SCWO effluent and the titanium-lined heat exchangers exhibited leakage caused by corrosion.[121] Salt plugging of the SCWO reactor was also observed during demonstration testing.[122]

Control of salt plugging is proposed through chemical pre-treatment and operational controls. Chemical treatment of the energetics hydrolysate to precipitate aluminum is proposed to minimize the quantity of insoluble, inorganic salt formation in the SCWO reactor.[123] However, the effectiveness of this strategy has not been adequately demonstrated (beaker tests were performed to verify the feasibility of the proposed separation method), and it is unknown how effective precipitation and removal will be or whether it will be adequate to prevent salt plugging. Operational strategies to minimize salt plugging could include periodic subcritical water flushing of the SCWO reactor to dissolve salt deposits. This has been demonstrated,[124] but will require further optimization.

Corrosion control is proposed through the use of corrosion resistant linings (i.e., platinum or platinum alloys) of the SCWO reactor and heat exchangers, but this has not been demonstrated. Welding of a platinum sleeve into the demonstration SCWO reactor was unsuccessful, but there are multiple options for reactor lining that are being investigated (although not yet proven) for the Newport demilitarization facility's SCWO system. Therefore, appropriate materials of construction for the SCWO remain unresolved. As a final option, less corrosion-resistant linings could be used with salt plugging minimization strategies, but this would require periodic replacement of the reactor or reactor lining.

A limited management strategy (use of condenser, scrubber, and carbon filtration) has been proposed for intermediate gaseous effluents. This equipment has not been tested with the proposed process. The concern is with the loading and unknown characterization (e.g., potentially containing untreated PCBs) of uncondensed gaseous effluent being sent to the carbon filtration system.

Scalability and Availability

As for scale-up, a number of critical unit operations have been tested in sizes predictive of full-scale. There is extensive data showing that scale-up of chemical reagent hydrolysis is relatively simple.[125] Full-scale hydrolysis tanks are commercially available. Large scale energetic hydrolysis has been demonstrated by the government. Munition access, via baseline reverse assembly or cryofracture, is based on existing full-scale technologies.

The basis for scale-up of the SCWO reactor to the proposed capacities has not been fully described or demonstrated. Concerns remain over the operation and organic destruction effectiveness of the SCWO reactor at larger diameters and/or lengths. Assurance that scale-up concerns will be successfully resolved is enhanced by the ongoing SCWO scale-up efforts for the Newport Chemical Demilitarization Facility.

The availability of equipment was not provided but is not expected to be a problem because of the multiple potential sources of equipment items. Most equipment should be commercially available, either off-the-shelf or made-to-order.[126] The platinum-lined SCWO reactor could not be fabricated in time for the demonstration, which indicates that this will be one of the most challenging aspects of equipment procurement. Adaptations/modifications of baseline equipment may require some minor design modifications.

Summary

Most of the neutralization/SCWO process equipment has a good history of operations, is readily available, and scalable. Baseline reverse assembly, cryofracture, neutralization, and the HDC were developed and are historically used for chemical weapons demilitarization. The DSHS, rotary hydrolyzers, and MPF each have an historical commercial industrial basis; however, the rotary hydrolyzers will need some optimization. SCWO is an emerging technology and is the least mature component of the total solution, most notably regarding the undemonstrated strategy for minimization of plugging and corrosion. This causes some reservation regarding the maturity of SCWO.

B.4.2.2.1.5 Process Operability

Several aspects of the proposed system are advantageous with respect to process stability. Agent hydrolysis and energetics hydrolysis had no stability problems during demonstration, and the ERH had minimal stability problems during demonstration. These operations are predicted to be insensitive to modest changes in process conditions and should be relatively stable operations with conservative designs. The PRH, HDC, and the induction heated MPF are expected to be similarly robust. Inherent process stability of the neutralization/SCWO process is enhanced by the batch nature and HT&R operating protocols for hydrolysis and SCWO.

There are some concerns, however, with respect to process stability with regard to the SCWO and the DSHS. Stable operation of the SCWO was demonstrated to be of concern for agent hydrolysates as evidenced by the formation of two salt plugs during the 100-hour VX hydrolysate simulant test run. The provider asserts that the insoluble salt plugging that occurred during this run was primarily a result of corrosion of the Inconel reactor and that use of a platinum lined reactor will eliminate the problem.[127] While chemical analysis of some of the salt plug material supports this explanation, there remains the possibility of salt plugging due to soluble salts created from the agent hydrolysates alone. Pressure fluctuations were also still occurring during the SCWO mixed energetics/dunnage hydrolysate validation runs, indicating the periodic buildup of salts in the reactor. Additional long-term testing of the SCWO system with agent and energetics/dunnage hydrolysates, to include a more thoroughly investigated use of additive compounds, will provide additional information on the long term stability of SCWO. The DSHS experienced several control instabilities due to feed buildup. These issues are expected to be improved with the addition of hoppers and auger feeders prior to the hammer-mill and micronizer.

There are some additional concerns regarding process stability. Further studies in the energetics hydrolysis area are required to assure the stability of processing all energetics and transportability of the resulting hydrolysates due to the viscosity of some partially hydrolyzed energetics. While thorough data was acquired on the operating parameters of the batch ERH, there still remains some risk for passage of excess energetics to the HDC that must be minimized. Thorough design data for the HDC must be developed in order to determine safe and consistent operating parameters of a continuous system as proposed for full-scale.

RAM characteristics for the full-scale plant are difficult to assess at this time because of limited testing conducted on many of these unit operations under the proposed conditions. Nevertheless, the full-scale system is expected to have average RAM characteristics. Baseline reverse assembly has known (marginal to average) RAM characteristics while cryofracture, agent and energetics hydrolysis, and rotary hydrolyzer operations are expected to have good RAM characteristics. SCWO RAM can only be assessed as marginal due to problems encountered during demonstration (plugging and corrosion). Appropriate materials of construction for the SCWO reactors and heat exchanger remain to be demonstrated for treatment of agent hydrolysates, which contain chloride and fluoride ions, known to accelerate corrosion of materials in high temperature environments. The DSHS is expected to have average RAM characteristics; but this can only be verified through additional testing and optimization.

The majority of unit operations in the neutralization/SCWO process are basic in concept and relatively simple in design, but the large number of unit operations required makes the overall system complex. Major unit operations include baseline reverse assembly (with modifications), cryofracture, DSHS, CSTRs for agents and energetics, rotary hydrolyzers, HDCs, an induction-heated MPF, and SCWO units.[128] Interfaces for the full-scale system are straightforward and well defined. The most complex interfaces for the process will be for DSHS, which contains nineteen separate units.[129] The full-scale system is expected to be moderately flexible with manageable demands for startup/shutdown, idle, upset recovery, and campaign changeover. A moderate number of operators with low-to-moderate skill levels will be required for the full-scale process. Unknown and potentially lengthy preventive and routine maintenance requirements are predicted for SCWO and the DSHS while known or standard preventive and maintenance requirements are expected for the remaining unit operations.

B.4.2.2.1.6 Process Monitoring and Control

The total process is not particularly demanding with respect to monitoring and control. Most of the unit operations have been and can be monitored and controlled using commercially available controls and instrumentation, including on-line monitoring and HT&R procedures.[130]

The effectiveness of the monitoring and control approach was validated in demonstration testing for agent hydrolysis and the ERH. However, there are some concerns remaining with these areas and with the HDC (following the ERH). There is an unresolved problem of false positives when monitoring for agent in the VX hydrolysate matrix (current work on an improved MINICAMS may solve this problem). There is no method for monitoring the potential passage of energetics (that remain on metal parts) from the ERH to the HDC, although any residual energetics are expected to be small and should be destroyed in the HDC with no deleterious effects. Although the HDC is designed to handle some energetics, ERH operational criteria, based on demonstration test data, are relied on to ensure that excess energetics do not pass to the HDC.

The monitoring and management strategy for PCBs is unknown; it is unclear if PCBs will be destroyed in the HDC or in the SCWO (via condensation in the ERH or condenser) or will remain with the solids in the HDC.

In general, the SCWO monitoring and control technologies were demonstrated to be effective. However, the SCWO monitoring and control system, relying on conductivity measurements of the liquid effluent, was unable to predict salt plugging of the reactor during the 100 hour VX hydrolysate simulant test.

Demonstration testing showed that development of monitoring and control for the DSHS system is required. There were numerous problems during wood shredding, mainly due to uneven material flow between size reduction units that caused nesting in the feed hoppers and plugging of the units. The provider proposes to use collection hoppers equipped with screw feeders in the full-scale facility to mitigate these problems.[131] For size reduction of DPE suits, the DSHS system was unable to segregate metal from the plastic, a step necessary to prevent damage to the granulator blades. For the full-scale facility operations, the provider proposes to remove the metal pieces from the DPE suits before shredding. It is not clear what monitoring and control techniques will be needed to produce the plastic material particle size required for SCWO feed. The use of thickening agents and/or other additives in the slurry to assure proper transport to the SCWO may require monitoring and control not established during demonstration.

In terms of safe operation, the SCWO monitoring and control technologies were able to prevent or control process upsets. The control system did shut down the SCWO demonstration unit on several occasions, presumably preventing process upsets. The SCWO control system also provides an on-line backup control computer. In the event of a computer system failure, the operator has 60 sec to switch control to the backup computer and avoid an automatic system shutdown. Cryofracture, hydrolysis in CSTRs, and the thermal treatments can easily be controlled to prevent upsets. The use of HT&R following agent and energetics neutralization minimizes the downstream consequences of any process upsets in these unit operations.

Monitoring and control systems for the CSTRs, DSHS, HDCs, and MPF are not complex. Monitoring and control systems for baseline reverse assembly, cryofracture, and SCWO are moderately complex, but monitoring and control of these operations has been demonstrated and proven effective (with the exception of predicting salt plugging in the SCWO reactor). The full-scale monitoring and control of the ERH will be more complex than that required in demonstration, which revealed the potential need for monitoring the full-scale ERH to prevent fires from undissolved energetics adhering to the ERH lifts, flights, or walls. Monitoring and control strategies need to be developed specifically for each energetic feed. For example, the proposed means to control foaming and boiling during M83 burster hydrolysis is complex; involving delayed start of sparge air and steam heating.

In summary, the process can be effectively monitored and controlled. There are some concerns remaining with respect to the dunnage shredding operation, the ERH, and SCWO, but these are considered manageable.

B.4.2.2.1.7 Applicability

General Atomics' neutralization/SCWO process is capable of demilitarizing all ACWs at all sites.

B.4.2.2.2 Safety/Worker Health and Safety

B.4.2.2.2.1 Design or Normal Facility Occupational Impacts

Workers are protected during normal operations by a number of administrative measures/controls and by some design features. The primary destruction processes (hydrolysis, ERH, HDC) are all remote operations that minimize worker exposure.[132] However, the HDC, PRH, DSHS, and cryofracture accessing operations may require worker intervention. The fully automated process control system accounts for the fact that shut-off of the feed and energy supply stops all processes. All of the processes, with the possible exception of VX and energetics hydrolysis, have no known, inherent tendency to cascade out of control. However, the VX and energetic hydrolysis reactions can be effectively controlled.

The neutralization/SCWO process uses five major process chemicals (sodium hydroxide, phosphoric acid, kerosene, liquid oxygen, and liquid nitrogen) in very high quantities.[133] Only one hazardous chemical (sodium hydroxide) is used in the primary destruction processes, the hydrolysis of the agents and energetics. The others are used during secondary SCWO treatment (kerosene, liquid oxygen, phosphoric acid, and provider-proprietary additives) and in the post treatment gas polishing system. Liquid nitrogen, a potential asphyxiant when evaporated, is used during projectile cryofracture accessing operations. All are low-to-moderate inhalation hazards, but sodium hydroxide, phosphoric acid, and liquid nitrogen are acute dermal hazards. Phosphoric acid is the most severe inhalation hazard and has a workplace inhalation permissible exposure limit of 1.0 mg/m^3.[134] The wood dust resulting from the processing of contaminated wooden dunnage can pose a chronic inhalation hazard to workers. The process does not require any flammable process chemicals, but does use a combustible fuel (kerosene) to supply thermal energy to the SCWO. All process chemicals are commonly used in industry and have well established handling procedures and industrial safety standards.

Equipment containment issues identified during demonstration need to be resolved. Although the hydrolysis reactors and SCWO provide vapor containment at the equipment level, the ERH and DSHS demonstrated limited containment capabilities. Redesign of the ERH and development of an effective DSHS management strategy would be required to eliminate the potential for chronic exposure to hazardous intermediate products (i.e., NDPA and wood dust). The ability of the HDC to contain the repeated deactivation of internal M557 fuze components through thermally-induced detonation has not been validated.

The projected physical workplace environment generates a few manageable risks. The scope of the manual operations associated with the shredder is not well defined in the final proposal; nevertheless, there appears to be an associated potential for continuous, awkward, repetitive motions and moderate lifting that could lead to risk of soft tissue skeletal injuries. Potential thermal dermal hazards associated with liquid nitrogen cryofracture operations and HDC hot surfaces are effectively mitigated by the prudent use of insulation and barricades. The process generates moderate noise and minimal vibration hazards. The potential need for PPE during cryofracture, HDC, and DSHS operations will lead to manageable worker thermal stress. Some maintenance may be required during operations, but the associated need for PPE is expected to be minimal. The HDC and SCWO units are self-decontaminating to 5X after normal shutdown, but may not reach a 5X level after a forced or emergency shutdown. A 3X self-decontamination capability is expected for the hydrolysis stirred reactors, ERH, and PRH, but this capability was not a test objective and was not established during demonstration. Other upstream processes (e.g., baseline reverse assembly, cryofracture accessing, and DSHS) are not expected to have any self-decontamination capability. Some process intermediates (e.g., VX hydrolysate) interfere (generate false positives) with agent monitors. General Atomics did not provide an interference management strategy. However, development of an effective one is not expected to require extensive development or modifications of existing equipment.

In summary, while the overall process is inherently low risk, equipment containment and agent monitoring issues will improve worker safety during normal operations. Effective administrative and process controls, self-decontamination capability, and manageable process chemicals enhance safety.

B.4.2.2.2.2 Facility Accidents with Worker Impact

Workers are protected during normal operations by a number of administrative measures/controls and by design features. Agent and energetic destruction occurs at relatively low temperature and near ambient pressure. The SCWO (750°F) and cryofracture (-321°F) systems generate extreme process temperatures and SCWO generates high internal pressures (approximately 3,400 PSI). These operating parameters are inherent to the process and pose a high potential for leaks and significant operator risk. The proposed use of high performance protective barriers effectively mitigates these risks.[135] In addition, the severity of potential accidents is minimal because the most hazardous operations (SCWO, hydrolysis, and rotary hydrolyzers) are remote operations with effective, fully automated process controls.[136] The VX and energetic hydrolysis reactions and SCWO are exothermic reactions, with slight, but easily manageable, potentials for cascading out of control. Further, these reactions can be effectively controlled. Elimination of the feed and/or energy supply effectively stops the reactions. Early HT&R points within the most critical process streams (agent and energetic hydrolysis) enhance worker safety. The HDC, PRH, DSHS, and cryofracture accessing operations may require worker intervention.

The process uses five major process chemicals in very high quantities.[137] Since none of the process chemicals are acute inhalation hazards, the severity of any leaks should be manageable and should pose a low health risk. Prudent use of commercial chemical monitors and standard HAZMAT spill procedures should effectively mitigate the risk associated with sodium hydroxide, 85% phosphoric acid, or kerosene leaks or spills. Both liquid nitrogen, a potential asphyxiant when vaporized, and liquid oxygen pose negligible inhalation risk. However, leaks of both the process chemicals and agent and energetic hydrolysates pose a significant acute dermal hazard. Storage and use of the kerosene poses only a minor fire risk. The wood dust resulting from the processing of contaminated wooden dunnage can pose a chronic inhalation hazard to workers. All process chemicals are commonly used in industry and possess well-established handling procedures and industrial safety standards

Equipment containment issues identified during demonstration need to be resolved. Incidents occurring during demonstration[138] verified that current proposed ERH and HDC processing parameters are capable of igniting or detonating, respectively, energetic materials (Comp B and M557 fuzes) during processing. While the provider proposes equipment design changes to control the hazards, they are not eliminated and containment is not assured without additional testing. In addition, fine wood dust generated by the wood micronizer poses a potential explosive hazard. The wood dust from contaminated dunnage and potential leaks of ERH and HDC off-gases are intermediate process generated hazards that need to be addressed prior to further process development.

Although the process does not require any flammable process chemicals, it does use a combustible fuel (kerosene) to supply thermal energy to the SCWO. However, there is minimal risk of a fire or explosion because only insignificant volumes of flammable gases are generated and there is a lack of any apparent ignition sources.[139] Asphyxiation caused by nitrogen displacement of air is remotely possible. Any potential fugitive emissions can be effectively monitored and minimized. In short, the risk from gaseous emissions is manageable and minimal.

Most final products have been identified and characterized and pose little risk to the operators. While it was not demonstrated as such, the induction-heated MPF is expected to generate 5X level explosive deactivation and chemical decontamination.

In summary, although the process inherently involves some severe physical hazards, the proposed prudent use of engineering and administrative controls should greatly reduce both the severity and probability of their occurrence. However, the effectiveness of the proposed equipment redesign efforts to address ERH fugitive emissions and energetic ignition containment issues and the HDC containment issues identified during demonstration need to be verified.

B.4.2.2.2.3 Facility Accidents with Public Impact

The process requires five major process chemicals to achieve complete destruction of both the agent and explosives. None are highly volatile and all are typical of chemicals used in light industry. All process chemicals are characterized as low-to-moderate toxicity and persistency. The process requires a relatively large quantity of process chemicals. The process generates a large volume of intermediate chemicals (agent and energetics hydrolysates) which, when fully processed, pose minimum potential inhalation hazard to the public. The process has not demonstrated a potential for cascading out of control. Since the process does not require any agent accumulation and only limited energetic accumulation,[140] the severity of potential incidents is greatly reduced. Early HT&R points within the agent destruction process stream enhance public safety. Since both agent destruction and energetic deactivation are achieved by hydrolysis at low (ambient) pressure and temperatures, the probability and severity of potential leaks is minimal. Although a combustible process chemical (kerosene) is used and trace volumes of flammable gases are generated, the risk of a fire or explosion is minimal.

In summary, because of the low volatility of the process chemicals, major intermediates, and products, the minimal potential for fires or explosions, and an effective process control system, there is minimal public risk affiliated with the neutralization/SCWO process.

B.4.2.2.2.4 Off-Site Transportation Accidents

Five major process chemicals would have to be transported on-site. Of these chemicals, none is an acute inhalation hazard or carcinogenic. However, both process chemical and solid waste effluents transportation requirements will be high relative to the amount of chemical agent treated.

The process chemicals are DOT classified as corrosive (sodium hydroxide[141] and phosphoric acid[142]), combustible (kerosene),[143] a nonflammable gas-oxidizer (oxygen),[144] or as a nonflammable gas (nitrogen).[145] They are not acute inhalation hazards and would pose minimal risk to nearby populations in the event of a transportation accident.

Waste materials that would have to be transported off-site have been identified and are well characterized for all feeds. The waste products will be dried salts from the SCWO effluent stream and 5X decontaminated metal parts or solids from the MPF and HDC process streams. Of the waste materials identified to date, none are classified as poisonous or hazardous by DOT for transportation purposes.

Standard HAZMAT and fire department PPE, containment equipment, and techniques are sufficient to contain any potential spills. No special training beyond OSHA HAZMAT and DOT requirements is needed. Evacuation zones for potential process chemical spills are minimal-to-average and the largest does not exceed 100 yards.[146]

In summary, only standard HAZMAT or fire department PPE and training are required when responding to any potential spill. The need to transport high volumes of hazardous process chemicals is offset somewhat by the average volumes of solid waste generated. There is minimal risk associated with transportation issues.

B.4.2.2.3 Human Health and Environment

B.4.2.2.3.1 Effluent Characterization and Impact on Human Health and Environment

Effluent characterization data demonstrated minimal impact on human health and environment. The chemistry of the process (agent/energetics hydrolysis and SCWO) is well characterized and has been demonstrated to produce acceptable treatment results. The hydrolysis process had no perceivable problems and is expected to operate as proposed. The most significant unknown for effluent characterization is the management strategy for PCBs, because the treatment of these compounds was not demonstrated (see Section B.3.3). Although the SCWO system should adequately treat this compound the accountability and management of this pollutant is not addressed in the final report.

The air effluent from the SCWO system demonstrated primarily non-toxic gases with negligible SOx and NOx production. Dioxins/furans were found in the gaseous effluent from the SCWO at 25-100 pg/m^3 levels,[147] 250 to 1,000 times less than typical incinerator emission limits.[148] Although characterization of product gases from HDCs and the MPF was not included in the demonstration test program, their effluent streams will be condensed, scrubbed and discharged to the heating, ventilation, and air-conditioning (HVAC) system. The impact of these unit effluents will be assessed later, but should not adversely affect the effluent quality of the final plant. In addition, SCWO gaseous effluents will be vented through an in-line carbon filter and the HVAC charcoal filters, lowering the risk of toxic gaseous effluents.[149] Odors from SCWO, HDC, and MPF processes will be reduced by engineering controls (carbon filter and HVAC), and odor is not expected to be an emission issue.

There is no projected liquid effluent. The SCWO brine, the primary liquid product, will be sent to the BRA where the water will be evaporated and condensed for reuse. The remaining dried salts will be containerized before disposal in a hazardous waste landfill. The baseline brine reduction operation as proposed by the provider is not employed at TOCDF. Disposal of scrubber liquid at an off-site location was found to be more cost effective than on-site drying and disposal. This raises concerns about the ability of the provider to recycle scrubber brine as proposed, reducing off-site waste disposal. This could require significant changes to the provider's water effluent and reuse plans, since the provider indicates in the final report that there will be no liquid effluents.

Effluents to land will consist of the residues of fractured projectile bodies, dried scrubber salts, HDC/MPF solids, and SCWO salts. No management strategy for heavy metals was provided.

SCWO effluents during demonstration contained lead,[150] nickel, and chromium.[151] These metals will be concentrated in the BRA dried salts. The provider states that platinum lining will reduce metals concentrations by limiting corrosion of the reactor, however this was not demonstrated. The technology provider states this waste stream will not exhibit RCRA hazardous characteristics,[152] but this still must be verified through testing with the platinum-lined reactor. A large volume of solid wastes will be produced and it is expected there will be no major problems with disposal strategies.

Sampling and analysis methodologies have been proven for major constituents and breakdown products in air and liquid for the unit processes. Monitoring uses standard technologies including ACAMS and DAAMS tubes (both GC gas sampling). Appropriate and valid monitoring of SCWO liquid effluents for agents VX, HD, and GB was validated.

The overall impact on human health and environment is acceptable.

B.4.2.2.3.2 Completeness of Effluent Characterization

Gaseous and liquid effluents from SCWO are well characterized for all demonstrated effluents. Characterization of product gases from HDCs and the MPF was not part of the demonstration program and therefore was not performed. PCB treatment effectiveness was not addressed in demonstration. Minor constituents (i.e., heavy metals and dioxins/furans) are not included in the material balance, nor discussed in the report.

The overall effluent characterization is acceptable.

B.4.2.2.3.3 Effluent Management Strategy

There is a general waste management plan but there are no specifics on waste disposal.[153] A commercial SCWO facility is given as an example, but no details are provided. The SCWO and scrubber salts from the BRA may require stabilization of heavy metals prior to disposal; this issue was not addressed in the provider's final report. All waste streams should be amenable to further treatment if necessary. The provider's plan cites the baseline operation as a model. The baseline brine reduction operation as proposed by the provider is not employed at TOCDF. Disposal of scrubber liquid at an off-site location was found to be more cost effective than on-site drying and disposal. This raises concerns about the ability of the provider to recycle scrubber brine as proposed, reducing off-site waste disposal. The ATP is developing an evaporator/crystallizer system for the Newport CDF which may be substituted for the drum dryers. If SCWO salts are not dried as proposed, plant recycled water options may not be feasible and other waste streams may be created that need further management. There is no discussion of the treatment of TSCA controlled PCB’s or any plan for possible PCB waste stream disposal.

All air streams from reactors are scrubbed and filtered through the HVAC before discharge. Liquid and solid waste streams are sent to the SCWO for final treatment. The dried brine from the SCWO liquid slurry is held before disposal.

The technology provider has had some experience in managing similar waste streams, but has no experience in managing agent-derived RCRA waste. Overall, analysis indicates that effluents appear treatable and disposable.

B.4.2.2.3.4 Resource Requirements

Specific water and energy requirements could not be quantitatively verified from the information in the technology provider's final report,[154] however, a qualitative assessment has determined that no unusual requirements are anticipated. Water recovery and recycle may further mitigate water use.

B.4.2.2.3.5 Environmental Compliance and Permitting

The provider does not specifically discuss permits for the two preliminary designed facilities.[155] Based on demonstrated equipment, permits will be required for final discharge streams but anticipated discharge limitations can be met with demonstrated controls. The provider did not address a specific program for training, inspections, or compliance monitoring in the final report.

The technology provider had no discussions on corporate permit experience in the final report. The Army has obtained RCRA and CWA permits for a bulk mustard neutralization facility in Maryland. The Army is obtaining a RCRA permit for a bulk VX neutralization and SCWO process at the Newport Chemical Activity in Indiana.

Lack of detail in the provider's final report lowers confidence in compliance and permitting, however an acceptable permitting strategy is possible.

B.4.2.2.4 Potential for Implementation

B.4.2.2.4.1 Life Cycle Cost

Based upon the information provided in General Atomics' final technical report,[156] it was possible to develop total capital cost estimates for both Pueblo and Blue Grass. These estimates, presented in Table B.4-5, are expressed in constant dollars with no inclusion for either escalation, de-escalation, productivity gains/losses in labor or material supply, or cost growth in materials. The accuracy of the cost estimate is within the +20/-10% range. The analytical approach used to develop these estimates is presented in Attachment B-D.

As indicated in this table, the total capital cost for the proposed neutralization/SCWO process for the destruction of ACWs at both Pueblo and Blue Grass is comparable to that for the baseline incineration process. At Pueblo, the total capital cost may be approximately 10% less than/equal to that of baseline incineration, whereas at Blue Grass the total capital cost may be approximately 5% less than/equal to that of baseline incineration. The cost analysis showed that nearly 65% of the total capital cost for the solution proposed neutralization/SCWO process is attributed to equipment and buildings common to baseline incineration and the two other alternative technologies tested.

Table B.4-5. Total Capital Cost Estimate for General Atomics' Neutralization/SCWO Process

General Atomics Neutralization/SCWO Process	Pueblo Total Capital Cost ($Millions)	Blue Grass Total Capital Cost ($Millions)
Installed Core Process Equipment	96	97
Installed Baseline Equipment Additions	35	36
Total Installed Equipment Cost	**131**	**133**
Buildings and Support Facilities	225	230
Total Capital Cost	**356**	**363**
Comparison to Baseline	**About 10% Less**	**About 5% Less**

Sufficient information currently does not exist to make a reasonable estimate of proposed O&M costs for neutralization/SCWO. However, based upon a review of the proposed process, it was independently estimated that the O&M labor requirements would be comparable to those for baseline incineration. Furthermore, because O&M labor requirements account for 65 to 70% of the total O&M costs for baseline, it is likely that the total O&M costs will be comparable to baseline. This is also because no extraordinary chemical usage or utility requirements are anticipated for the neutralization/SCWO process.

B.4.2.2.4.2 Schedule

The basic schedule assumptions, key milestone activities, and key activity duration periods used to develop an implementation schedule are summarized in Attachment B-D. The following key points are unique to the implementation of the proposed neutralization/SCWO process:

- Completion of the EIS and ROD approval takes a total of 16 months.
- Duration of Maturation Testing for both Pueblo and Blue Grass is 8 months.
- Operations, based on information provided by General Atomics, is 33 months and 18.5 months for Pueblo and Blue Grass, respectively.

Based on these durations and those specified in Attachment B-D, the key milestones and corresponding dates to implement the neutralization/SCWO process on a full-scale basis were developed. These are summarized in Table B.4-6 for both Pueblo and Blue Grass.

As indicated in the table, the schedule estimates developed for the demilitarization of ACWs utilizing the General Atomics neutralization/SCWO indicate the following dates for completion of operations:

- Pueblo: September 2011
- Blue Grass: July 2011

Applying the same analytical approach to the schedule for baseline incineration (see Attachment B-D), the schedule for implementing the proposed neutralization/SCWO process is comparable to that for baseline incineration. Using similar key milestone start dates and assumptions, the completion dates for the baseline plants at Pueblo and Blue Grass are:

- Pueblo: December 2009
- Blue Grass: May 2010

Although these implementation schedules are not completed until after the CWC date of 29 April 2007, demilitarization operations for neutralization/SCWO and baseline incineration are estimated to likely be completed within the possible 5-year CWC extension. Within the confidence level (75% likelihood of success) of these schedules, the implementation schedules of neutralization/SCWO and baseline incineration are comparable. The most significant uncertainty with the baseline incineration's estimated schedule is with respect to permitting. It is assumed that there is no difference in the time required for the RCRA Part B approval process between the neutralization/SCWO process and baseline incineration. However, this assumption does not necessarily reflect the history of public opposition to baseline incineration. It is believed that the program completion dates for the neutralization/SCWO process and baseline incineration are essentially the same for either Pueblo or Blue Grass.

Table B.4-6. Implementation Schedule for General Atomics' Neutralization/SCWO Process

Key Milestones	Dates for Pueblo	Dates for Blue Grass
EIS Start	31 October 1999	31 October 1999
Maturation Testing Start	1 January 2000	1 January 2000
RFP Release	31 August 2000	31 August 2001
Final EIS/ROD	28 February 2001	28 February 2001
Contract Award	28 February 2001	28 February 2002
Final Design (65% Completion)	31 August 2001	31 August 2002
RCRA Part B Issued	30 November 2002	30 November 2003
MDB Construction Start	30 November 2002	30 November 2003
MDB Construction Finish	31 July 2005	31 July 2006
Systemization Start (Pilot Train)	1 January 2006	1 January 2007
Systemization Start (All Trains)	1 July 2008	1 July 2009
Operations Start	1 January 2009	1 January 2010
Operations Finish	30 September 2011	15 July 2011

B.4.2.2.4.3 Public Acceptance

Based on input from the Dialogue, the neutralization/SCWO process was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

B.4.3 Parsons/AlliedSignal Neutralization/Biotreatment

This section of the technical evaluation report covers the description and evaluation of the technology proposed to PMACWA by Parsons/AlliedSignal.

B.4.3.1 Description of the Proposed Technology

The process uses modified baseline reverse assembly to access agent and energetics, which are then neutralized using caustic or water hydrolysis and finally biotreated. Hardware is thermally decontaminated.

B.4.3.1.1 ACWA Total Solution

As shown in Figure B.4-4, Parsons/AlliedSignal proposed total solution starts with munition pretreatment, which uses baseline reverse assembly, water-abrasive cutting, and fluidmining. The projectiles are accessed using baseline reverse assembly. The MDM will be used to access the agent cavity and drain the projectile. Projectile fuzes and bursters are removed by the PMD. The fuzes are fed to the continuous steam treater (CST) and the bursters are fluid mined using water. The rockets will be punch and drained using baseline equipment and then radially cut in three places simultaneously—separating the fuze, warhead, motor, and fin assembly. Bursters are then fluid mined to remove the energetics. The igniter/anti-resonance rod assembly is pulled out of the motor and the M28 propellant grain is pushed out of the casing in its entirety. The grain is then sheared and shredded to produce a slurry.

Projectiles, basketed munition hardware, washed rocket sections, dunnage, and other solid wastes are thermally decontaminated to 5X in either the MPT, an inductively heated vessel with a superheated steam reactive environment or the CST, a rotary version of the MPT with a similar structure to the baseline Deactivation Furnace System (DFS). Steam is condensed from the MPT and CST offgas and sent to the Condensate Recovery System (CRS). Water hydrolysis is used to neutralize mustard agents, and sodium hydroxide caustic hydrolysis is used to neutralize nerve agents and energetics in Continuously Stirred Tank Reactors (CSTRs) similar to the Army's ATP process. Drained agents and CRS effluents are treated in the Agent Hydrolyzer while slurried energetics (from cutting, mining/washing) and spent abrasive wash are treated in the Energetics Hydrolyzer.

Agent and energetic hydrolysates are pH-adjusted, combined, and mixed with reagents and premixed nutrients for aerobic digestion (biotreatment) in the Immobilized Cell Bioreactor (ICB™). For nerve agents only, a side stream from the clarifier is removed and subjected to a UV oxidation polishing step. For all agents, the clarifier side stream is then sent to water recovery where it is evaporated to concentrate the salt content. Sludge from the ICB is dewatered, packaged, and RCRA landfilled. Liquid from sludge dewatering is sent to the recovered water storage tank for re-use. All process offgas is mixed with air and catalytically

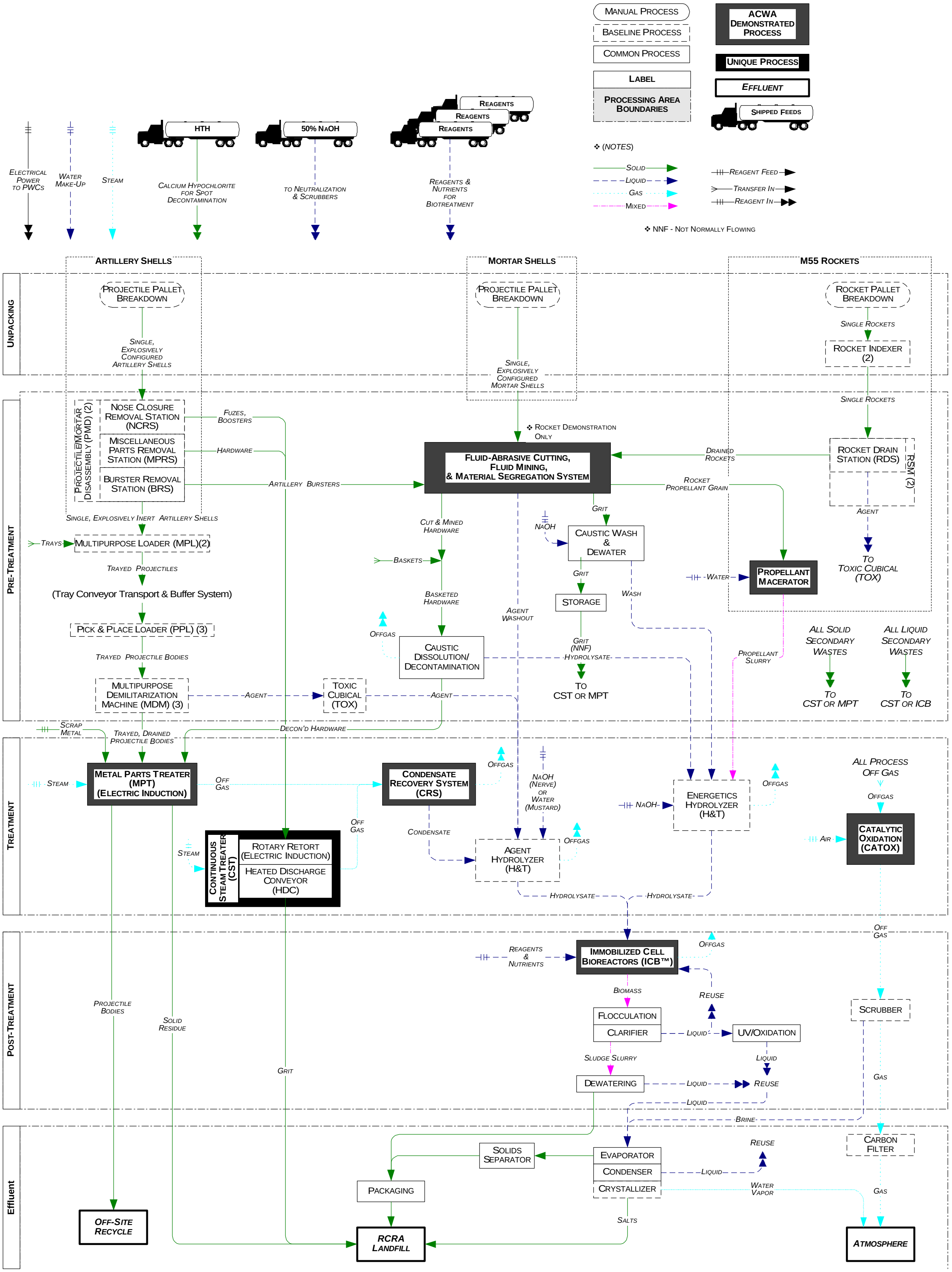

Figure B.4-4. Parsons/AlliedSignal Total Solution Process Flow Diagram converted by the catalytic oxidation (CatOx) system, followed by scrubbing, carbon filtration, and release to the atmosphere. Oxidized liquid and scrubber brine are dried—first concentrated by evaporation, with water condensed and reused, followed by crystallizing, with water vapor released to the atmosphere and dry salts sent to a RCRA landfill. 5X munition bodies are commercially recycled and 5X solid waste is landfilled.

No process is proposed for M23 landmines.

B.4.3.1.2 Unit Operations Not Demonstrated

As discussed previously in Section B.3.3, baseline reverse assembly, carbon filtration, and brine reduction were not demonstrated. Other unit operations proposed by Parsons/AlliedSignal were also not selected for demonstration. The reasons PMACWA elected to not demonstrate these units are as follows:

Continuous Steam Treater (CST). This is a new addition to the proposed full-scale process that was incorporated after demonstration was conducted. It is described as a rotary version of the MPT.

Dunnage Processing (non-contaminated). The originally proposed non-contaminated dunnage processes (shredding, neutralization, and biotreatment) were not considered pertinent to ACWA mixed munitions demilitarization.

B.4.3.1.3 Unit Operations Demonstrated

This section explains the rationale for selecting the Parsons/AlliedSignal's neutralization/biotreatment demonstration unit operations, the objectives of testing, and significant deviations from the planned testing.

Agent Hydrolysis. The Army has previously demonstrated agent hydrolysis extensively. PMACWA ran agent hydrolysis units primarily to provide representative feedstock for biotreatment and to characterize the intermediate product stream for residual agent, Schedule 2 compounds, and other substances required to verify the mass balance.

The specific test objectives of these demonstration units included the following:

- ❑ Design, fabricate, and deliver GB and VX hydrolysate production systems with the production capacity of 100 gallons of hydrolysate per run
- ❑ Use the hydrolysate recipes developed and tested by ECBC.
- ❑ Demonstrate that the agent concentration in the hydrolysate solution is less than the Waste Control Limit by using the analytical methods developed and approved by ECBC
- ❑ Characterize solid, liquid, and gas process streams.
- ❑ Provide agent hydrolysate in support of demonstration testing

Approximately 1,100 gallons of GB hydrolysate and 400 gallons of VX hydrolysate were produced in a newly constructed 100-gallon CSTR at CAMDS. The design and manufacture of a hydrolysis system provided information on equipment and operational parameters that can be used for scale-up to a full-scale facility. Approximately 145 gallons of VX hydrolysate and 761 gallons of GB hydrolysate were available for use in the ICB units at CAMDS.

Approximately 4,200 gallons of HD hydrolysate were produced in a campaign of 120 batch runs. The equipment used was not intended to be a model for scale-up to a full-scale facility, but was an expedient design suitable for use in the contained environment of the Chemical Transfer Facility at Aberdeen Proving Ground. Approximately 2,200 gallons of the HD hydrolysate were available for use in the ICB unit at ECBC.

Energetics Hydrolysis. Other government agencies have previously demonstrated energetics hydrolysis; however, further knowledge of the process was needed for evaluation, feedstock for biotreatment was required, and the characterization of the intermediate product streams for residual energetics and other substances were required to verify the mass balance.

The test objectives of this demonstration unit included the following:

- Produce hydrolysate feed for use in subsequent unit demonstration testing.
- Characterize solid, liquid, and gas process streams.
- Gather process operation information to support future scale-up.

Eight hundred ninety (890) pounds of M28 propellant was hydrolyzed with 6% sodium hydroxide to produce approximately 2,000 gallons of hydrolysate in one production run at the Radford Army Ammunition Plant, Radford, Virginia. Four hundred fourteen (414) pounds of Comp B and 63 pounds of Tetrytol were also hydrolyzed using 6% sodium hydroxide in 78-pound batches at the Pantex Plant, Amarillo, Texas and used as feed stock for the ICBs.

Rocket Cutting and Fluid Mining. Fluid abrasive cutting and fluid mining are reasonably well-established industrial operations; the ability to cut through the materials in an M55 rocket was not the major reason for demonstrating the operation. Rather, the rationale for demonstrating these operations was to verify their application to accessing energetics in the ACW components. Another reason for demonstrating these operations concerned adaptation of fluid-abrasive cutting to the baseline reverse assembly equipment, as proposed by Parsons/AlliedSignal. Fabrication of robotics for automating fluid-abrasive cutting was not viewed as a requirement, but demonstrating the effectiveness of the system to access, extract, and wash out energetics was required. In addition, characterization of the quantity and type of grit required, fluids produced, energetics remaining in the rocket, and the size distribution of energetic particles from rocket access and washout was considered important.

The rocket cutting and fluid mining unit operation was designed to demonstrate the fluid-abrasive cutting and fluid mining of M55 rocket energetic components. The objectives of this demonstration unit included the following:

- Demonstrate the ability to perform circumferential cuts of a rocket at required locations along the rocket length
- Demonstrate effective fluid mining and separate collection of rocket bursters, motor propellants, and residual agent simulant

- ☐ Demonstrate the ability to maintain control of rocket metal and plastic parts from cutting and fluid mining operations
- ☐ Determine energetic particle size of fluid mined rocket bursters and propellant
- ☐ Determine the requirements for separating used grit from the residual cutting solution

The demonstration tests were conducted with ten 115-mm inert M60 rockets, which are filled with concrete and plaster of Paris, and ten M61 rockets, which are filled with ethylene glycol and contain the same M417 fuze, Comp B burster, and M28 propellant as the M55 rocket. The demonstration unit used fluid-abrasive cutting to remove the fuzes and cut the rocket casing, used fluid mining to wash out the burster energetics, and proposed to fluid mine the propellant. However, the demonstration of propellant fluid mining was terminated prior to the start of validation testing.

There were several aspects of the proposed fluid cutting and mining or wash out operations that PMACWA had considered to demonstrate, but were not in the final matrix. These included fuze washout, fluid-abrasive cutting of mortars, and use of the process effluents for subsequent unit feeds. These items were determined not to be necessary for a successful demonstration. The fuze washout and cutting of mortars were removed from the proposed process, so their need for demonstration is no longer applicable.

B.4.3.1.3.1 Immobilized Cell Bioreactor

AlliedSignal has established the ICB as a commercial treatment for industrial wastewater. Thus, a primary reason for demonstrating the ICB was to validate it with the hydrolysates generated from ACW materials in the proposed configurations.

PMACWA determined that it was necessary to conduct separate ICB demonstrations because the HD/Tetrytol hydrolysate ICB uses a different design than the ICBs for VX/Comp B/M28 propellant hydrolysate and GB/Comp B hydrolysate and the products of each of these hydrolysates represented unique challenges to biotreatment technology. Furthermore, the ICB requires several weeks to acclimate, and validation testing requires approximately 40 days; it is effectively impossible to run two separate validation tests with a single ICB within the period available for the ACWA demonstration.

In addition to the primary operation of the ICB, the demonstration also included water recycling to verify the effectiveness of the Fenton’s reagent (hydrogen peroxide/ferrous sulfate) on each specific feed both for destruction of the compounds of concern and for its impact on water recycle. This also allowed the demonstration to obtain a detailed characterization of what remains in solid biomass (which is required for disposal) and what constituents return with the recycled water. In addition, three ICB CatOx units were included as part of the ICB unit operation (one for each ICB). The CatOx units were included to validate their performance with the ICB gaseous effluent and to allow a detailed characterization of product gases for final treatment.

The ICB was designed to demonstrate the ability to biotreat the agent and energetic hydrolysates generated as discussed in Section B.3.3. The objectives of these demonstration units included the following:

- Validate the ability of the unit operations to eliminate Schedule 2 compounds present in the hydrolysate feeds
- Confirm the absence of agent in the unit operations' effluents
- Validate the ability of the Agent Hydrolysis processes, and the ICB, Flocculation Reactor, and Clarifier unit operations to achieve a DRE of 99.9999% for agent
- Validate the ability of the Energetic Hydrolysis processes, and the ICB, Flocculation Reactor, and Clarifier unit operations to achieve a DRE of 99.999% for energetics
- Develop mass loading and kinetic data that can be used for scale-up of the ICB, Flocculation Reactor, and Clarifier unit operations
- Validate the ability of the CatOx to eliminate the volatile organic compounds, semivolatile organic compounds, and Schedule 2 compounds specified in the demonstration study plan from the ICB process gas streams
- Determine the potential impact of operating conditions on the fouling and plugging of the CatOx
- Characterize the gas, liquid, and solid waste streams from the unit operations for the constituents specified in the Demonstration Study Plan

ACWA conducted three separate ICB demonstrations, one for each of the following combinations of agent and energetic hydrolysates:

- HD hydrolysate and Tetrytol hydrolysate, which simulates the material contained in the M60 105-mm artillery shell
- VX hydrolysate, Comp B hydrolysate, and M28 propellant hydrolysate, which simulates the material contained in the M55 rocket
- GB hydrolysate and Comp B hydrolysate, which simulates the material contained in the M426 8-inch artillery shell

Each ICB demonstration unit consisted of the ICB plus an associated Flocculation Reactor, Clarifier, and ICB CatOx.

Certain aspects of the ICB operations were considered for demonstration but were not included in the final test matrix. These included determining the sensitivity of the ICB to expected impurities such as MPT liquid effluents and demonstrating sludge dewatering and brine reduction for detailed characterizations for disposal requirements. These items were determined not to be necessary for a successful demonstration.

B.4.3.1.3.2 Metal Parts Treater

The MPT is a thermal treatment unit, which treats metal parts and dunnage to 5X conditions by maintaining the temperature above 1,000°F for the required time. Although the ability of the MPT to effectively treat metal parts to a 5X condition was not a primary reason for demonstrating the unit, the need to demonstrate the MPT resulted from several issues raised during the initial evaluation. The issues included the ability to treat dunnage, the ability to control agent driven from metal parts, and the need for characterization of products for all process streams.

Due to the lack of information of the effluents from the MPT, it was considered important to test the unit with as many varied feeds as possible. The MPT was therefore demonstrated using mortar bodies containing a quantity of agent representing a 10% heel of GB, VX, and HD. This was considered a worse case scenario based on Parsons/AlliedSignal's original approach of washing out the projectiles. The MPT was also tested with carbon, PCP-contaminated wood, fiberglass rocket firing tubes, and DPE.

Part of the gaseous effluent treatment for the MPT includes another CatOx followed by charcoal filters. The most important reason for conducting this demonstration was to characterize the effluents from the MPT. The demonstration of the CatOx was also considered important because this unit has the potential to extend the life of carbon filters in variety of demilitarization applications. If the MPT were to produce agent or schedule 2 compounds in the gas phase, the CatOx could treat them; validation of this capability was a reason for the demonstration. A direct challenge of neat agent was seen as the ultimate test of this unit, so HD, VX and GB were all directly fed into the unit to determine the ability of the CatOx to destroy any agent volatilized in the MPT.

The MPT unit operation was designed to demonstrate the MPT, its associated CRS, and the attached CatOx. The objectives of these demonstration units included the following:

- Validate the ability of the MPT process to treat dunnage
- Determine what pyrolysis products are produced in the MPT during processing of dunnage, and their impact on the downstream condenser
- Characterize the liquid effluent from the MPT condenser to determine its suitability for processing in the Agent Hydrolysis reactor
- Validate the ability of the MPT condenser and the CatOx to eliminate chemical agents and Schedule 2 compounds from the process gas stream
- Determine the potential impact of operating conditions on the fouling and plugging of the CatOx
- Characterize the gas, liquid, and solid waste streams from the MPT for the constituents and properties specified in the Demonstration Study Plan
- The MPT unit operation was tested with the following:
  - M2A1 mortar body with 10% liquid agent heel (GB, VX, and HD)
  - wood pallet material spiked with 0.4% PCP
  - carbon
  - fiberglass shipping and firing containers
  - double bagged DPE with boots and gloves

In addition, the CatOx portion of the unit was tested with direct GB, VX, and HD vapor feed.

B.4.3.2 Technical Evaluation

The PET has determined that neutralization followed by biotreatment as proposed by Parsons/AlliedSignal is a viable solution for the destruction of chemical weapons containing mustard, but is not a viable solution for the destruction of chemical weapons containing nerve agents GB and VX. The inability of the ICBs to effectively treat the Schedule 2 compounds produced as a result of caustic neutralization of nerve agent is the main reason for determining that the Parsons/AlliedSignal biotreatment process is considered unacceptable for processing nerve agents. The inability of the process to adequately treat nerve agent derived Schedule 2 compounds will be reflected in the evaluations of several factors, as noted below.

B.4.3.2.1 Process Efficacy/Process Performance

B.4.3.2.1.1 Effectiveness

The effectiveness of the aqueous neutralization of chemical agents was demonstrated previously by the Army, and was confirmed for HD, GB and VX during this demonstration. HD was not detected in the hydrolysate product at levels as low as 11.4 μg/L,[157] indicating a destruction efficacy of greater than 99.99997% for HD. GB was not detected in the hydrolysate product, with a detection limit of 7.4 μg/L, indicating a destruction efficacy of greater than 99.999989% for GB. VX was not detected in the hydrolysate product with a detection limit of 16 μg/L or lower, indicating a destruction efficacy of greater than 99.99991% for VX. The destruction of vesicants H and HT was not validated in demonstration testing as planned. However, based on the results of the HD testing and earlier laboratory data[158] there is a high degree of confidence that both of these agents can be adequately destroyed using this process.

The MPT has been validated for the destruction of residual agents HD, GB and VX on munition hardware. The CatOx unit was also validated to destroy HD, GB and VX in the gaseous effluent. The MPT unit alone destroys at least 99.9998% of GB, with the CatOx validated to greater than 99.999998% destruction with GB. The MPT unit alone destroys at least 99.998% of VX, with the CatOx validated to greater than 99.9999993% with agent VX. The MPT unit alone destroys at least 99.98% of HD, with the CatOx validated to 99.9995% destruction with agent HD. One observation of HD breakthrough at levels below the HD screening level occurred during CatOx agent spike testing.[159] Based on all available data, the overall neutralization/biotreatment process was effective for the destruction of the chemical agents of concern.

The effectiveness of the aqueous neutralization of energetic constituents was demonstrated for Comp B, Tetrytol, and M28. For neutralization of Comp B, RDX was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit as low as 2 PPM. This indicates a destruction efficacy of greater than 99.9991% for RDX. TNT was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit as low as 2 PPM. This indicates a destruction efficacy of greater than 99.9989% for TNT.[160] For neutralization of Tetrytol, tetryl was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit of 2 PPM. This indicates a destruction efficacy of greater than 99.9998% for tetryl. TNT was not detected in hydrolysate at a detection limit of 0.1 mg/L or in filtered solids at a detection limit of 19 PPM. This indicates a destruction efficacy of greater than 99.9995% for TNT.[161] For neutralization of M28, nitrocellulose was not detected in hydrolysate at a detection limit of 5 mg/L. This indicates a destruction efficacy of greater than 99.985% for nitrocellulose.[162] Nitroglycerin was not detected in hydrolysate at a detection limit of 0.1 mg/L. This indicates a destruction efficacy of greater than 99.9992% for nitroglycerin.[163] The destruction efficacy for these energetic constituents was calculated to be greater than 99.999% for all but the nitrocellulose component of the M28. The nitrocellulose portion of the M28 did not achieve greater than 99.999% destruction due to a high detection limit. The effectiveness of the process to destroy rocket propellant is related directly to the ability of the accessing process to feed the propellant in the proper configuration. This was not achieved during demonstration and requires further study. This issue is addressed in detail later in this report. Based on all available data the process for deactivating energetics was effective for the destruction of the energetics of concern.

The effectiveness of the process to decontaminate chemical weapons hardware has been validated. HD, GB, and VX contaminated munitions were successfully processed through the MPT/CatOx to a 5X condition; no detectable agent remained on any of the tested parts.[164] Comp B bursters were washed out using fluid-jet technology and validated to be 3X treated. During removal of the warhead, the water jet successfully cut through and released the ignition powder contained in the M62 igniters for all tested rockets. Fuzes were cut off M61 rockets without incident. Based on all available data the process for decontaminating chemical weapons hardware was effective for the destruction of the agents and energetics of concern.

The ability of the process to decontaminate or destroy all other contaminated wastes has been validated with successful testing of charcoal, wood and DPE in the MPT.[165] Although not tested with agent, as planned, the material achieved a 5X condition based on time and temperature.

The effectiveness of the process in the presence of known impurities or additives has also been validated in part. Testing with munitions grade agent and energetics validates the effectiveness of the process in the presence of impurities and additives associated with these compounds. The testing of PCP contaminated wood lends support for the ability of the process to treat impurities of concern. Based on all available data the confidence in the effectiveness of the process in the presence of impurities and additives is high. The MPT condensate water will contain up to 120 mg/L levels of various aldehydes, ketones, organic acids, and alcohols; however, many of these have not yet been adequately identified and their impact on the neutralization process is unknown

The proposed processes for agent detoxification, deactivation of energetics, and decontamination of chemical weapons hardware have been validated as part of this demonstration. Treatment of contaminated processing wastes was also validated. The overall process is considered very effective for the destruction of agent, energetics and contaminated wastes.

B.4.3.2.1.2 Products

Feeds to the neutralization/biotreatment processes, intermediates generated in the hydrolysis and MPT units, and final products from the CatOx units were well characterized based on data achieved during demonstration. However, there was incomplete characterization of non-target organic materials in the final products from the ICB process, especially for nerve agent ICBs. In general, the major products from hydrolysis and biotreatment of organic materials are biomass, carbon dioxide, water, nitrogen, and mineral salts including sodium chloride, sodium fluoride, sodium sulfate, and sodium phosphate. The combination of the MPT and CatOx also gives carbon dioxide, water, nitrogen, and mineral salts. Mass balances were available only for two munitions at the time of the evaluation, GB M55 rockets and HD 105-mm projectiles;[166] some specifics were missing and the mass balances do not appear to have used validated data from the demonstration.[167]

Neutralization/biotreatment uses hydrolysis as the primary destruction mechanism for both agent and energetics. It was validated that there was no agent formation in the process once the agent was hydrolyzed.[168] In accordance with the demonstration plan, ICB effluents from GB demonstration were not dried; this precluded validation that GB will not reform if fluoride and DIMP in the effluents are heated to remove water. Two cases in which GB was detected in the gas stream of the ICB are hypothesized to be interferent problems because no agent was detected in the aqueous phase.

Data from demonstration testing confirm that Schedule 2 compounds are produced as a result of agent hydrolysis. Isopropyl methylphosphonic acid (IMPA), diisopropyl methylphosphonate (DIMP), and methylphosphonic acid (MPA) were generated from GB hydrolysis, whereas ethyl methylphosphonic acid EMPA and MPA are generated as a result of VX hydrolysis. Diisopropylaminoethanethiol (VX-thiol) is also formed during VX hydrolysis and thiodiglycol was generated from HD hydrolysis. Thiodiglycol was reduced to below detectable limits in the ICB with a destruction efficacy of greater than 99.97%.[169] However, the ability of HD-ICB to effectively use recycle water containing higher levels of salt than observed during demonstration is unknown. IMPA and MPA are only partially eliminated in the GB-ICB. Removal of these two compounds started at 89% and 67%, respectively, and the removal of IMPA dropped during the demonstration as it built up in the recycle water. By the end of the demonstration period, removal of both Schedule 2 compounds stood at 70%.[170] EMPA and MPA are only partially eliminated in the VX-ICB. Removal of these two compounds started at 90 and 77%, respectively, and the removal of EMPA dropped during the demonstration as it built up in the recycle water. By the end of the demonstration period, removal of EMPA stood at 76%.[171]

Hydrolysis of the nerve agent inventory at Blue Grass Chemical Activity (254,286 lbs. munitions grade VX from 12,816 155-mm VX projectiles and 17,739 M55 VX rockets; and 611,285 lbs. munitions grade GB from 3,977 8-inch GB projectiles and 51,740 M55 GB rockets) would produce an estimated 290,563 lbs. of isopropyl methylphosphonic acid (IMPA), 174,577 lbs. of ethyl methylphosphonic acid (EMPA), 36,473 lbs. of diisopropyl methylphosphonate (DIMP), and 19,790 lbs. of methylphosphonic acid (MPA).[172] These compounds are all listed on Schedule 2, Part B of the *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction* (referred to as the Chemical Weapons Convention or CWC). The data from demonstration testing clearly showed a steady decrease in destruction efficiency of MPA, IMPA, DIMP, and EMPA resulting in an increase in the concentration of these compounds in the ICB effluent over time.[173]

The CWC requires that a process for destruction of chemical weapons convert the chemical agent in an essentially irreversible way to a form unsuitable for the production of chemical weapons.[174] The Executive Council of the Technical Secretariat of the Organisation for the Prohibition of Chemical Weapons has determined on several occasions that chemical weapons destruction processes resulting in Schedule 2 chemicals should be approved by the Executive Council on a case by case basis to ensure that the products of destruction do not pose a threat to the object and purpose of the CWC.[175,176] Based on the destruction levels reported by the provider, an estimated 31,000 to 87,000 lbs. of IMPA, 17,000 to 42,000 lbs. of EMPA, 7,000 to 25,000 lbs. of DIMP, and 4,000 to 7,000 lbs. of MPA would be present in the waste from biotreatment at Blue Grass. Thus, use of the proposed biotreatment process would require that the Executive Council determine that between 60,000 and 160,000 lbs. of Schedule 2 compounds in ICB process wastes pose no threat to the object and purpose of the CWC. Alternatively, use of the Parsons/AlliedSignal biotreatment process would require further treatment prior to disposal to ensure that the Schedule 2 compounds could not be recovered from the ICB effluent; this treatment is both unspecified and undemonstrated. Neither alternative can be considered a likely prospect at this time; for this reason, the Parsons/AlliedSignal biotreatment process is considered unacceptable for processing nerve agents.

No EA2192 was detected at the completion of the VX hydrolysis; however, other hazardous intermediates are produced. Although full-scale corelations are difficult to make, data from demonstration testing shows that the following hazardous substances were produced:

- ❑ 1,2-dichloroethane and 1,4-dithiane from HD hydrolysis. These substances are treated effectively in the ICB and CatOx.
- ❑ Very low (sub-ng/m^3) levels of total dioxins/furans were present in off-gas from the HD-ICB CatOx (64 pg/m^3 TEQ). Low levels (up to 160 ng/m^3 total dioxins/furans) were present in the MPT off-gas produced from HD heel testing, from treatment of PCP-spiked wood, and from treatment of DPE; CatOx treatment reduced these to single digit ng/m^3 levels of total dioxins/furans (100 pg/m^3 TEQ). These are levels at which minimal health effects would be expected,[177] but below typical incinerator effluent limits.[178,179] Additionally, these emissions would be further reduced by the charcoal filters downstream of the CatOx. However, quantifying the effectiveness of the filters was not within the scope of the demonstration testing.
- ❑ Cyanide from Tetrytol, M28, and Comp B hydrolysis; the ICB reduced cyanide levels to below detection limits.[180]
- ❑ Nitrogen oxides (NOx) (up to tens of thousands of PPM from the production of energetic hydrolysate) can be treated by commercial systems in the full-scale design if required.
- ❑ *N*-nitrosodiphenylamine from the hydrolysis of M28 propellant will require containment during the hydrolysis process.
- ❑ NOx up to hundreds of PPM from the VX heel mortar test at the MPT CatOx. These can be treated using commercial systems if required.
- ❑ Phenols, which appear to be generated in the GB-ICB unit but remained below hazardous levels during demonstration.
- ❑ Vinyl chloride at up to hundreds of μg/m^3 from HD heel testing; no data were presented on the ability of the CatOx to remove low molecular weight compounds, especially chlorinated organics. These levels, while lower than acceptable workplace levels,[181] still exceed concentrations associated with an elevated cancer risk.[182]

The impact on these systems of adding laboratory wastes and recycling MPT condensate into the agent neutralization was not within the scope of the demonstration testing, but is unknown. These streams may change the composition of the hydrolysate, potentially adding non-biodegradable substances.

The MPT treats the dunnage associated with carbon, wood pallets, DPE, and fiberglass firing tubes. Although no information was available for PCBs (see section 3.3), PCP was added to the dunnage during demonstration testing and the results from the MPT treatment of this feed showed no PCP above detectable limits.

In summary, demonstration data provide an acceptable characterization of the products of the mustard process. Non-reformation of mustard was validated, as was the acceptable treatment of thiodiglycol, a Schedule 2 compound. Acceptable treatment of most hazardous intermediates (formed at relatively low levels) was validated for this process. However, the neutralization/biotreatment process was unable to effectively treat Schedule 2 compounds produced by GB and VX hydrolysis and is considered unacceptable for processing nerve agents.

B.4.3.2.1.3 Sampling and Analysis

Prior to the start of neutralization/biotreatment unit operations testing, most non-standard sampling and analysis methodologies passed validation testing. These included analysis for the following types of chemical substances:

- High-level: acetate and formate and anions in all matrices; cyanide in energetics hydrolysates.
- GB and VX low-level analyses for neutralization matrixes[183,184]
- HD low-level analyses for neutralization matrixes[185]
- Nitrocellulose analysis for the M28 hydrolysate matrix
- Low level energetics for neutralization matrixes[186]
- Hazardous substances: acetates and formates, volatile organic compounds, anions, metals, and mercury in all matrices; cyanide and energetics in energetics hydrolysates; semivolatile organic compounds in all matrices except VX hydrolysate

Neutralization/biotreatment will use the following standard sampling and analysis methodologies:

- Gas sampling methods for energetics followed the CHPPM-developed and EPA-accepted Sampling Train for Energetic Materials protocol
- Modified standard gas sampling techniques for other hazardous substances

These standard methodologies required no further validation as part of the ACWA demonstration.

For the ICB and MPT units, it was expected that standard analytical methods would be appropriate. However, to analyze samples from many of the sample locations, dilution of the samples was required to reduce matrix interferences.

Several non-standard sampling and analysis methodologies failed validation testing or did not perform acceptably during demonstration. For this reason, the ACWA demonstration was unable to validate or verify methodologies for the analysis of the following types of chemical substances:

- Residual semivolatile organic compounds for VX hydrolysis failed validation because of the high levels of dilution required to avoid matrix interferences.
- Headspace gas from GB hydrolysis failed to provide usable samples due to the high moisture content and high pH of the headspace.
- Many of the samples from the ICB units required significant dilution to minimize the matrix interferences. This dilution resulted in reporting of target analytes as non-detected with significant elevation of the detection limit, which diminished the usability of the data.[187]
- Interferences were noted during the collection and analysis of gas samples from the MPT and ICB for agents.
- Schedule 2 and agent breakdown product analysis results of the ICB process streams indicate that interferences may have impacted the quality of the data.[188]
- Some gas samples from the GB/Comp B ICB unit were reported to contain significant interfering peaks, major chromatographic problems, reduced instrument response for target analytes, and deterioration of the GC system. [189]

During the Parsons/AlliedSignal demonstration, most of the data generated has been deemed usable for evaluation of the technology and characterization of the process effluents. The level of verification for each type of analysis is given in Table B.4-7. Available documentation is insufficient to properly evaluate the performance of available analytical methods used for characterizing operations not demonstrated.

Table B.4-7. Level of Verification for Parsons/AlliedSignal Analyses

Type of Analysis	Amount of Usable data
Feed and Product Composition	Acceptable
Low Level Agent	Acceptable
Low Level Energetics	Acceptable
Hazardous Substances	Acceptable for hydrolysis, gas samples Less for ICB and MPT condensate samples

In summary, difficulties were encountered with some of the sampling and analysis techniques used for the mass balance and for determining residual levels of agent, energetics, and other compounds of concern during the MPT and ICB Demonstration Test Program. Overcoming these sampling and analytical difficulties will require a method optimization effort; the sampling and analysis methodologies have been verified and validated with reservations.

B.4.3.2.1.4 Process Maturity

In general, the unit operations that comprise the neutralization/biotreatment total solution have a level of maturity adequate for timely implementation for mustard agents. However, the biotreatment unit operations for nerve agents have a level of maturity inadequate for timely implementation.

Pre-Treatment

Fluid-abrasive cutting of rockets and fluid mining of the bursters were successfully demonstrated at full scale. Fluid and fluid-abrasive cutting are commercial processes and have been operated at production scale for large metal parts.[190] However, subsequent fluid mining of propellant from rocket motor cases was unsuccessful in demonstration. Therefore, the final process proposes to push the propellant grain, in its entirety, from the motor case, section the propellant using the rocket shear machine, and size-reduce the sections.[191] To some extent, the feasibility of these operations was demonstrated, but further development is needed, especially for the propellant size reduction.

For projectiles, the total solution uses the well-developed baseline reverse assembly process modified to include fluid mining of the bursters.

Treatment

The proposed chemical reagent hydrolysis operations for agents and energetics use common, commercial/industrial CSTR-based processing systems (vessels, fluid transport, heat exchangers, control principles, etc.). The agent hydrolysis process (Army ATP system) is well developed and demonstrated. Agent hydrolysis has been demonstrated for HD (55-gallon reactor), and for VX and GB (100-gallon reactor) in the ACWA program. There is, however, an unknown effect of the proposed recycling of the MPT condensate to the agent hydrolyzer and then to biotreatment. This aspect of the process was not within the scope of the demonstration testing.

The hydrolysis of energetics was successfully demonstrated in equipment representative of full scale. Comp B, Tetrytol, and M28 propellant were hydrolyzed in 6% and 12% caustic solutions. The caustic treatment for destruction of energetics and propellant is still in the initial development stage and has not been optimized; therefore, processing conditions are subject to change (e.g., concentrations, loading, reaction times). The process remains unoptimized for hydrolysis of Comp B, Tetrytol, and M28 propellant. However, optimization of these simple batch processes is not considered difficult.

The MPT was successfully demonstrated at a representative subscale. The metal parts were successfully decontaminated to a 5X condition, and organic materials (carbon, DPE, fiberglass, and wood) were reduced to char and ash. Destruction of PCBs in the resin/fiberglass matrix of the M441 shipping and firing container of the M55 rocket was not tested in the MPT (see section 3.3). It is unclear where (or if) actual destruction will take place. Steam superheaters required for a full scale MPT are used in the metal parts manufacturing industry. The basic principle of the MPT is sound (induction heating and steam) and was somewhat validated during demonstration, but as a total system it is not very mature. Although technically feasible, the CST furnace system is less mature and very little information is available for a complete assessment at this time, as it is a conceptual design with limited details[192] and has never been built or demonstrated. The merging of radio frequency induction heating with rotary retort is expected to be difficult due to such factors as metal fatigue and temperature extremes. Other concerns are with transport of steam and gas handling through blast gates. The CST is conceptually a modified baseline DFS; however, notable modifications are expected to make the system compatible with a steam environment.

Post-Treatment

ICB treatment of HD hydrolysate was successfully demonstrated at 1/40 scale. Test results indicate 90% Chemical Oxygen Demand (COD) removal[193] with thiodiglycol being destroyed to below detectable levels. There were problems with establishing pH control in the 2nd and 3rd chambers of the ICB with greater biological activity than predicted occurring in the 2nd chamber where the pH dropped to 5.5 (the lower limit for stable biodegradation). The problem was eventually solved by better pH monitoring and control and by chemical buffering of the first chamber.[194] The biotreatment of HT or H hydrolysate was not demonstrated, but the chemical analysis of HT hydrolysate indicates that the hydrolysate should be capable of biotreatment.[195]

Significant optimization of the biotreatment process will be required for GB and VX hydrolysates. Destruction of Schedule 2 compounds for both the GB- and VX-ICB was inadequate (see Section B.4.3.2.1.2). Based on DRE calculations, the destruction efficiency of the nerve agent Schedule 2 compounds was generally decreasing over time. As noted by the provider, “conditions in the bioreactor were not conducive to microbial growth and thus phosphorous incorporation into biomass and were reflected in lower than expected alkyl phosphonate removal.”[196] Both nerve agent demonstration systems were at 1/8th scale.[197] The effectiveness of the UV/Ox system cannot be validated from demonstration due to a lack of influent/effluent data.[198] The UV/Ox demonstration system was originally intended for minor polishing of the clarifier effluent.

The CatOx system was demonstrated at a representative subscale as part of the ICB and MPT demonstrations. The MPT CatOx system successfully destroyed direct injections of VX and GB.[199] The test conducted with direct injected HD, however, did result in detectable levels of HD exiting the CatOx.[200] Although considered an extreme case, design of the CatOx unit for full scale will require special consideration to assure no breakthrough of agent occurs. Demonstration operations revealed higher than expected organic loadings of the CatOx from MPT gaseous effluents. The CatOx, as designed, is best suited for the heavy halogenated organic molecules similar to chemical agent and is not well suited for removing the unanticipated low-molecular weight gases such as methane from the gas stream. Again, the need for appropriate CatOx design is imperative for the full scale. The proposed CatOx technology is used in industrial applications[201] and appears to provide promise for use in a full-scale facility. Additionally, for all agent applications, Parsons/AlliedSignal proposes the use of charcoal filters subsequent to the CatOx as a redundant system to provide the maximum degree of agent containment.

Scalability and Availability

The proposed process can be built with readily available equipment. All demonstration units and all anticipated full-scale units use common off-the-shelf/made-to-order equipment with specialty items based on existing and applicable designs.[202] For all of the equipment, no special materials of construction are needed (mild or stainless steel should suffice). Fluid-abrasive cutting is a commercial process and has been operated at production scale for large metal parts. Hydrolysis tanks can easily be manufactured. ICB installation is simple and straightforward; skid-mounted units requiring only utility connections were used during demonstration. AlliedSignal has built and installed full-scale ICB units at wood treatment plants, coal tar distillation plants, and other varied industrial locations. For metal parts treatment using a full-scale MPT, steam superheaters at the required capacity are commercially available. Catalytic treatment units are commercially available. However, availability of the specific ICB and catalytic converters for this system will depend on throughput and other requirements. They may be available off-the-shelf or they may have to be custom-designed and built. In addition, water jet processes for projectiles will require special design, development, and assembly. The rocket cutting subsystem for demonstration testing uses a “modified pipe-threading lathe” with no provisions for ‘automation or remote operations.’ A production system would require automation of this operational step. The CST is still at the concept level and may require extensive design.

As for scale-up, a number of critical unit operations have been tested in sizes predictable of full-scale. There is extensive data showing that scale-up of chemical reagent hydrolysis is relatively simple. Full-scale hydrolysis tanks, steam superheaters, and CatOx units are commercially available. Energetics hydrolysis at near implementation scale has been demonstrated by the Government. Munition access via baseline reverse assembly modified for fluid cutting and spray washing is based on existing full-scale technologies. Equipment for processing the rocket motor propellant will require further investigation. A full-scale MPT-type furnace (using air, not steam) has been built and tested with munitions that were contaminated with fuel oil.[203] Although scale-up for the MPT is not considered difficult, considerable design effort, especially for secondary waste processing, will be required. Induction heaters for MPT are not directly scalable from the demonstration unit and insufficient information prevents scale-up extrapolation. The size of the induction heater required for the full scale MPT is within the range of commercially available induction heaters. Catalytic treaters are commercially available, but the CatOx design for full-scale will need to accommodate the significantly higher organic loading than originally designed for in demonstration. A basis of design for scale-up of the CatOx units was not provided.

The nerve agent ICBs experienced scalability difficulties during demonstration. The 200-gallon bench test showed a greater than 98% removal of nerve agent Schedule 2 compounds and provided the design basis for the demonstration test. However, the bench scale (200 gal) was not predictive of the demonstrated three-stage GB and VX biotreatment process (10,000 gal),[204] resulting in low confidence in the ease of scaling-up from an unoptimized 10,000-gallon system to a 40,000-gallon system.

In response to initial start up problems, the HD ICB validation tests were performed at 2/3rds of the anticipated flow rate in order to ensure that the HD system was able to operate without further adjustments in the schedule window provided for validation testing. The HD system subsequently operated for 40 continuous days without further adjustment. Effects on the HD-ICB with respect to saline ICB effluent recycle and the inclusion of hydrolyzed MPT condensate in the feed are unknown and may have significant impacts when scaling up the system. The operating parameters of the ICB for mustard should be determined during optimization testing.

Summary

Most of the neutralization/biotreatment process equipment has a good history of operations, is readily available, and scalable. Baseline reverse assembly and neutralization were developed for and/or are historically used for chemical weapons. The fluid systems (cutting, mining, and washing), steam induction furnaces, catalytic treaters, and biotreatment have an historical commercial industrial basis. Reservations arise from the conceptual state of modifications to baseline reverse assembly for M55 rockets and the CST for dunnage and fuzes. There are also concerns with the optimization of the integrated HD-ICB system. Process maturity is considered unacceptable for nerve agents because of the inability to adequately convert Schedule 2 compounds in the GB- and VX-ICBs.

B.4.3.2.1.5 Process Operability

Several aspects of the proposed system are beneficial with respect to process stability. Caustic hydrolysis of agent is judged to be relatively stable due to the ability to monitor the reaction and control it based on feed and temperature; the process had no stability problems during the ACWA demonstration of VX, GB, and HD hydrolysis. Energetics hydrolysis was demonstrated to be stable with a controlled feed rate. The biotreatment of HD was demonstrated to be stable after correction of pH and reduction in feed loading. The stability and robustness of the MPT (and expected of the CST) is based on high temperature operating environments. The low temperature and low-pressure operations of the hydrolysis operations and biotreatment, in addition to the ability to HT&R after agent and energetics hydrolysis, are deemed beneficial with respect to stability.

There are also several concerns with respect to process stability. Stable nerve agent biotreatment was not successfully demonstrated[205] and the uncertainty over whether the instability can be linked to one or more causes leads to questionable stability at full-scale. While the energetics hydrolysis demonstrations were successful in neutralizing energetics, further studies in this area are required to ensure the stability in processing all energetics at the proposed full scale rate and the effective materials transport of the resulting hydrolysates due to the viscosity of the polymeric products. Specifically, there is a concern that the still undemonstrated M28 accessing process may not produce the particle size required for proper and timely hydrolysis. There still exists a concern that the ACW feed, that contains heavy metals and other impurities in concentrations greater than tested in demonstration testing, may have an adverse effect on the hydrolysate biotreatment. Similarly, there are unknown but potentially negative effects on the hydrolysis and biotreatment processes when the MPT and CST condensates are recycled.[206] Stability limits for the MPT/CatOx process are not well investigated and the actual requirements for the CatOx are still undetermined for treating volatilized organic compounds. Although it is anticipated that all these concerns can be mitigated, further studies in these areas is required.

RAM characteristics for the full-scale plant are difficult to assess at this time because of the limited testing conducted on many of these unit operations under the proposed conditions. Nevertheless, the full-scale system is expected to have average RAM characteristics. The baseline reverse assembly, the fluid-abrasive cutting and fluidmining steps are expected to have average RAM characteristics, and agent and energetics hydrolysis operations are predicted to have good RAM characteristics based on the ACWA demonstration and ATP studies. RAM of the biotreatment systems is expected to be average because the simplicity of operation is countered with poor flexibility. RAM of the MPT is difficult to predict, but is expected to range from poor to average based on the number of units, numerous robotic controls in conveying the projectiles, and because it is a batch high-temperature operation.

The full-scale system is expected to have mixed operating flexibility. Manageable demands (i.e., time, labor, and utilities) are expected for startup/shutdown of the batch operations—agent and energetics hydrolysis and the MPT/CST-CRS-CatOx assemblies. The bioreactors are expected to have less predictable but acceptable flexibility characteristics. Bioreactors are generally slow to start-up,[207] which may be a repeatable and problematic operation if the biomass dies off. Nevertheless, the HD-ICB unit maintained the biomass during changing environmental conditions (pH and temperature) for the entire validation run.

While a majority of the unit processes are relatively simple, the overall system is very complex based on the number of unit operations: 16 to 20 ICBs, 6 MPTs, a minimum of 20 to 24 CatOx units, baseline reverse assembly and additional accessing equipment, shredding equipment, hydrolysis operations, a CST/HDC system, and crystallizers.[208] The modified baseline reverse assembly process incorporating water-jet operations will require many complex manipulations to assure complete access to the propellant and burster explosives. A moderate to high number of operators, requiring low skills, is required primarily because of the high number of ICBs and thermal treatment units. Numerous but standard preventive and routine maintenance requirements are expected for these reasons as well.

B.4.3.2.1.6 Process Monitoring and Control

The process uses commercially available and appropriate monitoring and control technologies including on-line, real-time chemical monitoring and liquid hold-and-test procedures.[209] Chemical monitoring includes pH and specific gravity at critical control points, chemical oxygen demand (COD), biological oxygen demand (BOD), and nutrient level for the ICBs. Agent monitoring is used at the MPT discharge, and the CatOx inlet, and CatOx effluent is monitored for volatile sulfur or phosphorus compounds. There are commercially available controls for the hydrolysis reactors, ICBs, MPT, CST, and CatOx. Energetic hydrolysis is monitored through temperature and controlled through addition rate.

There are some concerns with respect to monitoring and control, however. There is no control of gaseous effluents exiting the bioreactor CatOx units and heavy reliance is put on the carbon filtration system to capture volatile organic compounds from the other CatOx units.[210] The ability to maintain acceptable process operating limits in the GB and VX ICBs was not demonstrated. The technology provider stated that the poor results might be attributed to failure of pH control, poor aeration, poor biomass settling, and/or the high BOD feed concentration,[211] but it is not clear that these problems can be effectively overcome in a full-scale facility. Additional monitoring proposed for the GB and VX bioreactor performance includes on-line pH, dissolved oxygen (DO), and Total Organic Carbon (TOC) analysis. It is also proposed to use a phosphorus NMR with automatic sampling to give a 24-hour turn around on organo-phosphorous analyses. [212] There is an unsolved problem of false positives when monitoring for agent in the VX hydrolysate matrix (current work on an improved MINICAMS may solve this problem).

The monitoring and control system should effectively prevent or control process upsets. Hydrolysis and biotreatment units have long response times which helps prevent process upsets, and HT&R processes are used following agent and energetics neutralization. The HD bioreactors are also expected to accept modest fluctuations of temperature, pH, mass loading, and aeration.

There are some concerns with respect to controlling process upsets as well. Demonstration showed that there are large quantities of organics going to the CatOx unit from the MPT. In the full-scale facility, the generation of VOCs will be controlled by staged temperature ramping of the MPT, and proper CatOx operating temperature will be maintained by regulating preheater energy input and airflow to the CatOx. During various MPT/CatOx demonstration tests, chlorinated hydrocarbons, particulates, and high levels of low molecular weight hydrocarbons were observed in the CatOx effluent. [213] It is not clear how these effluents will be controlled in the full-scale system.

The process is comprised of many unit operations, most of which are not particularly demanding with respect to monitoring and control. Batch hydrolysis processes and ICBs require simple monitoring and control instrumentation, however, the chemical and biological processes occurring in the ICB are complex. Rocket access via baseline reverse assembly modified for water jet cutting may require a complex monitoring and control system for the physical materials handling and robotic manipulations. Effective process control is also critical for successful MPT/CST-CRS-CatOx operation and will require a complex monitoring and control system.

In summary, neutralization/biotreatment can be effectively monitored and controlled, however, there is a major concern with respect to the effective control of the GB and VX ICB systems.

B.4.3.2.1.7 Applicability

The PAS total solution is expected to be able to process and destroy all munitions that contain mustard. However, the PAS process does not provide a total solution for GB and VX munitions, due to the inability of the biotreatment units to demonstrate effective destruction of the schedule 2 compounds produced as a result of hydrolysis of GB and VX.

B.4.3.2.2 Safety/Worker Health and Safety

B.4.3.2.2.1 Design or Normal Facility Occupational Impacts

Workers are protected during normal operations by a number of administrative measures/controls and by some design features. The hydrolysis, rocket cutting, and CatOx processes are all remote operations that minimize worker exposure.[214] However, MPT, ICB, and dunnage shredding processing operations require worker intervention. The fully automated process control system accounts for the fact that shut-off of the feed and energy supply stops all processes eventually.[215] All of the processes, with the possible exception of VX and energetics hydrolysis, have no known, inherent tendency to cascade out of control. However, these reactions can be effectively controlled.

Parson's process uses seven major process chemicals (sodium hydroxide, sulfuric acid, hydrogen peroxide, ferrous sulfate, liquid nitrogen, aqueous ammonia and dextrose) in very high quantities.[216] Only one hazardous chemical (sodium hydroxide) is used in the critical destruction unit. The others (sulfuric acid, dextrose, ferrous sulfate, hydrogen peroxide, and aqueous ammonia) are used during secondary biotreatment and the post treatment pollution abatement system (gas polishing). Liquid nitrogen, although non-toxic, is a potential asphyxiant when vaporized in a contained area and is used to purge the MPT. All are low-to-moderate inhalation hazards,. Sodium hydroxide and sulfuric acid are acute dermal hazards. The sulfuric acid, used only in the nerve agent process, is the most severe inhalation hazard, with a workplace inhalation permissible exposure limit of 1.0 mg/m^3.[217] The process does not require any flammable process chemicals. Potential thermal hazards associated with liquid nitrogen storage and CatOx/MPT hot surfaces are effectively mitigated by the prudent use of insulation and barricades.[218]

Equipment containment issues identified during demonstration need to be resolved. Although the hydrolysis reactors and the ICB provide containment at the equipment level, worker exposure to intermediate gas products during sample collection required use of PPE for nerve agent. Minor redesign of the VX ICB sampling system should eliminate the hazard. The normal deactivation of M557 and other fuzes by thermally induced detonation in the CST poses some risk to workers through the possibilities of fragmentation and/or over-pressure.

The projected physical workplace environment generates a few manageable risks. Some maintenance, not requiring PPE protection, may be necessary during ICB operations. The MPT/CST and CatOx units are self-decontaminating to 5X after normal shutdown, but may not reach 5X after a forced or emergency shutdown. A 3X self-decontamination capability is expected for the hydrolysis reactors, but this capability was not a test objective and was not established during demonstration. Other upstream processes (e.g., munition cutting, rocket motor shredding) are not expected to have any self-decontamination capability. There is a potential for continuous, awkward, repetitive motions and heavy lifting associated with proposed dunnage processing operations that pose some risk of soft tissue skeletal injuries. The process intermediates (VX hydrolysate and ICB sludge) interfered (generated false positives) with agent monitors. Parsons did not provide an interference management strategy; however, an effective one could be developed without extensive modifications of existing equipment.

In summary, the neutralization/biotreatment process poses minimal risk to workers during normal operations. Both hydrolysis and biotreatment are inherently low risk processes; equipment containment and agent monitoring issues could reduce worker safety during normal operations. Effective administrative and process controls, self-decontamination capability, and manageable use of process chemicals enhance safety at the equipment level.

B.4.3.2.2.2 Facility Accidents with Worker Impact

Workers are protected during accidents by a number of administrative measures/controls and by some design features. Agent and energetic destruction (hydrolysis) and the ICBs operate at relatively low temperature and near ambient pressure. Although Parson's process uses seven major process chemicals in very high quantities, all process chemicals are commonly used in industry and possess well established handling procedures and industrial safety standards.

The process generates a large volume of intermediate chemicals (agent and energetics hydrolysates and ICB and MPT/CST effluents) which pose low-to-moderate inhalation hazards for the workforce. Several of the intermediates are suspected human or confirmed animal carcinogens (see Section B.4.3.2.1.2). However, only hydrogen sulfide[219] and sulfur dioxide[220] were generated during demonstration in concentrations exceeding established workplace exposure limits. Prudent use of standard PPE during spill/leak response will effectively mitigate the hazard.

The severity of potential accidents is minimal because the most hazardous operations (hydrolysis, rocket cutting, M28 accessing) are performed remotely with fully automated process control that can effectively stop the process. The VX and energetic hydrolysis reactions are exothermic reactions with slight, but easily manageable, potentials for cascading out of control. Demonstration validated that a fully automated monitoring and control system is easily capable of mitigating the hazard. All other process systems are endothermic and very stable. Early hold, test and release points immediately following agent and energetic destruction enhance worker safety in the event of an accident or process upset.

The ability of the proposed CST to contain repeated initiations of M557 and other fuzes has not been established or verified. Incidents occurring during demonstration verified that hydromining alone is incapable of accessing the M28 propellant, and the proposed alternative approach (modified washout followed by shredding) ignites the propellant unless the operation is conducted under water.[221] The ability of available equipment to contain potential repeated fires has not been verified, nor has an effective fire management strategy been provided. However, all these operations are proposed to be conducted in containment areas and personnel exclusion areas. Demonstration reaffirmed that VX hydrolysate causes manageable agent monitoring interference (false positives) during hydrolysis and biotreatment. While both agent and energetic hydrolysis and bio-treatment processes are conducted at low (ambient) pressure and temperatures, the MPT requires extreme operating temperatures (>1,200°F) and the rocket cutting requires high operating pressures (>4,000 PSI). The use of high performance protective barriers and the planned isolation of the cutting operations should significantly mitigate the hazard and minimize the risk.

Because no flammable or combustible process chemicals are required and only trace amounts (<LEL) of flammable gasses are generated, there is only minimal risk of a fire or explosion.

Most final products have been identified and characterized and pose little risk to the operators. The representative MPT demonstration test unit validated the ability of the MPT to generate conditions that achieve both chemical and explosive 5X level decontamination.

In summary, the agent and energetic destruction and secondary treatment processes are inherently low risk. Issues that need to be addressed prior to process maturation efforts include: M28 propellant size reduction, MPT/CST energetic processing equipment containment, and the agent monitoring interference. The proposed prudent use of engineering and administrative controls should greatly reduce both the severity and probability of facility accidents affecting workers.

B.4.3.2.2.3 Facility Accidents with Public Impact

The public is protected during accidents by a number of administrative measures/controls and by some design features. Since agent destruction, energetic deactivation, and bio-treatment processes all take place at low (ambient) pressure and temperatures, the probability and severity of potential leaks is minimal. The process requires six major chemicals to achieve complete destruction of both the agent and explosives, and only ammonia is highly volatile. The process chemicals are characterized as having low-to-moderate toxicity and persistency. Although the process generates a large volume of corrosive intermediates (agent and energetics hydrolysates), they are a low-to-moderate inhalation hazard and pose negligible risk for exposure to the public. The process has not demonstrated a potential for cascading out of control. While the proposed process requires limited agent and energetic accumulation, early hold, test and release points and secondary containment (facility) ensure public safety. Because no flammable or combustible process chemicals are required and only trace (non-explosive) levels of flammable gasses are generated, there is minimal risk of a fire or explosion. The VX hydrolysate feed to the bio-treatment process has been demonstrated to interfere with standard agent detection systems; however, there should be only an insignificant increase in the potential for public exposure to agent, and minimal impact on public safety, because the agent will be neutralized to drinking water standards prior to bio-treatment.

In summary, because of the low volatility of both the process chemicals and intermediate products, the negligible potential for flammable gas generation, and an effective process control system, all credible identified accidents should have no impact on the public.

B.4.3.2.2.4 Off-Site Transportation Accidents

Seven major process chemicals (sodium hydroxide, sulfuric acid, hydrogen peroxide, ferrous sulfate, liquid nitrogen, aqueous ammonia and dextrose) would have to be transported on-site. Of these chemicals, none are carcinogenic. However, the total volume of both process and waste-stream materials is expected to be high.[222]

The DOT has classified the process chemicals as corrosives (sodium hydroxide, sulfuric acid),[223] oxidizer corrosive (hydrogen peroxide),[224] and non-flammable gases (ammonia and nitrogen).[225] They would pose relatively low hazard to nearby populations or workers in the event of a transportation accident. Sodium hydroxide, a corrosive compound with dermal and slight inhalation hazards, is the most hazardous process reagent.

The waste materials that would have to be transported off-site have been identified and partially characterized for all feeds; very high volumes of waste products are generated.[226] The waste products will be dried salts from the water recovery unit, the dried sludge cake from the biotreaters, ash from the destruction of dunnage in the MPT, grit from the fluid-abrasive cutting (FAC) operations, and 5X decontaminated metal parts and solids from the MPT process stream. The sludge cake remains to be fully characterized. Of the waste materials identified to date, none are classified by DOT as a poison or a hazardous material.

Standard HAZMAT and fire department PPE, containment equipment, and techniques are sufficient to contain most potential spills. However, standard fire department PPE is not adequate for sulfuric acid and ammonia spills. Evacuation zones would be less than 100 yards.[227] No special training beyond OSHA HAZMAT and DOT requirements is needed.

In summary, this technology poses very little risk of a serious transportation accident affecting the public. Standard HAZMAT responses are adequate, and would be needed only for the common industrial chemicals, sulfuric acid, and ammonia.

B.4.3.2.3 Human Health and Environment

B.4.3.2.3.1 Effluent Characterization and Impact on Human Health and Environment

The chemistry of the process, agent/energetics hydrolysis, ICB and MPT is expected to produce acceptable treatment results for HD/Tetrytol waste streams and result in effluents with low hazard and concern. The secondary treatment of the GB/Comp B hydrolysate and the VX/Comp B/M28 hydrolysate waste streams was incomplete and raised the concerns noted below.

Gases from hydrolyzers, ICBs, CST, and the MPT are sent through catalytic oxidizer (CatOx) units. All gaseous effluents are then discharged to the HVAC system. The CatOx air effluent contained primarily low toxicity gases such as hydrogen, carbon monoxide, methane, ethane, and propane, with low levels of SOx and NOx production.[228] The main compound of potential concern in the gaseous effluent is vinyl chloride, which was found at levels up to hundreds of $\mu g/m^3$ in the air effluent from the CatOx during HD heel testing. A CatOx unit was demonstrated to destroy neat GB and VX to below detection levels; neat HD was destroyed to below detection levels in two runs, and was found at below the HD screening level in the third run.[229] Dioxins/furans were found in the air effluent from the CatOx at sub-ng/m^3 levels, at levels below typical RCRA emission levels for incinerators. The carbon filtration HVAC would reduce the levels of compounds of concern still further. During dunnage treatment in the MPT, significant concentrations of large molecular weight compounds passed through or were formed in the CatOx. These compounds caused false agent alarms. Additionally, low molecular weight compounds (methane) achieved only 90% destruction in the CatOx. Odors from biological processes will be reduced by engineering controls (CatOx and HVAC) and are not expected to be an emission issue. There is no hold and test for gaseous effluents after redundant treatment by the CatOx and HVAC.

The provider projects no liquid effluent.[230] PAS proposes to use a dewatering system based on an evaporator/crystallizer. The water vapor discharge will be condensed and returned to the process stream. No water effluents are expected. (However, if dewatering proves unsuccessful, then water discharges could require further treatment due to high levels of phenols and other priority pollutants that could exceed local total toxic organic compound levels allowable under the Clean Water Act[231] [CWA]).

Effluents to land will consist of 5X projectile bodies from the MPT, ash from dunnage treatment, inorganic salts, grit from rocket cutting, and dewatered sludge. The ICB sludge from the HD demonstration passed the RCRA TCLP test. Dioxins/furans and heavy metals other than lead are found in the sludge from HD processing at concentrations well below regulatory concern. Replacement of activated carbon in the ICBs and the ultimate disposal of these cells was not described. A large volume of solid waste will be produced, but is expected there will be no major problems with disposal strategies.

HD/Tetrytol hydrolysate ICB biological treatment system removed Schedule 2 compounds in the brine waste tank by more than 99.9%, energetics hydrolysis products and other organics were effectively destroyed as well. The brine waste stream passed TCLP screening test. Overall, the HD/Tetrytol ICB wastewater treatment system was found to be highly effective in treating secondary wastes.

The GB/Comp B hydrolysate biological treatment system was inadequate. The effluent from that system contained a complex mix of volatile organic compounds, semi-volatile organic compounds, and inorganic anions, which could not be fully quantified due to the lack of analytical validation (described in Section B.4.3.2.1.3). This complex effluent suggests that treatment of the GB hydrolysate in the tested ICB unit may be inadequate, and strongly suggests that the effluent stream had high contaminant loading; although effluent toxicity is not well quantified, the subsequent release was unacceptable. Examples of several contaminants include fluoride, which is present in the GB ICB sludge above the land disposal regulation waste water limit,[232,233] and lead, which is present at concentrations above RCRA toxicity characteristic limits.[234,235] The effluent from the GB-ICB system contained unacceptable levels of Schedule 2 compounds, as noted in Section B.4.3.2.

The VX/Comp B/M28 hydrolysate biological treatment system was also inadequate. Although the effluent passed the RCRA TCLP test, it also contained a complex mix of volatile and semi-volatile organic compounds as well as inorganic anions, which could not be fully quantified. The VX-ICB effluent stream also had high contaminant loading and the subsequent release was again unacceptable. The effluent from the VX-ICB system will contain unacceptable levels of Schedule 2 compounds, as noted in Section B.4.3.2.

A significant unknown for effluent characterization is the management strategy for PCBs, because the treatment of these compounds was not demonstrated (see Section B.3.3). Although the MPT/CST/CatOx system should adequately treat these compounds, the accountability and management of this pollutant was not addressed in the final report. The treatment efficacy of any PCBs in the nerve agent ICBs is doubtful because of the high level of contaminants remaining in the effluents.

Sampling and analysis methods for monitoring agent in the gas streams and in hydrolysate was analytically validated (see Section B.4.3.2.1.3); methods for monitoring agent in bioreactor effluents were not analytically validated as part of this demonstration. Methods for monitoring Schedule 2 compounds in the ICB effluents was subject to interferences that may have impacted the quality of the data. Air monitoring uses standard technologies including ACAMS and DAAMS tubes (both GC gas sampling). During the demonstration, detections of GB and VX by air monitoring were suspected to be false positives due to other phosphorous compounds in the waste stream. However, no proposed monitoring modifications were identified. Sampling and analysis methodologies have been proven for major constituents and breakdown products in air and liquid for the unit processes. Monitoring volatile and semivolatile organic constituents in the ICB sludge effluent was not validated during demonstration, however, TCLP extractions are expected to provide adequate monitoring of the final process effluents.

The overall effectiveness of effluent characterization and impact on human health and environment was validated for processing mustard-containing munitions. The potential and actual effluents from this process are associated with an acceptable level of concern and the system includes appropriate and proven methods for monitoring process effluents and internal releases. However, demonstration data for the neutralization/biotreatment process for nerve agent-containing munitions did not validate that this is an acceptable process. The ICB secondary treatment process does not adequately remove schedule 2 compounds from effluents. The process is also considered unacceptable because of the complex mix of hazardous compounds and presence of CWA pollutants above levels of concern in potential effluents.

B.4.3.2.3.2 Completeness of Effluent Characterization

Gaseous and liquid effluents from the hydrolysis unit are well characterized with validated material balance for all demonstrated effluents. Effluents from the HD-ICB and the MPT/CatOx units are acceptably characterized. The major effluents expected from hydrolysis and biotreatment of agents and energetics are carbon dioxide, water vapor, nitrogen, inorganic salts, and biomass. The VX- and GB-ICB wastewater effluents contained a complex mix of volatiles, semi-volatiles and inorganic anions that could not be fully quantified due to analytical validation issues. Product gases from MPT/CatOx unit was not fully characterized due to overload of organic material. PCB treatment effectiveness was not addressed in the demonstration. The technology providers plan for PCBs was not provided in their draft final report although adequate treatment in the MPT/CatOx may be possible. Demonstration that there are Schedule 2 compounds in the biomass was analytically validated for nerve agent. However, the full-scale design for the process[236] does not consider the effluent characterization performed during the demonstration (e.g., the presence of Schedule 2 compounds in the effluents).

In summary, the mustard containing munitions process effluent characterization is sufficient to support the validation of that process. However, the level of unknown organics in the effluents from the nerve agent process will require additional testing for acceptable effluent characterization.

B.4.3.2.3.3 Effluent Management Strategy

The technology provider included a waste management plan with many significant unknowns.[237] There is no final treatment or disposal scenario (possibly MPT or CST) for spent carbon, and no consideration is given to solidification of dried salts from the crystallizer or for the biomass.

Air streams will not be held and tested after CatOx treatment, but will be discharged to the HVAC and carbon filters for secondary treatment. Sludge, metal parts, dunnage ash, and grit can all be held and tested. Most solid waste is potentially RCRA-regulated hazardous waste (heavy metals expected) with some non-hazardous expected. The technology provider has a demonstrated history in managing industrial waste biosludges. It was demonstrated that there are Schedule 2 compounds in the biomass from GB and VX processing. The GB- and VX-ICB wastewater effluent also contained a complex mix of volatile and semi-volatile organic compounds as well as inorganic anions, which could not be fully quantified. This unquantifiable effluent raise concerns that treatment of the GB and VX hydrolysate in the tested ICB unit may be inadequate. No discussion of treatment of these wastes was presented.

The effluent management strategy for processing mustard munitions has insufficient detail but the effluents appear to be treatable and disposable. The effluent management strategy for processing munitions with nerve agent is considered unacceptable because the ICB effluent cannot be disposed of as planned (see Section B.4.3.2.1.2). The strategy for munitions with nerve agents is not acceptable for sludge disposal because of Schedule 2 compounds.

B.4.3.2.3.4 Resource Requirements

Specific water and energy requirements could not be quantitatively ascertained from the information in the technology provider's draft final report, however, a qualitative assessment has determined that there are no expected exceptional requirements. Water recovery and recycle may further mitigate water use.

B.4.3.2.3.5 Environmental Compliance and Permitting

Parsons/AlliedSignal did not provide a permitting strategy in their draft final report.[238] The provider asserted that other Army contractors at the Chemical Stockpile Disposal Program (CSDP) have an extensive and rigorous program that will be adopted for the ACWA program.

The reaction chemistry is well defined for treatment of munitions containing mustard agents. Effluents from biological treatment of nerve agent hydrolysate contained schedule 2 compounds. An initial concept design package as well as a RCRA, CAA, and CWA waste analysis plan were identified for some treatment streams in the demonstration study matrix. The Army has obtained RCRA and CWA permits for a bulk mustard neutralization and biotreatment facility in Maryland. The Army is obtaining a RCRA permit for a bulk VX neutralization process at the Newport Chemical Activity in Indiana.

The overall environmental compliance and permitting strategies are accepted with reservations because Parsons/AlliedSignal did not provide enough detail. Alternate information indicates that permitting of the proposed mustard munitions process is feasible.

B.4.3.2.4 Potential for Implementation

B.4.3.2.4.1 Life Cycle Cost

Based upon the information provided in Parsons/AlliedSignal's final technical report,[239] it was possible to develop total capital cost estimates for both Pueblo and Blue Grass. These estimates, presented in Table B.4-8, are expressed in constant dollars with no inclusion for either escalation, de-escalation, productivity gains/losses in labor or material supply, or cost growth in materials. The accuracy of the cost estimate is in the +20/-10% range. The analytical approach used to develop these estimates is presented in Attachment B-D.

As indicated in this table, the total capital cost for the proposed neutralization/biotreatment process for the destruction of ACWs at both Pueblo and Blue Grass is comparable to that for the baseline incineration process. At Pueblo, the total capital cost may be approximately 10% less than or equal to that of baseline incineration, whereas at Blue Grass the total capital cost may be approximately 5% less than or equal to that of baseline incineration. The cost analysis showed

Table B.4-8. Total Capital Cost Estimate for Parsons/AlliedSignal's Neutralization/Biotreatment Process

Parson/AlliedSignal Neutralization/Biotreatment Process	Pueblo Total Capital Cost ($Millions)	Blue Grass Total Capital Cost ($Millions)
Installed Core Process Equipment	97	113
Installed Baseline Equipment Additions	30	31
Total Installed Equipment Cost	**127**	**144**
Buildings and Support Facilities	225	230
Total Capital Cost	**352**	**374**
Comparison to Baseline	**About 10% Less**	**About 5% Less**

that nearly 65% of the total capital cost for the neutralization/biotreatment process is attributed to equipment and buildings common to baseline incineration and the two other alternative technologies tested.

Sufficient information currently does not exist to make a reasonable estimate of the O&M costs for the neutralization/biotreatment process. However, based upon a review of the proposed process, it was independently estimated that the O&M labor requirements would be comparable to those for baseline incineration. Furthermore, since O&M labor requirements account for 65 to 70% of the total O&M costs for baseline, it is likely that the total O&M costs will be comparable to baseline. This is also due to the fact that no extraordinary chemical usage or utility requirements are anticipated for neutralization/biotreatment.

B.4.3.2.4.2 Schedule

The basic schedule assumptions, key milestone activities, and key activity duration periods used to develop an implementation schedule are summarized in Attachment B-D. The following key points are unique to the implementation of the neutralization/biotreatment process:

- Completion of the EIS and ROD approval takes a total of 16 months.
- Duration of Maturation Testing for Pueblo and Blue Grass is 8 months and 12 months, respectively; additional maturation testing is required at Blue Grass because a reconfigured system that was not tested during demonstration is being proposed.
- Operations, based on information provided by Parsons/AlliedSignal, is 28 months for both Pueblo and Blue Grass.

Based on these durations and those specified in Attachment B-D, the key milestones and corresponding dates to implement neutralization/biotreatment on a full-scale basis were developed. These are summarized in Table B.4-9 for both Pueblo and Blue Grass.

Table B.4-9. Implementation Schedule for Parsons/AlliedSignal's Neutralization/Biotreatment Process

Key Milestones	Pueblo	Blue Grass
EIS Start	31 October 1999	31 October 1999
Maturation Testing Start	1 January 2000	1 January 2000
RFP Release	31 August 2000	31 August 2001
Final EIS/ROD	28 February 2001	28 February 2001
Contract Award	28 February 2001	28 February 2002
Final Design (65% Completion)	31 August 2001	31 August 2002
RCRA Part B Issued	30 November 2002	30 November 2003
MDB Construction Start	30 November 2002	30 November 2003
MDB Construction Finish	31 July 2005	31 July 2006
Systemization Start (Pilot Train)	1 January 2006	1 January 2007
Systemization Start (All Trains)	1 July 2008	1 July 2009
Operations Start	1 January 2009	1 January 2010
Operations Finish	30 April 2011	30 April 2012

As indicated in the table, the schedule developed for the demilitarization of ACWs utilizing the neutralization/biotreatment technology estimates the following dates for completion of operations:

- Pueblo: April 2011
- Blue Grass: April 2012

Applying the same analytical approach to the schedule for the baseline incineration (see Attachment B-D), the schedule for implementing neutralization/biotreatment is comparable to that for baseline incineration. Using similar key milestone start dates and assumptions, the completion dates for the baseline plants at Pueblo and Blue Grass are:

- Pueblo: December 2009
- Blue Grass: May 2010

Although these implementation schedules are not completed until after the CWC date of 29 April 2007, demilitarization operations for neutralization/biotreatment and baseline incineration are estimated to likely be completed within the possible 5-year CWC extension. Within the confidence level (75% likelihood of success) of these schedules, the implementation schedules of neutralization/biotreatment and baseline incineration are comparable. The most significant uncertainty with the baseline incineration's estimated schedule is with respect to permitting. It is assumed that there is no difference in the time required for the RCRA Part B approval process between neutralization/biotreatment and baseline incineration. However, this assumption does not necessarily reflect the history of public opposition to baseline incineration. It is believed that the program completion dates for the neutralization/biotreatment process and baseline incineration are essentially the same for either Pueblo or Blue Grass.

B.4.3.2.4.3 Public Acceptance

Based on input from the Dialogue, neutralization/biotreatment for nerve agents was deemed unlikely to obtain public acceptability due to the inability to validate the biotreatment process in demonstration. The biotreatment process is acceptable if the technology can be successfully demonstrated. The neutralization/biotreatment for mustard agents was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

B.5 Conclusions and Recommendations

B.5.1 Conclusions

B.5.1.1 Burns and Roe Plasma Arc Process

The Burns and Roe process, using a plasma arc process to demilitarize chemical weapons, was not validated for agent destruction during demonstration testing due to the lack of maturity. In addition, based on input from the Dialogue, it is unlikely that this process will be publicly acceptable. Therefore, this process cannot be considered a viable total solution. The basis for this conclusion is summarized below.

B.5.1.1.1 Process Efficacy/Process Performance

The Burns and Roe team's proposed total solution uses a Plasma Waste Converter (PWC) as the sole destruction mechanism. The PWC represents a robust, indiscriminate thermal treatment technology capable of destroying organic materials. The proposed process uses multiple PWCs, with similar configurations, to destroy all ACW materiel. The demonstration utilized a single, multi-purpose PWC for the objective of testing several different feeds.

The demonstration results indicate a lack of process maturity for the PWC—this translates into a need for significant redesign, development, and testing before full-scale implementation of the system. Problems with PWC operation and reliability during systemization and operation of the equipment led to changes in test configuration and schedule delays resulting in an inability to complete all of the planned tests. The most significant impact of the operational and reliability problems experienced during systemization and operations was the Army's decision to cancel the planned campaigns with chemical agent. The result of not testing chemical agents is an inability to validate the technology at this time for 99.9999% DRE of chemical agents. Other planned demonstration tests were completed and provided valuable data for the evaluation of the technology. The ability of the process to destroy energetics, metal parts, and secondary wastes of ACWs was validated, and additional operations were successfully conducted with an agent simulant and an agent hydrolysate. Characterization for materials that were tested was completed; however, there remains a lack of agent-derived intermediate and final product characterization.

The PWC process uses commercially available controls and instrumentation, but the monitoring/control strategy is not fully defined or demonstrated. Many of the sampling and analysis methodologies for constituents in the process streams were verified, but several still require optimization while others require significant effort to complete the verification process.

B.5.1.1.2 Safety/Worker Health and Safety

The plasma arc process poses moderate, but manageable risk to workers during normal operations. The PWC process chemicals and intermediates are low-to-moderate health hazards. The PWCs rely on negative pressure to achieve equipment-level containment. The observation of fugitive gaseous emissions during demonstration leads to concern over the PWC containment capability. This indicates the potential for worker exposure and will necessitate a significant increased use and reliance on PPE to provide worker protection.

Although PWC operations are isolated, maintenance operations around the PWC could cause unnecessary exposure to hazardous intermediates and nickel particulates. Proposed solutions to minimize or eliminate demonstrated fugitive emissions and steam surge, or potential M28 processing upsets, will require an extensive redesign effort. While severe physical hazards such as extreme temperature during PWC operations are present, the demonstrated use of engineering and administrative controls should greatly reduce both the probability and severity of an accident.

While the process does not generate any materials that are highly volatile or acute inhalation hazards, it does generate and store limited quantities of flammable gas. Secondary facility containment, administration procedures, automated process controls, and HT&R capability mitigate the hazards posed by potential facility accidents and result in negligible public risk. The process involves low volumes of process chemicals and solid waste products that are not highly volatile, flammable, or an acute inhalation hazard. Therefore, there are no unusual transportation accident response requirements and minimal public risk.

B.5.1.1.3 Human Health and Environment

Nominal operating parameters were not established during demonstration and are not well defined. Concerns and impacts to human health and the environment cannot be properly assessed without effluent characterization data from standardized demonstration runs. Air infiltration to the PWC during demonstration and the lack of agent derived data prevented complete characterization of the effluents. The PCG sampling for energetics and dunnage runs indicated an absence of hazardous constituents; however, predicted conversion of feed materials to a synthesis gas was not demonstrated. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Effluents appear to be treatable and disposable; however, the provider's permit strategy is dependent on the RCRA synthesis gas exemption. Yet, data in demonstration indicates this exemption may not be achieved (e.g., BTU content, specified pollutants, etc.). The provider did not include information on permits for similar processes, and there is no history of permitting a PWC for treatment of agent waste. It is unclear how regulatory agencies will evaluate the process.

B.5.1.1.4 Potential for Implementation

Life Cycle Cost: The plasma arc process’s total capital cost may be approximately equal to that of baseline incineration. It is likely that the total operations and maintenance (O&M) costs for the plasma arc process may be slightly (10 to 15%) greater than baseline.

Schedule: The schedule estimates developed for the demilitarization of ACWs utilizing the Burns and Roe plasma arc process indicates completion of operations for Pueblo in January 2012, and Blue Grass in April 2012. This schedule is essentially equivalent to that for baseline incineration, given the uncertainty inherent in the schedule estimates, particularly for permitting.

Public Acceptance: The plasma arc process was deemed unlikely to obtain public acceptability due to the incomplete demonstration and the perceived similarity to incineration.

B.5.1.2 General Atomics Neutralization/SCWO

The General Atomics process of neutralization followed by SCWO was validated during demonstration. In addition, based on input from the Dialogue, it is likely that this process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of all ACWs. The basis for this conclusion is summarized below.

B.5.1.2.1 Process Efficacy/Process Performance

The General Atomics proposed total solution uses modified baseline reverse assembly and cryofracture of projectiles for munitions access. Agent and energetics are destroyed by caustic or water hydrolysis followed by SCWO. Metal parts are washed with caustic followed by a 5X thermal treatment, and dunnage is shredded, mixed with caustic, and destroyed by SCWO.

Cryofracture and baseline reverse assembly operations are well developed and therefore were not demonstrated. During demonstration testing, the government validated that caustic or water hydrolysis is effective for the destruction of agents to 99.9999% DRE and the destruction of energetics to 99.999%. The agent hydrolysis process does, however, produce Schedule 2 compounds, which are precursors to agents and are regulated by the Chemical Weapons Convention; the SCWO effectively destroyed all Schedule 2 compounds. Three of General Atomics' critical unit operations were demonstrated—the dunnage shredding and hydropulper system (DSHS), energetics rotary hydrolyzer (ERH), and SCWO. Characterization of tested materials and products was completed to an acceptable degree. Most of the sampling and analysis methodologies required were verified and validated, and solutions for the remaining methods appear straightforward.

In general, the unit operations demonstrated a level of maturity that lends confidence for full-scale development, although there are concerns with respect to the maturity and operability of SCWO. The demonstrated SCWO reactor (made of Inconel™, a high nickel chromium steel) and titanium heat exchanger experienced corrosion, and the reactor showed susceptibility to salt plugging. As proposed by General Atomics, a platinum-lined SCWO reactor should reduce the reactor corrosion and plugging problems for full-scale. However, the proposed platinum demonstration unit could not be fabricated in time for demonstration testing. Operability problems notwithstanding, the SCWO effectively mineralized all Schedule 2 and other compounds of concern to produce an effluent essentially free of organics. The demonstrated ERH removed and hydrolyzed energetics from bursters, propellant from rocket motor sections, and the majority of energetics from fuzes. Concerns remain with the scale-up of the ERH and SCWO while maintaining stable treatment conditions.

While the total solution is complex because of the large number of unit operations, most are inherently stable and can be effectively monitored and controlled using commercially available controls and instrumentation.

B.5.1.2.2 Safety/Worker Health and Safety

The General Atomics' process poses minimal risk to workers during normal operations. The process requires relatively large quantities of process chemicals. Hydrolysis is a low temperature, near ambient pressure process with relatively stable reaction rates. The process chemicals pose only moderate health hazards. While the overall process is inherently low risk, equipment containment and agent monitoring issues increase worker risk during normal operations. While cryofracture and SCWO operate at extreme operating conditions and pose severe physical hazards, the demonstrated engineering and administrative controls should greatly reduce both the probability and severity of an accident. Equipment redesign is expected to ensure containment of the ERH fugitive emissions and HDC fuze detonations. Although containment issues exist, the process poses manageable concerns for worker safety.

Because of the low volatility of the process chemicals and products, minimal potential for fires or explosions, and an effective process control system, potential facility accidents pose minimal public risk. The process involves relatively large quantities of process chemicals and solid waste, but none are highly volatile, flammable, or an acute inhalation hazard. Therefore, there are no unusual transportation accident response requirements, and risk to the public is minimal.

B.5.1.2.3 Human Health and Environment

The SCWO process effectively treats agent hydrolysates, energetic hydrolysates, and dunnage, thus destroying essentially all organics and producing an effluent of low concern and impact to human health and the environment. The demonstrated liquid effluent (and subsequent dried salts in full-scale) contained significant concentrations of heavy metals from SCWO reactor corrosion and lead from some energetics. A platinum liner should eliminate much of the heavy metals from SCWO corrosion, but was not demonstrated. The solid waste stream may fail RCRA TCLP and require further treatment prior to disposal due to the presence of heavy metals. All effluents are well characterized. Gaseous effluents from the SCWO are expected to be of low hazard and concern. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Although details of the permitting strategy were not provided, permitting of a hydrolysis/SCWO process for the Newport Chemical Activity in Indiana indicates that an acceptable permitting strategy is possible for demilitarization of chemical weapons.

B.5.1.2.4 Potential for Implementation

Life Cycle Cost: Neutralization/SCWO's total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M costs for neutralization/SCWO will be comparable to baseline.

Schedule: The schedule estimates developed for the demilitarization of ACWs utilizing the neutralization/SCWO indicates completion of operations for Pueblo in September 2011 and Blue Grass in July 2011. This schedule is essentially equivalent to that for baseline incineration, given the uncertainty inherent in the schedule estimates, particularly for permitting.

Public Acceptance: Neutralization/SCWO was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

B.5.1.3 Parsons/AlliedSignal Neutralization/Biotreatment

The Parsons/AlliedSignal process of neutralization of mustard followed by treatment in the Immobilized Cell Bioreactor (ICB™) was validated during demonstration. In addition, based on input from the Dialogue, it is likely that the mustard process will be publicly acceptable. Therefore, this process is considered a viable total solution for the demilitarization of chemical weapons with mustard agent. The process for the demilitarization of chemical weapons with nerve agent was not validated during demonstration. Based on input from the Dialogue, it is unlikely that the nerve agent process will be publicly acceptable. Therefore, this process is not considered a viable total solution for the demilitarization of chemical weapons with nerve agent. The basis for these conclusions is summarized below.

B.5.1.3.1 Process Efficacy/Process Performance

The Parsons/AlliedSignal process uses caustic or water hydrolysis as the primary destruction method for the agent and energetics extracted from chemical weapons. The destruction of agents was validated to 99.9999% and the destruction of energetics was validated to 99.999%, in government testing. The Parsons/AlliedSignal team’s use of this technology, along with the thermal treatment of metal parts and other solid wastes, has been validated to effectively treat the components of chemical weapons. The agent hydrolysis process does, however, produce Schedule 2 compounds, which are precursors to agents and are regulated by the Chemical Weapons Convention. For mustard type munitions, these Schedule 2 compounds were effectively treated in the ICB system. The Schedule 2 compounds from nerve agent munitions were not adequately treated by the ICB system during demonstration testing as evidenced by the steady increase in concentration of these compounds in the ICB over time. The nerve agent ICB process is therefore considered not sufficiently mature and hence unacceptable, at this time, for the disposal of munitions containing nerve agent. The process is considered mature for the processing of mustard agent, although there are concerns with the optimization of the integrated ICB system and the maturity of the metal parts treater and continuous steam treater. The process is also considered stable for processing mustard munitions although the many unit operations required contributes to its complexity. The monitoring and control of the system is straightforward and effective using commercially available controls and instrumentation.

B.5.1.3.2 Safety/Worker Health and Safety

The Parsons/AlliedSignal process poses minimal risk to workers during normal operations. Although the process requires relatively large quantities of process chemicals, hydrolysis, and bio-treatment operate at low temperature and near-ambient pressure, involve slow stable reactions, and have demonstrated good equipment-level containment capability. However, there are concerns regarding VX hydrolysate agent monitoring interference and unverified MPT, CST, and M28 shredding equipment-level containment capabilities. Because the process chemicals and intermediate products are not highly volatile, flammable, or acute inhalation hazards, and the CatOx demonstrated the ability to effectively treat process gas emissions, process accidents pose negligible public risk. Although the process involves relatively large quantities of process chemicals and solid waste, there are no unusual transportation accident response requirements, and risk to the public is minimal.

B.5.1.3.3 Human Health and Environment

The ICB and MPT are expected to produce effluents of low hazard and concern for mustard munitions. The secondary treatment of the GB/Comp B hydrolysate and the VX/Comp B/M28 hydrolysate waste streams was incomplete and contained a complex mix of volatile organic compounds, semi-volatile organic compounds, and inorganic anions, which could not be fully quantified because some compounds were not anticipated. This poses unknown risks with respect to human health and the environment. This effluent also contained Schedule 2 compounds with unknown disposal options. The CatOx gaseous effluent is expected to be of low hazard and concern. A dewatering system based on an evaporator/crystallizer is proposed for water recycle; no water effluents are expected. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Although details of the permitting strategy were not provided, a bulk mustard hydrolysis/biological treatment process is undergoing permitting in Maryland indicating an acceptable permitting strategy is possible.

B.5.1.3.4 Potential for Implementation

Life Cycle Cost: Neutralization/biotreatment’s total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M costs for neutralization/biotreatment will be comparable to baseline.

Schedule: The schedule estimates developed for the demilitarization of ACWs utilizing neutralization/biotreatment indicates completion of operations for Pueblo in April 2011 and Blue Grass in April 2012. This schedule is essentially equivalent to that for baseline incineration, given the uncertainty inherent in the schedule estimates, particularly for permitting.

Public Acceptance: Neutralization/biotreatment for nerve agents was deemed unlikely to obtain public acceptability due to the inability to validate the biotreatment process in demonstration. Neutralization/biotreatment for mustard agents was deemed likely to obtain public acceptability due to validation in demonstration and the characteristics of the process.

B.5.2 Recommendations

B.5.2.1 Burns and Roe Plasma Arc Process

Based on the findings summarized in Section B.5.1.1, the Burns and Roe plasma arc process for demilitarization of ACWs can not be considered a viable total solution at this time. Therefore, the PET recommends that PMACWA not consider this process for future pilot testing.

B.5.2.2 General Atomics Neutralization/SCWO

Based on the findings summarized in Section B.5.1.2, the General Atomics neutralization/SCWO process is considered a viable total solution for the demilitarization of all ACWs. Therefore, the PET recommends that PMACWA consider this process for future pilot testing at any stockpile site with ACWs. As part of those piloting activities, and in preparation for the development of a pilot plant design, the PET recommends that the maturation testing focus on the following issues:

- Testing of bulk energetics hydrolysis to determine optimum operating parameters.
- Longer-term testing of agent hydrolysate and energetics hydrolysates/dunnage with a platinum-lined SCWO reactor and heat exchanger to optimize the following:
  - integration with the plastics shredding
  - removal of aluminum from energetic hydrolysate feed
  - salt transport in SCWO
  - resistance to corrosion.
- Testing of shorter rocket motor segments in the ERH to determine optimum operating parameters.
- General waste disposal practices.

B.5.2.3 Parsons/AlliedSignal Neutralization/Biotreatment

Based on the findings summarized in Section B.5.1.3, the Parsons/AlliedSignal neutralization/biotreatment process for the demilitarization of ACWs with nerve agents is not considered a viable total solution at this time. The neutralization/biotreatment process is considered a viable total solution for the demilitarization of ACWs with mustard agents. Therefore, the PET recommends that PMACWA consider this process for future pilot testing at any stockpile site with ACWs containing mustard agents. As part of those piloting activities, and in preparation for the development of a pilot plant design, the PET recommends that the maturation testing focus on the following issues:

- Testing of bulk energetics hydrolysis to determine optimum operating parameters.
- Testing of an MPT and CatOx system to optimize feed, discharge, and other operational parameters.
- Testing of an HD biotreatment unit to obtain data to optimize the following:
  - recycling of the proposed saline biotreater effluent
  - integration of hydrolyzed MPT condensate
  - monitoring and control parameters
  - biomass characterization
- General waste disposal practices.

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Attachment B-A Program Evaluation Team Members and Other Participants

Program Evaluation Team Members

Position	Name	Organization
Core Technical Evaluation Team (TET)	Jim Richmond—Chair	PMACWA
	Carl Eissner	PMACWA
	Fred Hildebrandt	PMACWA
	Greg Mason	ECBC
	Scott Susman	PMACWA
	Jon Ware	PMACWA
TET Adjunct Advisory Team	George Bizzigotti	Mitretek Systems
	Clifford Bunton	University of California at Santa Barbara
	Tom Cain	Mitretek Systems
	Will Fraize	Mitretek Systems
	Jon Horin	Mitretek Systems
	Rick Rhoads	Mitretek Systems
	Arlene Wusterbarth	Mitretek Systems
Demonstration Working Group (DWG)	Darren Dalton—Chair	PMACWA
	Armand Balasco—Coordinator	Arthur D. Little
	Rob O'Neill	Arthur D. Little
	Ric Bowen	Arthur D. Little
	Phil Marrone	Arthur D. Little
Environmental Team	Jon Ware—Chair	PMACWA
	Bobby Templin	Argonne National Laboratory

Citizens Advisory Technical Team (CATT)

Position	Name	Organization
CATT	Irene Kornelly	Colorado Citizen Advisory Commission
	Doug Hindman	Kentucky Citizen Advisory Commission
	Bob Palzer	Sierra Club
	Paul Walker	Global Green
	Support Contractor	SBR Technologies

Other Participants

Position	Name	Organization
Contracting Officer	Chuck Comaty	SBCCOM
Legal Counsel	Lisa Simon	SBCCOM
	Bob Poor	SBCCOM
Facilitators	Diane Affleck	ECBC
	Jon Walther	ECBC

Attachment B-B Implementation Evaluation Criteria

- **Process Efficacy**
  - **Process Performance**
    - **Effectiveness (Factor 1)**
    - **Products (Factor 2)**
    - **Sampling and Analysis (Factor 3)**
  - **Process Maturity (Factor 4)**
  - **Process Operability (Factor 5)**
  - **Process Monitoring and Control (Factor 6)**
  - **Applicability (Factor 7)**
  - **Safety**
- **Worker Health and Safety**
  - **Design or Normal Facility Occupational Impacts (Factor 8)**
  - **Facility Accidents With Worker Impact (Factor 9)**
- **Public Safety**
  - **Facility Accidents With Public Impact (Factor 10)**
  - **Off-Site Transportation Accidents (Factor 11)**
- **Human Health and Environment**
  - **Effluent Characterization and Impact on Human Health and Environment (Factor 12)**
  - **Completeness of Effluent Characterization (Factor 13)**
  - **Effluent Management Strategy (Factor 14)**
  - **Resource Requirements (Factor 15)**
  - **Environmental Compliance and Permitting (Factor 16)**
- **Potential for Implementation**
  - **Life Cycle Cost (Factor 17)**
  - **Schedule (Factor 18)**
- **Public Acceptance (Factor 19)**

Process Efficacy
Process Performance
Effectiveness (Factor 1)

	Question	Information Requirements
1	How effective (residual mg of agent per kg of agent feed on 100% weight basis) is the process for agent detoxification?	Provide test abstract, describing: • Agent(s) and quantity • Simulant(s) and quantity • Test conditions • Scale of test equipment • Analytical methods used in test • Conversion efficiency, e.g., reaction stoichiometry • Results If technology has been tested with simulant rather than agent, provide a rationale with chemical mechanism if available (chemical bonds made or broken and intermediate and final compounds generated) for detoxification of agent.
2	How effective is the (residual mg of energetics per kg of energetics feed on 100% weight basis) of the process for deactivating energetics?	• Provide test abstract, describing: Energetic(s) and quantity Simulant(s) and quantity Test conditions Scale of test equipment Analytical methods used in test Results • If technology has been tested with simulant rather than energetic, provide a rationale with chemical mechanism if available (chemical bonds made or broken and intermediate and final compounds generated) for deactivation of energetic.
3	How well does the process decontaminate the chemical weapons hardware, i.e., detoxify the agent, and deactivate the energetics that may adhere to or penetrate metal parts and other components of the chemical munition?	Provide test abstract, describing: • Component configuration (metal parts / component material and quantity) • Agent(s) and quantity • Energetic(s) and quantity • Simulant(s) and quantity • Decon method, type of decon, decon time, decon quantity, etc. • Test conditions • Scale of test equipment • Analytical methods used in test • Results

	Question	Information Requirements
4	How well does the process decontaminate or destroy all other contaminated processing wastes, both primary and secondary, including but not limited to packaging materials, rags, gloves, personal protective equipment, and spent decon?	• Provide a decontamination or destruction strategy supported by a summary of test data.
5	How effective is the process in the presence of known impurities /additives, including mixtures of agent and energetics and agent or energetics degradation products?	• Provide an analysis of the effectiveness of the process to handle the chemical variations of the munition.

Products (Factor 2)

	Question	Information Requirements
1	How well is the entire process characterized with respect to the various feeds, intermediates and final products?	• Provide complete mass balance for each process step including, but not limited to, recovered metal parts and wastes. • Identify and quantify all raw materials and products including, but not limited to, reagents and solvents required per kg of process feed. • Identify the types, amounts and compositions of process intermediates and product streams (emissions, gaseous, liquid, solid, etc.) generated by the process. • Identify and quantify the byproducts from the process. • Describe any additional pre- and post- treatment required for any product streams to make this a complete process.
2	To what extent will the products or byproducts react to form agents at any stage in the process?	• Provide test data to support irreversibility • Provide chemical mechanisms to support irreversibility.

	Question	Information Requirements
3	Do these processes produce any compounds listed on Schedule 1 or 2 of the Chemical Weapons Convention (CWC)? If so, how is it proposed to eliminate these compounds?	• Identify and quantify Schedule 1 and 2 compounds produced. • Provide strategy for eliminating CWC-Schedule 1 or 2 compounds.
4	Based on analysis or chemical mechanism, to what extent are hazardous intermediates (e.g., EA2192) or products (e.g., dioxins, furans) expected to be formed? If so, how is it proposed to eliminate these intermediates or products?	• Identify any hazardous intermediates or products that are expected to be formed. • Provide strategy for safely managing them.

Sampling and Analysis (Factor 3)

	Question	Information Requirements
1	How well are the sampling and analysis methodologies and techniques for the mass balance verified and validated?	• Provide references for standard sampling and analysis procedures. • Provide summaries of verification and validation testing for non-standard analytical procedures.
2	How well are the sampling and analysis methodologies and techniques for residual agent in the specific product matrix (including solids and metal parts) verified and validated?	• Provide references for standard sampling and analysis procedures. • Provide summaries of verification and validation testing for non-standard analytical procedures.
3	How well are the sampling and analysis methodologies and techniques for residual energetics in the specific product matrix (including solids and metal parts) verified and validated?	• Provide references for standard sampling and analysis procedures. • Provide summaries of verification and validation testing for non-standard analytical procedures.

	Question	Information Requirements
4	How well are the sampling and analysis methodologies and techniques for other compounds of concern (e.g., dioxins, furans and Schedule 1 or 2 compounds) in the specific product matrix (including solids and metal parts) verified and validated?	• Provide references for standard sampling and analysis procedures. • Provide summaries of verification and validation testing for non-standard analytical procedures.

Process Maturity (Factor 4)

	Question	Information Requirements
1	At what level has the technology been tested and with what materials and in what configurations?	• Provide a summary description of the history of operations of the individual system components. • Provide a summary description of the history of operations (conception to present) of the integrated system.
2	Can the proposed process be built with readily available equipment?	• Provide a list of major equipment items, their availability and supply sources. • Identify all unique design or material of construction specifications.
3	Are there elements of the process and the integrated system that would be difficult to scale-up?	• Identify scale-up ratio required for “production”. • Provide integrated process scale-up strategy for total program solution.

Process Operability (Factor 5)

	Question	Information Requirements
1	How stable is the process?	• Describe how technology responds to modest reaction condition changes - e.g., temperature, pressure, feed rate, feed purity. • Describe the control parameters and safe operating ranges of the process steps • Provide a summary of the test data, if available.
2	What is the expected Reliability/Availability/Maintainability of the full-scale system?	• Provide RAM characteristics for the system and critical components

	Question	Information Requirements
3	Does the full-scale process operate as an integrated system for the destruction of the proposed munition type?	• Describe the system integration of individual components • Describe how each individual component of the system contributes to the overall process
4	What is the expected operating flexibility of the full-scale system?	• Provide a description of the turn-down capability, ease of start-up, shutdown, restart, extended idle, changeover to different munitions/agent
5	What is the expected complexity of the full-scale process? How many operators and what skill levels are required? What are the number and types of unit operations required? Degree of compatability/interface of unit operations/technologies (including material handling between unit operations) Does the system require a munition disassembly process?	• Provide the projected plant staff (numbers, skill level and training requirements) • Provide the number and types of unit operations required • Describe the degree of compatability/interface of unit operations/technologies (including material handling between unit operations) • Describe any required munition disassembly process • Provide preventive and routine maintenance requirements

Process Monitoring and Control (Factor 6)

	Question	Information Requirements
1	How effectively can the process be monitored and controlled? Do appropriate monitoring and control technologies exist?	• Provide a matrix identifying monitoring and control methods proposed for each step in the process including both mechanical and chemical operations. Summarize all methodologies proposed for monitoring and process control including human interface, as well as remote and automated operations. Include any methods proposed for analysis of intermediate process streams.
2	How effectively does the monitoring and control system prevent or control process upsets?	• Describe potential process upsets and solutions to prevent or control the upsets.

	Question	Information Requirements
3	What are the levels of complexity required in monitoring and process control?	• Same as for Question 1

Applicability (Factor 7)

	Question	Information Requirements
1	How many types of chemical munitions can the process handle at each site?	• Provide a list of munitions that can be handled by the process. • Provide a description of the process for each agent filled munition listed. • Provide a description of all potential Chem Demil applications. • Identify the site or sites. • Describe any site specific technology variations.
2	To what extent does the process accept multiple feed components (agent, energetics, metal parts, process wastes) in multiple states (gas, liquid, solid)? To what extent does the process accept multiple feeds (agent, energetics, metal parts, process wastes) simultaneously?	• Provide list of materials that can be fed simultaneously. • Provide list of materials that can be fed separately.

Safety
Worker Health and Safety
Design or Normal Facility Occupational Impacts (Factor 8)

	Question	Information Requirements
1	How hazardous are the process materials used in the process?	• Provide a description of all raw materials, compounds, and byproducts. It is not necessary to include the agent or energetics as a raw material. • Provide a list of on-site quantities (stored and in use) of process materials • Identify the constituents, concentrations and persistency of the process materials • Describe any potential acute and chronic human health effects associated with the process materials • Describe the state of materials • Describe the material physical hazards
2	What is the extent of the physical hazards associated with design and/or normal operating conditions?	• Provide a qualitative description of worker interaction with system for operations and maintenance and workplace conditions (reference all significant physical hazards, e.g., extremes in temperature, equipment requiring repetitive motion or lifting, noise, vibration, high voltage, lasers) • Provide a qualitative description of personal protective clothing and equipment unique to the technology and its compatibility with surety protective clothing and equipment.
3	How well is worker protection achieved?	• Provide a description of the process. • Provide a preliminary hazard analysis (qualitative, in accordance with MIL-STD 882C or equivalent). • Provide an estimate of the number of operations and percent of hours in personal protective equipment unique to the technology. • Provide a qualitative description of process safeguards, excluding secondary containment (inherent, engineered, and administrative, training, and personal protective clothing and equipment). • Describe monitoring needs; description of monitoring availability, reliability, and detection levels. • Describe the potential interference with agent monitors.

Facility Accidents With Worker Impact (Factor 9)

	Question	Information Requirements
1	How hazardous are materials used in the process?	• Provide a description of all raw materials, compounds, and byproducts. It is not necessary to include the agent or energetics as a raw material. • Provide a list of on-site quantities (stored and in use) of process materials. • Identify the constituents, concentrations and persistency of the process materials. • Describe any potential acute and chronic human health effects associated with the process materials. • Describe the state of materials. • Describe the material physical hazards.
2	What is the extent of the physical hazards that could cause facility accidents?	• Provide a qualitative description of worker interaction with system for operations and maintenance and workplace conditions (reference all significant physical hazards, e.g., moving parts, high voltage, high pressure). • Provide a qualitative description of personal protective clothing and equipment required and compatibility with surety protective clothing.
3	What are the potential incidents (e.g., significant changes from normal operating conditions) that could lead to worker exposure to chemical or physical hazards?	• Provide a process description (including containment provisions, susceptibility to energetics initiation, etc.). • Provide a brief description of full range of potential accident scenarios (include accidents resulting from process upsets [mechanical failure and worker error], fires, spills, but not natural phenomena or deliberate sabotage). • Provide a preliminary hazard analysis (qualitative, in accordance with MIL-STD 882C or equivalent; should address the scenarios, including critical response times). • List prior accident and near-miss history (technology development and relevant commercial experience). • Provide a qualitative description of special or unique level of training or equipment required for protection from worker exposure to chemical or physical hazards.

	Question	Information Requirements
4	To what extent is worker exposure eliminated or minimized?	• Provide a process description (hold, test, and release capability). • Describe monitoring needs; monitoring availability, reliability, detection levels. • Describe the potential interference with agent monitors. • Provide a qualitative description of process safeguards, excluding secondary containment (inherent, engineered, and operational). • Describe the persistence of released materials. • Provide a qualitative description of special or unique level of training or equipment required for emergency response to facility accidents associated with the technology.

Public Safety
Facility Accidents With Public Impact (Factor 10)

	Question	Information Requirements
1	How hazardous are the process materials used in the process?	• Provide a description of all raw materials, compounds, and byproducts. It is not necessary to include the agent or energetics as a raw material. • Provide a list of on-site quantities (stored and in use) of process materials. • Identify the constituents, concentrations and persistency of the process materials. • Describe any potential acute and chronic human health effects associated with the process materials. • Describe the state of materials. • Describe the material physical hazards.
2	What are the potential incidents (e.g., significant changes from normal operating conditions) that could lead to public exposure to any hazardous material?	• Provide a process description (including containment provisions, susceptibility to energetics initiation). • Briefly describe the full range of potential accident scenarios (include accidents resulting from process upsets arising from mechanical failure and worker error, fires, spills, seismic events, but not other natural phenomena or deliberate sabotage). • Provide a preliminary hazard analysis (including contingency planning and preparedness) which addresses the scenarios, including critical response times (qualitative, in accordance with MIL-STD 882C or equivalent). • List prior accident and near-miss history (technology development and relevant commercial experience).

	Question	Information Requirements
3	To what extent is public exposure to hazardous process materials due to loss of containment eliminated or minimized?	• Provide a process description (hold, test, and release capability). • Describe monitoring needs; monitoring availability, reliability, detection levels. • Describe the potential interference with agent monitors. • Provide a qualitative description of process safeguards, excluding secondary containment (inherent, engineered, and operational). • Describe the persistence of released materials. • Provide a qualitative description of special or unique level of training or equipment required for emergency response to facility accidents associated with the technology. • Provide a qualitative description of special or unique public education and notification that would be required for emergency response associated with the technology.

Off-Site Transportation Accidents (Factor 11)

	Question	Information Requirements
1	How hazardous are the materials being transported on site?	• Provide a description of all raw materials, compounds, and byproducts to be transported on site. • Provide a list of transported quantities. • Identify the constituents, concentrations and persistency of the transported materials. • Describe any potential acute and chronic human health effects associated with the transported materials. • Describe the state of materials. • Describe the material physical hazards.
2	How hazardous are the materials being transported off site?	• Provide a description of all raw materials, compounds, and byproducts to be transported on site. • Provide a list of transported quantities. • Identify the constituents, concentrations and persistency of the transported materials. • Describe any potential acute and chronic human health effects associated with the transported materials. • Describe the state of materials. • Describe the material physical hazards.

3	What special emergency equipment/training are required to respond to off-site transportation accidents?	• Provide a qualitative description of level of training or special equipment required for emergency response to transportation accidents (reference standard HAZMAT training or other special requirements beyond DOT).

Human Health and Environment

Effluent Characterization and Impact on Human Health and Environment (Factor 12)

	Question	Information Requirements
1	What is the level of hazard or concern associated with potential and actual effluents to air?	• Provide quantity (rate/rate of feed) of effluents. Rates of emissions, discharges, etc. should be reported as both instantaneous rates and average rates. • Provide the constituents / concentrations of effluents. • Provide the toxicity and other hazardous characteristics of effluents. • Provide the acute and chronic human health and ecology impacts of effluents. • Describe the potential for uncontrolled releases to the environment. • Describe the potential for internal releases. • Describe the anticipated engineering controls for both effluents and internal releases.
2	What is the level of hazard or concern associated with potential and actual effluents to **water**?	• Same as Question 1
3	What is the level of hazard or concern associated with potential and actual effluents to **land**?	• Same as Question 1
4	Does the process or system include appropriate and proven methods for monitoring process effluents and internal releases?	• Describe the demonstrated or proven methods given the expected conditions (e.g., matrices, temperatures, pressures, interferents, etc.) and required detection limits. • Provide the method validation data.

Completeness of Effluent Characterization (Factor 13)

	Question	Information Requirements
1	How well characterized are the process effluents?	• See all above information requirements. • Provide an effluent Mass Balance.

Effluent Management Strategy (Factor 14)

	Question	Information Requirements
1	How well developed is the effluent waste management plan?	Provide a waste management plan with reference to: • Waste streams • Applicable laws and regulations • Process insensitivities and impact • Significant unknowns • Pollution prevention opportunities • Commercial applications • Projected storage needs
2	Are all waste streams treatable and/or disposable? If plan proposes off–site treatment or disposal, do facilities exist which will accept waste?	• Describe treatment and disposal of waste streams. • Identify existing on-site or off-site treatment or disposal facilities.
3	Does technology provider have experience in managing the waste streams?	• Describe experience managing the waste streams.
4	Can discharges be held (batched) and tested before release?	• Describe the methodology or process for holding and testing waste streams.
5	Are there any RCRA–regulated hazardous wastes?	• Describe waste streams in terms of RCRA status.

Resource Requirements (Factor 15)

	Question	Information Requirements
1	What is the projected water demand?	• Provide the total water requirements (potable and non-potable). • Provide the amount returned to source. • Provide the amount recycled.

2	What are the projected energy requirements?	- Provide the electricity requirement (new or expanded facility requirement?). - Provide the fuel requirement (BTU and type) (new or expanded facility requirement?).
3	Does the technology entail any special land-use requirements?	- Provide the projected temporary on-site requirements (cooling ponds, storage areas, tanks, etc.). - Provide the projected permanent on-site requirements (landfills, etc.)
4	How well developed is the pollution prevention strategy for resource utilization?	- Describe the pollution prevention strategy to address opportunities to minimize resource use.

Environmental Compliance and Permitting (Factor 16)

	Question	Information Requirements
1	How well developed is the permitting strategy?	- Describe the permitting strategy: include RCRA, CWA, CAA, TSCA, etc. Identify and address all relevant Federal, state, local, tribal requirements.
2	How well developed is the strategy to assure compliance with all environmental laws and regulations, including permit conditions?	- Describe the compliance strategy; identify and address all relevant Federal, state, local, tribal requirements. - Describe the compliance history.
3	Has the process been permitted in a similar application (technology provider's experience)?	- Describe the past history with public and regulators. - List existing permits, hazard assessments.

Potential for Implementation
Life Cycle Cost (Factor 17)

	Question	Information Requirements
1	What are the estimated life cycle costs to implement the technology?	- Provide estimated implementation costs.

Schedule (Factor 18)

	Question	Information Requirements
1	What is the estimated schedule to implement the technology?	• Provide an estimated schedule.

Public Acceptance (Factor 19)

	Question	Information Requirements
1	What is the likelihood of public acceptance?	• Provide past history with public and regulators. • Identify existing permits, hazard assessments. • Describe the nature of effluents. • Describe any known environmental concerns. • Other stakeholder information.

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Attachment B-C Evaluation of Sampling and Analysis

B-C.1 Analytical Method Validation

During the ACWA demonstration, each non-standard analysis method or standard method applied to a non-standard sample matrix (i.e., caustic hydrolysate) was subject to validation testing prior to any use of the method on actual test samples. The validation testing was based on the determination of a method detection limit conducted according to standard EPA procedures.[2] The determination of whether the method validation study was successful or unsuccessful was based on several criteria:

- Precision and accuracy requirements in the PMACWA Demonstration Test Program Validation Sampling and Analysis Quality Assurance Program Plan (QAPP)
- Review of spike recovery data and follow-up discussions with the analysts who performed the testing
- Professional judgment as to whether or not the analytical data resulting from the method could be effectively used to evaluate the technology and provide the information required to meet the demonstration test objectives as provided in the appropriate Demonstration Study Plan
- Many analysis techniques were used exactly as specified in standard compilations. Method detection limits have been routinely determined for these “standard” techniques; therefore, no additional validation testing was conducted for these methods.
- Data Quality Review
- All data obtained during demonstration was subject to quality review. The data quality review examined the results obtained for a variety of Quality Control (QC) parameters. For example:
- Blank contamination: Contamination can be demonstrated when the analytes (the specific compounds being analyzed) of interest are detected in blank samples. Blank samples may be prepared in the field or laboratory and are used to establish the contribution to sample contamination from handling in the field or laboratory. Field blanks are collected at the test site and transported with the other samples from the test site to the laboratory, then subjected to the entire sample preparation and analysis procedure.
- Matrix spike recoveries: A matrix spike is an aliquot of a sample with a known amount of an analyte of interest added to it. The recovery for that analyte, i.e., the measured amount divided by the spiked amount, allows an assessment of the accuracy of the analysis. A “matrix effect” occurs when other components of the sample increase or decrease the recovery above or below a prescribed value.
- Surrogate and internal standard recoveries: A surrogate is a compound related to the analytes of interest that is added in a known amount to all analytical samples. An internal standard is also added in known amounts to all samples, and is used to calculate the concentration of the analytes of interest. Recoveries of surrogates and internal standards also allow an assessment of the accuracy of the analysis.

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[2] 40 CFR 136 Appendix B

- Duplicate sample reproducibility: The reproducibility for an analyte, i.e., the difference between the measured amount in two samples collected from the same point at essentially the same time, allows an assessment of the precision of the analysis.
- Sample collection equipment performance: Evaluation of the sample collection equipment performance included, for example, a review of on-site analytical instrument and gas sampling equipment calibrations against the QC requirements specified in the QAPP. This review was used to establish the integrity of the sample collected, independent of sample analysis.

The data quality review also examines the analytical procedure to determine if interference occurred, i.e., some other substance that is not the analyte of interest caused the procedure to produce either a false positive or an elevated result for that analyte.

B-C.2 Determination of Data Usability

Once the QC validation was completed, the data were qualified according to the intended use of the data. If the sample collection and analysis techniques gave results that were within the preset QC limits, i.e., it worked well in practice, then the method was considered verified. In addition, there were certain cases where the method was considered verified because it produced usable data even if it failed some of the QC tests. One example of this occurred when matrix spike recoveries indicated that results for a certain technique were biased high, i.e., the measured results consistently exceeded the known amount in the QC sample. However, the data from that technique were considered usable because they were used to determine the destruction of a particular analyte and all analytical samples showed no detectable amount of that analyte. In other cases, the technique failed some of the QC tests in a way that indicate the data were not usable for all the test objectives. An example of this would be a technique that provided results that could not be used to confirm the presence or absence of a particular analyte in a process stream. In this case, the techniques were not considered verified, and the decrease in the levels of usable data was noted in the body of the report.

B-C.3 Required Corrective Actions

For those methods that were not validated or verified, corrective action will be required. The results of the data quality review and follow-up discussions with the analysts who performed the analyses allowed the corrective action to be broadly categorized as one of the following:

- Modification is relatively straightforward. The QC results or the analysts observations indicate a specific corrective action should be implemented, and suggest that the corrective action has a very high probability of succeeding.
- Method optimization is required. The QC results or the analyst’s observations indicate the general course of corrective action that has a reasonably high probability of succeeding. Some testing of the response of the method to specific sample collection or analysis parameters should be tested, and the results of those tests are expected to indicate the specific corrective action to be taken.
- Method development is required. The QC results or the analyst’s observations do not indicate any specific corrective action that should be implemented. Extensive testing of a variety of parameters will be required, and an unsuccessful resolution of the issue is

possible.

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Attachment B-D Analytical Approach for Estimating Costs and Schedules

The evaluation of criteria in the Potential for Implementation is based primarily on the proposed plans for implementation as specified by the individual technology providers, as well as on feedback from the public at the sites of concern. The analytical approach used to develop costs and schedules for the final technical evaluation is discussed below.

B-D.1 Cost Estimating Approach

The original approach to evaluating the technology provider's cost estimates for a full-scale demilitarization facility at both Pueblo, Colorado and Lexington (Blue Grass), Kentucky involved review of their life cycle cost (LCC) estimates (both total capital cost and operating and maintenance (O&M) costs) for accuracy. Following this review, adjustments would be made to the technology provider costs that were evaluated to be necessary. Finally, each individual technology provider's costs would be compared to the total capital and O&M costs associated with baseline incineration.

Upon review of the cost estimates provided by each technology provider in their Draft Final Demonstration Test Technical Reports, however, the costs were determined not to be suitable for a comparison with baseline estimates. This determination was based on the following reasons:

- ☐ The basic approach used to develop the cost estimates was not always clearly defined.
- ☐ Inconsistencies within any one and among the three technology provider's cost estimates were considerable.
- ☐ Capital cost estimates were incomplete with various omissions of direct, indirect, and contingency cost allowances.
- ☐ O&M costs associated with each technology were lacking entirely.

As a result, independent total capital cost estimates were developed for implementation of the three alternative technologies at both Pueblo and Lexington Blue Grass. Use of a standard, well-defined, consistent cost estimating approach allowed cost comparisons among the three technologies, as well as with baseline incineration. Because of insufficient and/or lack of information regarding O&M labor requirements, chemical usage, and utility requirements (e.g., fuel, water, power) for the alternative technologies demonstrated, independent estimates were developed for capital costs, but not O&M costs.

A bottom-up approach was used to develop capital cost estimates (equipment and facility) for each alternative technology. This approach began with using the technology providers' costs for "delivered core process equipment[3]" as the basis for development of the total capital cost estimate. As appropriate, these costs were augmented with baseline equipment costs (e.g., RSM, PMD, MDM, BRA, and PUB), as well as costs of baseline buildings/support facilities (e.g., MDB, PUB, CHB, PSB, P&MB, LAB, and ECF).

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[3] This is the only cost information that was used from the technology provider's Draft Final Demonstration Test Technical Report. The technology providers were considered the most knowledgeable about actual equipment procurement costs of the major process equipment items.

Equipment “workup” factors were developed for direct costs, indirect costs, process contingency, project contingency, and cost contingency. In developing these factors, the technical evaluation in Section B.4 of this report was used as the basis for discriminating among the three technologies. The direct and indirect cost factors reflected such considerations as government project, a five-year operating life, high degree of automated and remote operations, and mid-U.S. geographic locations.

Facility “workup” factors were also developed for direct costs, indirect costs, process contingency, and project contingency. A cost contingency factor was not included because no definitive start date had been established. This factor takes into account the uncertainty surrounding anticipated changes in labor productivity, labor rates, and unit prices that would occur during field construction/equipment installation. Moreover, the cost contingency factor is expected to be similar for the three alternative technologies and baseline; accordingly, the net effect in a comparative cost analysis would be non-existent.

The direct cost factor takes into account the costs of labor and materials necessary to install the core process equipment. These costs include equipment installation labor and installation materials and labor for site preparation/foundations, process structure, piping/ductwork, electrical, instrumentation, insulation/lagging, and paint. When this factor is applied to the "delivered core process equipment,” an “installed” equipment cost results. A direct cost factor of 120% was used for each of the three technologies.

The indirect cost factor accounts for costs associated with contractor construction costs. Such costs include engineering, contractor overhead/home office, working capital, field expense, construction management, fees, training, startup, and spare parts. This factor also includes government expenses, such as project management/support, taxes and insurance, and land. In this analysis, the government’s expenses are not included, but would be similar and applicable to all three alternative technologies. A 40% indirect cost factor was applied to the “installed” equipment cost, which included the process contingency.

The process contingency factor accounts for the uncertainty related to the maturity of the technology. The less mature the technology, the greater the process contingency factor that is applied to the “installed” equipment cost. Depending on whether the technology is in concept stage, pilot stage, or demonstration stage, this factor typically ranges between 0 and 50%. The process contingency factor used for the three alternative technologies ranged between 10 and 20%, whereas a 5% factor was used for baseline. The lower factor for baseline is attributed to the fact that the baseline technology is a commercialized technology with two full-scale plants currently in operation, while the three alternative technologies are in the pilot or demonstration stage.

The project contingency accounts for the uncertainty related to the stage of the project. The earlier the project stage, the greater the project contingency factor that is applied to the “installed” equipment cost (including process contingency and indirect costs). This factor typically ranges between 5 and 30%, depending whether the project is in concept stage, preliminary engineering/design stage, or release-for-construction stage. The three alternative technologies in this analysis are considered to be in stages *prior* to preliminary engineering/design; subsequently, project contingency factors used for these technologies ranged between 20 and 25%. A 10% factor was used for baseline incineration because this technology is in the preliminary engineering/design stage.

The accuracy of the independently developed estimates of total capital costs ranges between –10% and +20%.

B-D.2 Schedule Development Approach

The original approach for evaluating each technology provider's implementation schedule for a full-scale demilitarization facility at Pueblo, Colorado and Lexington (Blue Grass), Kentucky was to review their implementation schedule for accuracy, completeness, and realism. As necessary, adjustments to the technology provider's schedule would be made for items such as key activities, activity duration, key milestone start dates, and parallel versus serial activities. Finally, the individual implementation schedules would be compared with the corresponding schedule for baseline incineration.

Upon review of the schedule provided by each of the technology providers in their Draft Final Demonstration Test Technical Reports, however, it became apparent that these schedules were not suitable for comparing with that of baseline incineration. The reasons for this included:

- The basic approaches used to develop the schedules were not always clearly defined.
- Basic assumptions were not defined regarding key activity durations and key milestone start dates.
- Inconsistencies within any one and among the three technology provider's schedule were considerable.
- Schedules were incomplete with omission of key activities and little justification of why certain activities were occurring in parallel versus in series.

As a result, it was determined to develop independent schedules for implementation of each of the three alternative technologies at both Pueblo and Lexington Blue Grass. The advantage to this approach of using a standard, well-defined, and consistent schedule estimating methodology was to allow for a schedule comparison to be made not only among the three technologies demonstrated, but also to baseline incineration. Furthermore, it was decided that schedules would be independently developed through operations. Sufficient information currently does not exist regarding all that is required for closure of a demilitarization facility.

The bottom-up methodology used to develop full-scale implementation schedules consisted of several steps. First, an overall schedule philosophy was developed, and all basic assumptions were defined. Second, all key activities were identified and assessed as to whether they occurred in series or in parallel. Reasonable start dates and likely durations for these key activities were then estimated. The interrelationships or dependencies of key activities were also determined, and allowances were made for site-specific differences at Pueblo and Lexington Blue Grass.

Estimated duration for operations was the only schedule data that was used from each of the technology provider's Draft Final Demonstration Test Technical Reports. The technology providers were considered the most knowledgeable about actual operation and processing throughput for the major (core) process equipment items comprising their alternative technology.

A review of the processing throughputs found them to be reasonable and generally compatible with the baseline reverse assembly processing throughputs.

To develop the full-scale implementation schedules, the following basic assumptions were made:

- Pueblo and Lexington Blue Grass activities will not run in parallel. The Lexington Blue Grass Contract Award is delayed by 12 months due to the need for Kentucky Statute Revision.
- All three technologies require “Maturation Testing” that would be completed prior to Contract Award. For the Burns and Roe plasma arc process, this would involve 15 months of testing at Pueblo and 15 months at Lexington Blue Grass. For General Atomics’ neutralization/SCWO technology, 8 months of testing were allotted for both Pueblo and Lexington Blue Grass. For Parsons/AlliedSignal’s neutralization/biotreatment technology, testing was assumed to be 8 months at Pueblo and 12 months at Lexington Blue Grass.
- Contract Award cannot be made prior to Record of Decision (ROD)
- Allowing for Engineering/Design and Site Preparation to begin, Contract Award can be made prior to issuance of RCRA Part B Permit.
- Prior to submittal of the RCRA Part B Permit Application, 65% design is required.
- The RCRA Part B Permit is approved 15 months after application.
- Construction of the MDB cannot start until issuance of the RCRA Part B Permit.
- Pilot Testing is required after initial Systemization.
- Design/Equipment Modifications follows Pilot Testing. A final Systemization would be required after Design/Equipment Modifications.

Table B.5-1 lists the key activities and their durations that were identified. These activities and durations are based on the technical evaluation of the three alternative technologies demonstrated, past knowledge and experience with baseline incineration, and engineering judgment.

When estimating the duration of key activities, discrimination among the three technologies was made where appropriate and when applicable. Only for three activities—Environmental Impact Statement (EIS)/ROD, Maturation Testing, and Operations—was it determined to distinguish among the three alternative technologies for activity duration. This determination was based on the evaluation of the technologies and their performance during demonstration testing. In Table B.5-1 a range of estimates is indicated for these activities.

To compare these schedules with baseline incineration, a baseline schedule was also developed with the same basic assumptions. Based on information provided by the Program Manager for Chemical Demilitarization, a baseline incineration plant at Pueblo was assumed to require 34 months for construction, 22 months for systemization, and 29 months for operations. The corresponding durations for a baseline plant at Lexington Blue Grass are 34 months for construction, 22 months for systemization, and 22 months for operations.

Table B.5-1. Schedule Durations for Key Activities

Key Activities	Pueblo/Blue Grass Range of Activity Duration (Months)
EIS/ROD	16-19
Maturation Testing	8-15
Engineering Design	20
RCRA Part B Permit	18
MDB	32
Systemization (Pilot Train)	16
Pilot Testing	5
Design/Equipment Modifications	11
Systemization (All Trains)	6
Operations	18.5-33

As part of the final step in developing the implementation schedules, realistic start dates for key activities had to be determined and interdependencies had to be established. The relationships and critical dependence among various key activities are noted below.

- Preparation of the EIS begins on 31 October 1999.
- Completion of the EIS and ROD approval requires a total of 16 to 19 months, depending on the duration of Maturation Testing.
- Start of Maturation Testing is 1 January 2000.
- RFP release immediately follows completion of Maturation Testing.
- Contract Award cannot be made until signing of the ROD and a minimum of 6 months after release of the RFP.
- A 65% design is completed 6 months after Contract Award.
- The RCRA Part B Application cannot be submitted until completion of the 65% design.
- The RCRA Part B permit will be issued 15 months after submittal of the application.
- Systemization of the Pilot Train cannot begin until 5 months after MDB construction is complete to allow for completion of equipment installation.

- A 5-month period of Pilot Testing follows Systemization of the Pilot Train.
- Systemization of All Trains (6 months duration) follows Design/Equipment Modifications.

The confidence level (likelihood of success) for these estimated schedules is 75%.

Definitions of Selected Terms and Acronyms

Symbols

µg	micro-grams
°F	degrees Fahrenheit

A

ACAMS	Automatic Continuous Air Monitoring System
ACW	Assembled Chemical Weapon
ACWA	Assembled Chemical Weapons Assessment
ammonia	NH_3
APG	Aberdeen Proving Ground
ATP	Alternative Technology Program (development of chemical agent neutralization process)

B

BIF	Boiler and Industrial Furnace
BPS	Booster Punch Station (baseline reverse assembly equipment on MIN)
BRA	Brine Reduction Area (Baseline post-treatment drum drier equipment)
BRS	Burster Removal Station (baseline reverse assembly equipment on PMD)
BSR	Burster Size Reduction (baseline reverse assembly equipment; uses RSS)
BVD	Best Value Decision

C

CAA	Clean Air Act
CAMDS	Chemical Agent Munitions Disposal System (DCD, UT)
CatOx	Catalytic Oxidation (Parsons/AlliedSignal)
CATT	Citizens Advisory Technical Team
CDF	Chemical Demilitarization Facility
CFR	Code of Federal Regulations
CHPPM	Center for Health Promotion and Preventive Medicine (US Army)
CLIN	Contract Line Item Number
CO	carbon monoxide
CO_2	carbon dioxide
COD	Chemical Oxygen Demand
Comp B	Composition B, a high explosive composition of 60% RDX, 39.5% TNT, and 0.5% calcium silicate
CRS	Condensate Recovery System (Parsons/AlliedSignal)
CSDP	Chemical Stockpile Disposal Program
CST	Continuous Steam Treater (Parsons/AlliedSignal)
CSTR	Continuous Stirred Tank Reactor
CWA	Clean Water Act
CWC	Chemical Weapons Convention

D

DAAMS	Depot Area Air Monitoring System
DACWA	Dialogue on Assembled Chemical Weapons Assessment
DCD	Deseret Chemical Depot (Tooele, UT)
DDT	Deflagration-to-Detonation (an explosive transition)

DFS	Deactivation Furnace System (baseline furnaces consisting of rotary retort and HDC)
DGIR	Data Gap Identification Report
DGRR	Data Gap Resolution Report
DGWP	Data Gap Work Plan
DIMP	Diisopropyl methylphosphonate
dioxins	A group of chlorinated hydrocarbons consisting of multiple isomers of tetrachloro- through octachloro-p-dibenzodioxin
DMMP	dimethyl methylphosphonate (chemical agent simulant)
DOT	Department of Transportation
DPE	Demilitarization Protective Ensemble (highest level of chemical agent PPE)
DPG	Dugway Proving Ground (Dugway, UT)
DRE	Destruction Removal Efficiency
DSHS	Dunnage Shredder/Hydropulper System (General Atomics)
DWG	Demonstration Working Group (part of the ACWA PET)

E

ECBC	Edgewood Chemical and Biological Center
EDC	Energetics Destruction Chamber (Burns and Roe) or Explosives Detonation Chamber (Burns and Roe)
EIS	Environmental Impact Statement
EMPA	Ethyl methylphosphonic acid
EPA	Environmental Protection Agency
ERH	Energetics Rotary Hydrolyzer (General Atomics)
ET	Environmental Team (part of the ACWA PET)

F

FAC	Fluid-Abrasive Cutting (Parson/AlliedSignal)
furans	A group of chlorinated hydrocarbons consisting of multiple isomers of tetrachloro- through octachloro-p-dibenzofuran

G

GB	designation for nerve agent Sarin
GC	Gas Chromatography
gm	gram
GPS	Gas Polishing System (Burns and Roe)

H

HAZMAT	Hazardous Material
HD	designation for distilled sulfur mustard H
HDC	Heated Discharge Conveyor (baseline electric radiation tunnel furnace)
HEPA	High Efficiency Particulate Air (type of filtration system)
hr	hour(s)
HRT	Hydraulic Retention Time
HT	designation for blistering agent, mustard (H) with T
HT&R	Hold, Test, and Release/Rework
HTH	High Test Hypochlorite
HVAC	Heating, Ventilation, and Air Conditionings (includes carbon filtration where applicable)

hydrogen peroxide	H_2O_2

I

ICB	Immobilized Cell Bioreactor™ (Parsons/AlliedSignal)
IMPA	Isopropyl methylphosphonic acid
IRIS	Integrated Risk Information System
ITO	Inside Thermal Oxidizer

J

JACADS	Johnston Atoll Chemical Agent Disposal System

K

kW	kilowatt

L

LEL	Lower Explosive Limit

M

M2	4.2-inch mortar shell (HD or HT)
M28	designation for propellant formulation in M55 rockets
M2A1	4.2-inch mortar shell (HD or HT)
M417	an M55 rocket fuze
M426	8-inch artillery shell (VX or GB)
M60	105-mm artillery shell (HD)
M60	inert (no agent or explosives) version of the 115-mm M55 chemical rocket
M61	inert (no agent) version of the 115-mm M55 chemical rocket
MD	Maryland
MDM	Multipurpose Demilitarization Machine
methane	CH_4
MIL-STD	Military Standard
MIN	Mine Machine
MINICAMS	Miniature Chemical Agent Monitoring System
ml	milliliter
mm	millimeter
MPA	Methylphosphonic acid
MPC	Miscellaneous Parts Conveyor (baseline reverse assembly equipment on PMD)
MPF	Metal Parts Furnace (baseline furnace for drained munitions bodies)
MPL	Multipurpose Loader (baseline reverse assembly equipment)
MPRS	Miscellaneous Parts Removal Station (baseline reverse assembly equipment)
MPT	Metal Parts Treater (Parsons/AlliedSignal)

N

NaOCl	Sodium hypochlorite (supertropical bleach, household bleach)
NaOH	Sodium Hydroxide
NCRS	Nose Closure Removal Station (part of the PMD)
NDPA	Nitrosodiphenylamine
ng	nano-grams
nitrogen	N or N_2
NNF	Not Normally Flowing

NOx	nitrogen oxides

O

OPCW	Organisation for the Prohibition of Chemical Weapons
OSHA	Occupational Safety and Health Administration
OTO	Outside Thermal Oxidizer
oxygen	O or O_2

P

PAS	Pollution Abatement System (common emission control system consisting of quench cooling, chemical scrubbing, filtration, etc.)
PCB	polychlorinated biphenyls
PCG	Plasma-Converted Gas (Burns & Roe)
PCP	pentachlorophenol
PDS	Pull & Drain Station (baseline reverse assembly equipment on the MDM) or Punch & Drain Station (baseline reverse assembly equipment on the MIN)
PET	Program Evaluation Team
pg	Pico-grams (10^{-12} grams)
pH	the negative LOG of the concentration of hydrogen ions in solution (unitless)
PL	Public Law
PMACWA	Program Manager for Assembled Chemical Weapons Assessment
PMCD	Program Manager for Chemical Demilitarization
PMD	Projectile/Mortar Disassembly
PPE	Personal Protective Equipment
PPL	Pick & Place Loader (baseline reverse assembly equipment)
PPM	Parts Per Million
PRH	Projectile Rotary Hydrolyzer (General Atomics)
provider	the provider of a specific alternative technology
PSI	Pounds per Square Inch
PWC	Plasma Waste Converter (Burns & Roe)

Q

QA	Quality Assurance
QAPP	Quality Assurance Program Plan
QC	Quality Control

R

RAM	Reliability, Availability, Maintainability
RCRA	Resource Conservation and Recovery Act
RDS	Rocket Drain Station (baseline reverse assembly equipment on RSM)
RFP	Request for Proposal
RO	Reverse Osmosis (Parsons/AlliedSignal)
ROD	Record of Decision
RSM	Rocket Shear Machine (baseline reverse assembly equipment)
RSS	Rocket Shear Station (baseline reverse assembly equipment on RSM)

S

Sarin	nerve agent
SBCCOM	Soldier and Biological Chemical Command

Schedule 2	chemical agent precursors listed in Schedule 2 of the CWC
SCWO	Supercritical Water Oxidation (General Atomics)
SDS	Spent Decontamination System (baseline) or Spent Decontamination Solution (secondary waste from surface decontamination operations)
sodium hydroxide	NaOH
SOx	sulfur oxides
SSEB	Source Selection Evaluation Board
sulfuric acid	H_2SO_4

T

T	designation for bis-chloroethyl thioethylether
TCLP	Toxic Characteristic Leaching Procedure
TEQ	Toxic equivalency
TET	Technical Evaluation Team (part of the ACWA PET)
tetryl	a high explosive
Tetrytol	a high explosive comprised of 70% tetryl and 30% TNT
TNT	2,4,6-trinitrotoluene (a high explosive)
TO	Thermal Oxidizer
TOCDF	Tooele Chemical Agent Destruction Facility
TOX	Toxic Cubicle (baseline bulk agent buffer tank)
TSCA	Toxic Substance Control Act

U

UT	Utah
UV/Ox	Ultraviolet Oxidation

V

VX	designation for nerve agent methylphosphonothioic acid

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[141] 49 CFR 172.101, 49 CFR 173.124.

[142] 49 CFR 172.101, 49 CFR 173.136.

[143] 49 CFR 172.101, 49 CFR 173.120.

[144] 49 CFR 172.101, 49 CFR 173.115.

[145] 49 CFR 172.101, 49 CFR 173.115.

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[147] General Atomics, *Assembled Chemical Weapons Assessment (ACWA), Draft Test Technical Report*, 30 June 1999, pp. 3-129, 3-175.

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[159] Parsons/AlliedSignal, *Assessment of Technologies for Assembled Chemical Weapons Demilitarization, Demonstration Test Final Report*, 1 July 1999, pp. 3.4.2-2, 3.6.3-1, figures 3.4-1, 3.4-2.

[160] U.S. Army Center for Health Promotion and Preventive Medicine Directorate of Laboratory Sciences, laboratory results.

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[165] *Ibid*., pp. 3.4.2—1, 3.4.3—1-3.4.3—8, 3.4.3—11-3.4.3—12.

[166] *Ibid.*, Tables 4.3.2—20 and 4.3.2—21, following p. 4.3.2—9.

[167] For example, for GB M55 rockets, methylphosphonic acid or isopropyl methylphosphonate was found in the sludge from the clarifier at demonstration but are not shown in corresponding stream in the mass balance, *cf., ibid*., Table 4.3.2—20, p. 8, with pp. 3.5.3—52-3.5.3—53.

[168] *Ibid*., pp. 3.5.3—1, 3.5.3—51, 3.5.3—96.

[169] *Ibid.*, pp. 3.5.3—1-3.5.3—4.

[170] *Ibid*., pp. 3.5.3—52-3.5.3—53.

[171] *Ibid*., pp. 3.5.3—97-3.5.3—98.

[172] Extrapolated from data obtained during preparation of agent hydrolysate; see, Demonstration Working Group, PMACWA, Analytical Chemistry Results Database.

[173] Parsons/AlliedSignal, *Assessment of Technologies for Assembled Chemical Weapons Demilitarization, Demonstration Test Final Report*, 1 July 1999, pp. 3.5.3—52-3.5.3—53, 3.5.3—97-3.5.3—98.

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[215] *Ibid*., pp. 4.3.2-31—4.3.2-32.

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[234] Parsons/AlliedSignal, *Assessment of Technologies for Assembled Chemical Weapons Demilitarization, Demonstration Test Final Report*, 1 July 1999, p. 3.5.3-63.

[235] 40 CFR 261.24.

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Appendix C

Demonstration Results

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Appendix C
Demonstration Details

I. Description of Test Locations and Unit Operations

Demonstration testing of the proposed technologies was conducted at three Army test sites: APG, Maryland; DCD, Utah; and DPG, Utah. The Pantex Plant in Amarillo, Texas and Radford Army Ammunition Depot in Radford, Virginia were used to generate energetics hydrolysates. A summary of the ACWA demonstrations and the unit operations that were demonstrated follows.

Aberdeen Proving Ground, Edgewood Area, Maryland —Edgewood Chemical and Biological Center

Two unit operations were demonstrated at the ECBC located at Aberdeen Proving Ground—Edgewood Area, Maryland: the Burns and Roe Plasma Waste Converter (PWC) System and the Parsons/AlliedSignal HD/Tetrytol Hydrolysate Immobilized Cell Bioreactor (ICB).

The PWC system was demonstrated in one of ECBC's Toxic Test Chambers (Building E3566). The Toxic Test Chamber has been approved for agent and explosives testing and is 32 feet in diameter with a 20-foot ceiling. The chamber is constructed of two-inch steel backed with 24-inch reinforced concrete. In order to accommodate the Burns and Roe demonstration testing, a number of modifications were made to the test facility. A new water chiller system, propane system, and nitrogen system were installed. In addition, the electrical service and the carbon dioxide system were repaired and upgraded.

The HD/Tetrytol Hydrolysate ICB was located in Building E3570. The equipment was pre-assembled in 40-foot long cargo containers, which were placed in this facility. Some facility modifications were necessary to customize utility connections including ventilation, electric power, and water.

Deseret Chemical Depot, Utah —Chemical Agent Munitions Disposal System

Four unit operations were demonstrated at the CAMDS located at the DCD in Tooele, Utah: the General Atomics Energetic Rotary Hydrolyzer, the Parsons/AlliedSignal GB/Comp B Hydrolysate ICB, the Parsons/AlliedSignal VX/Comp B/M28 Hydrolysate ICB, and the Parsons/AlliedSignal Metal Parts Treater (MPT). In addition, GB Hydrolysate and VX Hydrolysate required for some of the ACWA demonstrations were generated at CAMDS in a neutralization reactor system.

The Energetics Rotary Hydrolyzer (ERH) was located inside the CAMDS ECC #1, an 8-foot cylindrical steel chamber approximately 20 feet in length. The ECC was capable of both agent and explosive operations. Some modifications were necessary to customize utilities.

The GB/Comp B Hydrolysate and the VX/Comp B/M28 Hydrolysate ICB systems were located in the Chemical Test Facility (CTF) at CAMDS. The MPT was also located in this facility. Substantial renovations were necessary to accommodate the non-agent testing of the ICBs and the agent testing of the MPT. Renovations included removal of old equipment, construction of a smaller agent facility within the larger test facility, upgrade of the ventilation system, customization of the utilities, and construction of a mezzanine to support the ICB off gas handling system and provide access for the collection of emission samples.

In addition, GB hydrolysate and VX hydrolysate were generated in a Neutralization Reactor System that was installed in the Bulk Item Facility. No major modifications were necessary; however, the balancing of the ventilation system was necessary after installation of the equipment.

Dugway Proving Ground, Utah – West Desert Test Center

Three unit operations were demonstrated at the West Desert Test Center located at DPG in Dugway, Utah: the Parsons/AlliedSignal Rocket Cutting and Washout System, the General Atomics Super Critical Water Oxidation (SCWO) Unit, and the General Atomics Dunnage Shredder and Hydropulper System.

The Rocket Cutting and Washout equipment was located in the DPG Suppressive Shield Containment Facility (Building 8231). This facility consists of a building containing an inner sealed steel enclosure designed for explosive containment. This facility was unused for a number of years and required substantial renovation prior to the installation of the equipment. The renovations included installation of a heating/cooling system, upgrade of electrical utilities, repair to the steel enclosure, and installation of video cameras.

The SCWO unit was located in Building 4165, which was an old chemistry laboratory. The SCWO skid was surrounded by polycarbonate (LEXAN) shielding. Facility modifications were necessary to customize utility connections including ventilation, electric power, deionized water system, and compressed air.

The Dunnage Shredder System was located in DPG’s Receipt and Inspection Building (Building 3342). Facility modifications were necessary to customize utility connections including ventilation, electric power, and water. The Hydropulper System was located in the same location as the SCWO.

II. Analytical Approaches

The primary purpose of the Demonstration Testing validation sampling and analysis support was to implement the sampling and analysis approach developed by each Technology Provider as detailed in their Final Study Plan. The overall Demonstration Test Program, including the preparation of the agent and energetic hydrolysate feed materials, consisted of the sampling and analysis of 15 unit operations conducted in five geographical locations over a period of five months. The Demonstration Test Program resulted in:

- The collection of approximately 2,300 samples for chemical characterization;
- Approximately 11,500 sample analyses; and
- About 210,000 analytical data results.

The management of these activities included coordination of, and support to, 16 teams of sample collection personnel, the submittal of samples to 19 analytical laboratories in approximately

1,100 shipments and the data processing of the analytical results submitted to the Program Manager by the laboratories for subsequent transmission to the technology providers.

In order to keep open and active communication between the field sampling personnel, the analytical laboratories, and ACWA staff, an Analytical Hot Line and a project specific e-mail box were established. The hot line was staffed each day by a group of Laboratory Coordinators who coordinated the communication between the field sampling teams and the analytical laboratories. These communication mechanisms were used by the field sampling personnel and the laboratories as a single contact point to request assistance/information, or request supplies such as sample bottles, gas sample collection media, coolers, etc.

At the outset of each Demonstration Test feed campaign specific field quality control sample requirements were provided to the sample collection personnel to comply with the Program QA/QC Plan. This included field blanks, trip blanks, field duplicates, and matrix spike/matrix spike duplicates. On a weekly basis throughout the Demonstration Test Program, the sample collection projections from each demonstration testing team were reviewed against the capacity availability of the contracted laboratories. This comparison was then used to assign the samples to be collected the following week to specific laboratories with the appropriate capabilities and capacity to analyze the samples. The laboratory assignments were then communicated to the field sample processing personnel. This was particularly challenging given the continuously changing test schedules of the various unit operations. Factored into the projected testing schedule was coordination of the three ACWA contracted process gas sampling companies to support the Test Facility operators in implementing the validation demonstration test approach described in each Technology Provider's Study Plan.

Visits to the Test Facilities were made by the DWG to oversee the tests and compare the actual sampling and analysis activities to the approach detailed in the technology providers Study Plan.

As samples were collected and shipped to the laboratories the progress of the Demonstration Tests were monitored daily for compliance with the Study Plans and any approved Study Plan modifications. The chain of custody and laboratory documentation were reviewed to determine if the required samples were collected and the appropriate analyses were requested.

The performance of each analytical laboratory involved in the program was monitored from both a data quality perspective and a timeliness and completeness perspective and the sample distribution throughout the laboratory network was adjusted accordingly to achieve the highest quality data possible in the shortest amount of time. In several circumstances, the sampling and or analytical methods implemented during the testing required adjustment or modification to accommodate unforeseen factors. This was conducted on an as needed basis and involved the sampling contractor, the analytical laboratory, and the Technology Provider as necessary. Any modifications to the methods were formally approved and documented.

Data management was critical to the sampling and analysis support of the Demonstration Test Program. Sample collection information was logged into the Program Manager's Data Management System at the sampling location. The login process created an electronic chain of custody (COC) that was then transmitted electronically through encrypted e-mail to a central data management location and to the individual laboratories receiving samples. The actual samples were then compared to the electronic COC at both the receiving laboratory and the central data management location. Laboratories provided results, whenever possible, in a standardized electronic data deliverable (EDD) format. Data were received via the Data Management System in the standard EDD format, standard e-mail, computer diskette, or hardcopy. Data not received electronically was manually entered via a custom software package to create the EDD format for importing into the main database.

All data was checked for internal consistency, consistency with the sample analysis requests, and the planned sampling and analysis approach. Numerous checks were conducted on the data prior to importing to the main database. These checks focused on the accuracy and consistency of the information (e.g. sample identification numbers, analysis methods, compound names, etc.), as well as any possible indicators of data entry errors, either in the field or at the laboratory (e.g. consistency of data units with the sampled media). Identified issues were brought to the attention of the responsible laboratory or field team for resolution prior to draft release of the data. Following the initial quality review the data was released as Draft to the technology providers.

The QA/QC Plan called for an additional quality review of the data. This effort consisted of a review of 1,100 hardcopy data packages and covered both data from the analytical laboratories and data from the gas sampling contractors. The results of the review were then applied to the analytical data prior to finalization. Implementation of the QA/QC Program included conducting audits of the field activities at each Demonstration Test site. Approximately mid-way through the analytical portion of the program, site visit laboratory audits were conducted and laboratory performance evaluation samples were submitted to the major commercial laboratories.

III. Agent and Energetics Hydrolysates

In order to test the post-treatment processes for General Atomics and Parsons/AlliedSignal—supercritical water oxidation and biodegradation—agent and energetic hydrolysate was required. The Government supplied the agent and energetics hydrolysates (as Government Furnished Material) for these tests to avoid duplication of equipment, save money, conserve limited test facilities, and enhance demonstration results through feedstock consistency. Details of the agent and energetic hydrolysate generation are below.

HD Hydrolysate. In excess of 4,000 gallons of HD hydrolysate was produced in a campaign of 120 batch runs made over the period 8 June–11 September 1998. HD was added to hot water in a 40-gallon stirred reactor, the HD being 3.8 wt% of the reactor contents. Following a reaction time of 2 hours at 194°F, the pH of the hydrolysate was adjusted to 11-12 with sodium hydroxide.

The equipment used was not intended to be a model for scale-up to a full-scale stockpile disposal system, but was an expedient design suitable for use in the contained environment of the Chemical Transfer Facility at the Edgewood Area of Aberdeen Proving Ground, MD. The basic reaction scheme, hydrolysis of HD in hot water followed by neutralization of the resulting acidic product with sodium hydroxide (with subsequent biotreatment of the hydrolysate) has been studied extensively by the Product Manager for Alternative Technologies and Approaches and has been selected for disposal of the HD stockpile located at Aberdeen Proving Ground.

GB Hydrolysate. A total of 1100 gallons of GB hydrolysate was produced in a campaign of 11 batch runs made over the period 18 December 1998–19 January 1999. In each run, GB (7 gallons) was added to 5% NaOH (93 gallons) in a 100-gallon capacity stirred reactor at ambient temperature over a period of 20-35 minutes and allowed to react for one hour after the completion of agent feed. The mole ratios and operating conditions were determined by the Edgewood Chemical and Biological Center (ECBC) based on prior bench-scale testing.

VX Hydrolysate. Following the GB hydrolysis campaign, and using the same equipment, 400 gallons of VX hydrolysate were produced in four batches conducted from 2 March–2 April 1999. In each run, VX (35 gallons) was added to 20% NaOH (67 gallons) over a period of 70 minutes. The reactor temperature at the start of VX feed was set at 135^{o}F. After the completion of VX feed, the reactor temperature was maintained at $194\text{-}200^{o}$F for a period of 5 to 20 hours. At this scale of operation, it was found necessary to increase the caustic ratio and reaction time from those determined in bench-scale testing at ECBC. The basic reaction scheme, hydrolysis of VX in caustic (with subsequent SCWO treatment of the hydrolysate) has been selected for disposal of the VX stockpile at the Newport Chemical Demilitarization Facility, Newport, IN.

Energetics Hydrolysate

Comp B and Tetrytol Hydrolysate. The hydrolysis of Comp B and Tetrytol explosives was conducted at the Pantex Plant, Amarillo, Texas using both 6% and 12% sodium hydroxide solution. The reactions were conducted in both 50 gallon and 200 gallon glass lined reactors by heating the sodium hydroxide solution to approximately 90^{o}C, adding the explosive, and agitating the solution at temperature for approximately 8 hours. A total of 470 pounds of Comp B and 184 pounds of Tetrytol were hydrolyzed at batch sizes of up to 78 pounds, resulting in approximately 1,000 gallons of Comp B hydrolysate and 160 gallons of Tetrytol hydrolysate. Caustic to explosive ratios consisted of approximately 20 to 1 for the 6% solution supporting Parsons/AlliedSignal’s technology and 5 to 1 for the 12% solution supporting the General Atomics' technology. Gas, liquid and solid samples were taken and analyzed in order to characterize the products of the reaction.

M28 Propellant. The hydrolysis of M28 propellant was conducted at the Radford Army Ammunition Plant, Radford, Virginia, also using both 6% and 12% sodium hydroxide solution. The reactions were conducted in both a 30-gallon stainless steel reactor and 2,200-gallon carbon steel reactor by heating the sodium hydroxide solution to approximately 90^{o}C, adding the propellant, and agitating the solution at temperature for approximately 12 hours. A total of 83 pounds of M28 was hydrolyzed in two equal batches using the 12% caustic solution and a single batch of 890 pounds of M28 was hydrolyzed using the 6% caustic solution. The caustic to propellant ratios were the same as for the explosives hydrolysate discussed above. Six batches of laboratory scale hydrolysate were also generated in order to analyze the products of the reaction in the gas, liquid, and solid phases.

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Appendix D

Dialogue Participant Minority Report

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Appendix D
Dialogue Participant
Minority Report

It is my recommendation that further efforts to find alternatives to incineration focus on the long term needs for destruction of non-stockpile chemical warfare material as well as other hazardous waste rather than methods for weapons stockpile destruction. None of the technologies examined by the ACWA program are mature enough to justify the enormous cost in time and money required to develop them to the point where they can safely destroy chemical weapons.

The primary concern is the safe and rapid destruction of the aging chemical weapons stockpile. As the data presented in the Supplemental Report to Congress show, the search for alternatives, while useful in the long term, does not satisfy this immediate need. The original directive to the Army was to demonstrate two or more alternatives to incineration and $40 million was allocated for this purpose. In fact three technologies were examined, although it took more than five months past the original deadline and $37 million over the original budget. Yet this has proven insufficient for the few, vocal foes of the Army’s baseline incineration program. It appears likely that next year’s budget will have approximately $140 million to further examine three additional alternative technologies while continuing work with the original three.

The stage is now set for an endless pursuit of perfection. We are faced with the unpalatable choice of immediately proceeding with further development or waiting for the next three technologies to be tested. If we further develop one or more of the first three alternatives tested, it is with the knowledge that if these prove inferior to any of the next three tested the development effort will be wasted. If we wait, we lose another one or two years while weapons sit in bunkers and deteriorate further. In addition, there are other, even more immature technologies that were proposed under the ACWA Broad Agency Announcement (BAA), and there is already a call from anti-incineration activists to examine these as well. An endless, exhaustive search for the magic bullet that will cure all the perceived evils of the current chemical demilitarization program will not solve the fundamental problem: the presence of decaying stockpiles of chemical weapons in communities around the nation. It is time to act.

The original contention of anti-incineration activists was that there were alternatives “ready to go” and the goal of ACWA was to demonstrate such technologies. None of the technologies demonstrated or offered for demonstration could truthfully be described as “ready to go.” Despite almost $220 million dollars invested and three years of delay, it is clear we are not close to implementing an alternative to incineration for the destruction of assembled chemical weapons. The Program Manager for ACWA estimates that it will require 12.5 to 14.6 years before any of these technologies could finish weapons disposal at any site. The independent Arthur Andersen report estimates only a fifty percent chance that weapons in Kentucky and Colorado could be destroyed in the next 13 to 14 years. Indeed, there is good reason to believe that a 12 to 15 year time frame is an optimistic assessment based, specifically, on the past history of chemical demilitarization and, more generally, on the well documented problems of moving any complex chemical process from the research bench to production. Indeed, a recent Rand study showed that private chemical concerns routinely underestimate the time and money required for new plant development and construction by approximately two fold despite considerable experience and strong incentives to make correct predictions. It is difficult to imagine that the Department of Defense (DOD) will set new records for speed and frugality in chemical plant development, particularly a chemical plant charged with the high profile, technically difficult, and politically sensitive mission of chemical weapons destruction. And, of course, waiting for the results of additional technology demonstrations will further postpone the day on which the true hazard posed by chemical weapons storage is eliminated.

Faced with the prospect of, at the very least, 12-15 years of additional delay and the expenditure of billions of additional dollars with no guarantee of a safer or better alternative to incineration at the end of that time, there must be a clear and compelling case made for further exploration of alternatives. Given the well known risks resulting from further storage of deteriorating chemical weapons stockpiles, the budgetary pressures facing our military, the immature level of the technologies described in the Supplemental Report to Congress, the certainty that delaying to research and develop any alternative process will mean that the U.S. will fail to meet the Chemical Weapons Convention (CWC) destruction deadline even if we presume a five year extension, and the uncertainty that any viable process will result from this program, I do not see such a case made. This uncertainty and risk must be weighed against the facts that the baseline incineration system grew out of an extensive and wide-ranging Army research program that examined alternatives several times, has passed independent scientific examination from the National Research Council (NRC) twice, regulatory scrutiny from four states and the U.S. Environmental Protection Agency (EPA), and, last but by no means least, has been successfully and safely operating for years at full scale at two sites. For all these reasons, I can not recommend any alternative technology for the destruction of assembled chemical weapons, although I do think that a long term search aimed at providing destruction methods for non-stockpile chemical munitions, such as old rounds found on firing ranges, should continue. Unfortunately, not only has the search for alternatives failed to produce any process clearly superior to incineration for the immediate need of destroying aging weapons stockpiles, the budgetary demands of the ACWA program threaten the proven baseline system, a situation I find extremely distressing. The only proven solution ready for deployment is the baseline incineration system. I strongly urge its continued support.

Wesley Stites
Arkansas Citizens' Advisory Commission

Appendix E

Acronyms and Abbreviations

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5X	the state of agent decontamination after heating to 538°C (1,000°F) for 15 minutes, signifying that the material is clean of chemical agent and may be released from government control
ACWA	Assembled Chemical Weapons Assessment
APG	Aberdeen Proving Ground
BAA	Broad Agency Announcement
BRAC	Base Realignment and Closure
CAC	Citizens' Advisory Commission
CAMDS	U.S. Army Chemical Agent Munitions Disposal System
CATT	Citizens' Advisory Technical Team
COC	Chain of Custody
CST	Continuous Steam Treater
CSTR	Continuously Stirred Tank Reactor
CTF	Chemical Test Facility
CWC	Chemical Weapons Convention
DCD	Deseret Chemical Depot
DGIR	Data Gap Identification Report
DGRR	Data Gap Resolution Report
DGWP	Data Gap Work Plan
DMMP	Dimethyl methylphosphonate (chemical agent simulant)
DOD	Department of Defense
DPE	Demilitarization Protective Ensemble
DPG	Dugway Proving Ground
DRE	Destruction and Removal Efficiency
DSHS	Dunnage Shredding/Hydropulping System
DWG	Demonstration Working Group
ECBC	Edgewood Chemical and Biological Center
ECC	Explosives Containment Cubicle
EDC	Energetics Deactivation Chamber
EDD	Electronic Data Deliverable
EPA	U.S. Environmental Protection Agency
ERH	Energetics Rotary Hydrolyzer
FY	Fiscal Year
GB	Sarin, a nerve agent
HD	Distilled mustard
HDC	Heated Discharge Conveyor
ICB	Immobilized Cell Bioreactor
Kg	Kilogram
MPT	Metal Parts Treater
NEPA	National Environmental Policy Act
NRC	National Research Council
O&M	Operations and Maintenance
OPCW	Organization for the Prohibition of Chemical Weapons

ORI	Operational Readiness Inspection
PCB	Polychlorinated Biphenyls
PCG	Plasma Converted Gas
PCP	Pentachlorophenol
PET	Program Evaluation Team
PL	Public Law
PMATA	Product Manager for Alternative Technologies and Approaches
PMCD	Program Manager for Chemical Demilitarization
PWC	Plasma Waste Converter
QA/QC	Quality Assurance/Quality Control
RC&W	Rocket Cutter and Washout
RCRA	Resource Conservation and Recovery Act
RDX	Royal Demolition Explosive
SCWO	Supercritical Water Oxidation
SOP	Standard Operating Procedure
TCLP	Toxic Characteristic Leaching Procedure
TNT	Trinitrotoluene
TSCA	Toxic Substances Control Act
U.S.	United States
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
VOC	Volatile Organic Compound
VX	Nerve agent