Assembled Chemical Weapons Assessment Program

Supplemental Report to Congress

June 2001

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A Message from Michael A. Parker
Program Manager

The information contained in this supplemental report documents the requirements to identify and demonstrate alternative technologies as set forth in Public Law 104-208. A very aggressive schedule has been met in completing the demonstration and evaluation of the final three of six alternative technologies identified in 1998. All participants in the Assembled Chemical Weapons Assessment (ACWA) program, staff, affected stakeholders, and industry have worked diligently to ensure successful demonstrations were completed. The criteria used to evaluate these final three technologies demonstrations were developed early in the ACWA program in collaboration with a diverse group of affected stakeholders, now known as the Assembled Chemical Weapons Assessment Dialogue. As I stated in the first ACWA Report to Congress, "Meaningful stakeholder involvement has been, and will continue to be the cornerstone of this program."

The evaluation of the technologies demonstrated was presented to the ACWA Dialogue during a meeting held in Lexington, Kentucky, from January 24-26, 2001. The results and subsequent conclusions concerning the technologies tested can be found in Section II.C. Over the course of the last year, demonstrations consisting of 9 major process unit operations were conducted. During demonstration, approximately 1,100 samples were taken, and analysis was conducted at 15 laboratories, yielding 125,000 analytical data results. Continuous stakeholder involvement was executed via a Dialogue-established Citizens' Advisory Technical Team (CATT), which worked in concert with the ACWA Technical Evaluation Team members. The ACWA program has now turned its focus toward meeting the requirements of Public Law 105-261, "Strom Thurmond National Defense Authorization Act for Fiscal Year 1999." Extensive engineering design efforts are underway to ensure all National Environmental Policy Act, Resource Conservation and Recovery Act, and legal certification requirements are met in order to deploy an alternative technology.

Meaningful stakeholder involvement throughout the life of our nation's chemical weapons demilitarization effort is critical to establishing and maintaining public trust. Continuing the collaboration with the Program Manager for Chemical Demilitarization is also critical to facilitate the deployment of an alternate technology if that is the ultimate decision.

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A Message from the Dialogue on Assembled Chemical Weapons Assessment

BACKGROUND AND CONTEXT

The Program on Assembled Chemical Weapons Assessment was established in 1996 under Public Law 104-208 to facilitate and accelerate the destruction of chemical weapons stockpiles in the United States by investigating non-incineration, alternative technologies. As an integral part of ACWA, the Dialogue on Assembled Chemical Weapons Assessment was formed in May 1997 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;[i] 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 three 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 Dialogue has raised and highlighted a number of critical issues in prior messages to Congress, most recently in the 2000 Annual Report to Congress.[ii] Rather than repeating all of these important issues, the Dialogue has focused below on the most germane issues given the current status of the ACWA Program.

The following message contains:

A Programmatic Assessment of ACWA

- An assessment of the successes and limitations of the ACWA Program.

Recommendations Regarding Next Steps

- Recommendations regarding the ACWA process and data and how they should be applied to follow-on activities.

[i] Alabama, Arkansas, Colorado, Hawaii (Johnston Atoll), Indiana, Kentucky, Maryland, Oregon, and Utah.
[ii] In addition to the 2000 Annual Report to Congress, the ACWA Program has submitted reports to Congress in December 1997, December 1998, and September 1999 (Supplemental Report to Congress).

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PROGRAMMATIC ASSESSMENT OF ACWA

Four Technologies Successfully Demonstrated

Over the past two years, six technologies have been demonstrated—three in fiscal year 1999 (Demonstration I) and another three in fiscal year 2000 (Demonstration II). Of these six, chosen from an initial group of twelve proposals, four successfully completed ACWA demonstrations for destroying assembled chemical weapons. This is a major accomplishment, double the initial mandate in ACWA's founding legislation, Public Law 104-208, to identify and demonstrate "not less than two alternatives" to "baseline" incineration for the destruction of chemical weapons.

These four demonstrations have utilized technologies of neutralization/supercritical water oxidation, neutralization/bioremediation, neutralization/transpiring wall supercritical water oxidation/gas phase chemical reduction, and electrochemical processes to destroy chemical agents, explosives, propellant, and related materials ("dunnage" including wood, fiberglass, rubber, PCBs, and metal parts). As reported in the technical sections of this report, chemical agents were destroyed by these technologies to "six nines," that is, to 99.9999%; energetics were destroyed to 99.999%, also meeting performance objectives. In addition to technologies for destruction, technologies for weapons accessing and disassembly and dunnage treatment were successfully demonstrated, for example, shredding and water jet cutting.

The success of these initial four ACWA demonstrations bodes well for future application of these technologies to all chemical weapons stockpile sites including not only Blue Grass, Kentucky, and Pueblo, Colorado (which still await technology decisions) but also all stockpile sites as both complements and substitutes to existing technologies. The safety, efficiency, and environmental soundness of these technologies also no doubt portend future applicability to hazardous and toxic waste management in general as indicated in the EPA Report, "Potentially Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media" (August 2000, EPA 542-R-00-0004).

Engineering Design Studies for Two Technologies Continue Successfully

Two of the first three technologies demonstrated in fiscal year 1999 were carried forward into Engineering Design Studies (EDS I) this past year for additional testing and engineering scale-up. While the first year of technology demonstrations was intended to provide proof of concept, that is, that the technologies worked, EDS has three objectives: (a) to gain additional information necessary to develop a preliminary facility design; (b) to develop a preliminary hazards analysis, life-cycle costs, and schedules; and (c) to develop the necessary environmental data to support the NEPA (National Environmental Policy Act) and RCRA (Resource Conservation and Recovery Act) processes.

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Both of these EDS I two-stage technologies—neutralization followed by bioremediation for mustard agent, and neutralization followed by supercritical water oxidation for both nerve and mustard agents—continue to show successful results, subject to completion of testing.

This second year of technology testing has been very helpful in resolving key questions of optimum materials choice, through-put rates, operating parameters, chemical balances, effluent characterization, and other related issues, which normally arise in engineering designs. While some of these issues will continue to be refined as more technology development takes place this coming year, one should not construe this as immaturity in technology development. The baseline incinerator design, for example, continues to undergo thousands of engineering changes over a decade after its first construction on Johnston Atoll. The "modified baseline" incinerator design, proposed as one option for the Pueblo, Colorado, chemical weapons stockpile, also represents a major departure from past demilitarization systems.

One or more of the two successful technologies from Demonstration II (transpiring wall supercritical water oxidation and gas phase chemical reduction, and electrochemical processing) will enter EDS II testing and design in fiscal year 2001. We remain very optimistic that all of these non-incineration, alternative technologies will be very competitive with incineration in cost, schedule, and safety. We also emphasize that these alternative technologies utilize a hold, test, and release approach that is very important to public concern about health and environmental management.

Environmental and Acquisition Activities Initiated for Colorado and Kentucky

This past year planning has begun to expedite both environmental and acquisition planning for stockpiles in Colorado and Kentucky along four parallel paths. First, a Colorado Working Integrated Process Team (WIPT) has met to develop RCRA permit applications for four technology options—baseline incineration, modified baseline incineration, neutralization and bioremediation, and neutralization and supercritical water oxidation—in order to allow permit applications to be submitted for Pueblo as soon as the EIS (Environmental Impact Statement) and ROD (Record of Decision) process is finalized. We are pleased that the WIPT process will be largely open to the public and that a Community Involvement Plan was approved at the meeting on December 6, 2000. In Kentucky, a Working Integrated Process Team (WIPT) has been formed and met for the first time on January 10-11, 2001. We applaud the Kentucky WIPT's process that actively involves all stakeholders and is open to the public to the greatest degree possible. Transparency and stakeholder participation have been two key principles of the ACWA process and we hope and expect this will continue throughout all site-specific activities.

Second, the ACWA Program is drafting an Environmental Impact Statement (EIS) for the design, construction and operation of one or more pilot testing facilities at one or more chemical weapons stockpile installations including the Pueblo Chemical Depot (PCD) and Blue Grass Army Depot (BGAD). In addition, site specific EISs will be prepared by the Chemical Demilitarization Program for the destruction of the chemical weapon stockpiles stored at PCD

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and BGAD. The Pueblo EIS is currently being drafted and should be out for public comment in Summer 2001 to support a technology decision.

While we applaud a thorough environmental impact process and are sensitive to its legal complexities, concern remains within the Dialogue that two EIS's may be duplicative. Also, the Dialogue believes that recent legislation in Public Law 106-398 prohibiting Pueblo from considering technologies that were not demonstrated before May 2000 may violate the spirit of the NEPA process and inhibit serious comparisons of all relevant technology choices.

Third, an interagency group consisting of the ACWA Program Manager, the Chemical Demilitarization Program Manager, the Army Corps of Engineers, and the Operations and Support Command has been organized to develop a Request for Proposals (RFP) to be issued right after the technology decisions for Pueblo and Blue Grass.

Finally, a July 14, 2000 memorandum from the Under Secretary of Defense for Acquisition, Technology, and Logistics has prompted a full review of the entire Chemical Demilitarization Program including certification of the new alternative technologies. This Defense Acquisition Executive (DAE) Review is currently ongoing and the Dialogue is hopeful that it will result in appropriate recommendations. One key to a fair technology review will be the importance of uniform schedule and cost assumptions for all technologies—both incineration and alternatives—in order to be able to compare options for a timely and cost-effective solution. Such assumptions have not been uniform in the past. We are hopeful that the DAE process will level the playing field for all technologies. We also want to point out that such an acquisition review process is typically applied to weapons procurement decisions and is less transparent to the public than environmental decision-making processes. Therefore, the decisions reached through the DAE process may prove problematic from a public acceptability standpoint.

This next year will be extremely important for both Colorado and Kentucky citizens in their selection of destruction technologies for chemical weapons stockpiles; we hope that current environmental and acquisition planning will prove effective in openly facilitating appropriate, understandable, and acceptable choices for both states.

Continued Model Program for Involving Stakeholders in Government Activities

The process of destroying deadly weapons of mass destruction is one that understandably strikes fear and deep concern over public health and environmental impacts in local communities. Families, schools, businesses, and industry are situated only a few miles from these chemical weapons stockpiles and destruction facilities. The risks of continued storage, transportation, and demilitarization are not insignificant.

Because of past controversy at many chemical weapons sites, the ACWA program sought to integrate stakeholder involvement in its technology development program from the start. A national Dialogue was formed in May 1997 to ensure the integration of concerns and ideas of

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local, state, and federal officials, citizens, and others into the decision-making process of the program. The Dialogue, now approaching four years old, includes individuals from the nine states with stockpiles (including Hawaii for Johnston Atoll in the Pacific); state regulators; tribal representatives; U.S. Environmental Protection Agency (EPA) staff; Department of Defense (DOD) staff from affected bases and headquarters; and representatives from national citizen groups (such as Global Green USA and the Sierra Club) that regularly work on weapons demilitarization issues.

The ACWA Dialogue has convened every four to six months over the past four years and has been facilitated by a professional mediation group, the Keystone Center. Four volunteer Dialogue members, the “Citizens’ Advisory Technical Team” or CATT, and an independent technical advisory, SBR Technologies, have also been very involved in the proprietary acquisition process. The National Research Council of the National Academy of Sciences has also provided another independent review of the competing technologies.

Throughout the ACWA program, openness, transparency, stakeholder involvement, and consensus building have been watchwords. The program has demonstrated not only viable and innovative technologies but also a decision-making process whereby the best science and engineering can be successfully combined with concerns of affected communities and political realities of chemical weapons destruction. Almost 300,000 American citizens reside within the Immediate Response Zones of the eight continental U.S. stockpile sites where some 30,000 tons of nerve and mustard agent have been stored for years. The ACWA program, by involving and empowering these communities, has given them some ownership in difficult technology decisions and thereby helped to meet the ultimate goal of full chemical weapons destruction.

The ACWA program was recognized in 1999 as one of 98 semi-finalists, from a pool of 1600 applicants, for an Innovations in Government award administered by Harvard University. We believe that it serves as a model for democratic decision-making and consensus building in controversial government programs and should be emulated across programs and agencies.

RECOMMENDATIONS REGARDING NEXT STEPS

Continue ACWA Dialogue and Associated Public Involvement Processes

The ACWA National Dialogue should continue as an entity that provides advice to the ACWA Program Manager. Given the changing nature of the Program, the role of the Dialogue should evolve to address the future goals and tasks of the Program. The Dialogue anticipates one additional meeting during calendar year 2001 and urges the Program Manager to maintain a transparent communication style with the ACWA Dialogue and broader public. In addition, the Dialogue believes it is important to maintain the involvement of the CATT through the DAE process.

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Conduct EDS II Testing for Two Technologies Demonstrated During 2000

Public Law 105-261 gave PMACWA the authority to prepare for the immediate implementation of successfully demonstrated technologies. In preparing to implement the two technologies successfully demonstrated in 1999[i], PMACWA is conducting Engineering Design Studies (EDS I) and developing the necessary environmental data to support the NEPA (National Environmental Policy Act) and RCRA (Resource Conservation and Recovery Act) processes. The Dialogue recommends that the DOD should pursue EDS II activities for the technologies successfully demonstrated in 2000.[ii]

Examine ACWA Technologies for Possible Deployment at All Sites

The Dialogue recognizes that the many technical, regulatory and public acceptability challenges created by the destruction of chemical weapons are complex and evolving. In that context, the Dialogue recommends that all successfully demonstrated alternative and baseline technologies be evaluated for applicability and deployment at all sites. This recommendation extends to baseline and alternative technologies; integrated technology systems as well as individual unit operations; primary, secondary and dunnage waste streams; stockpile and non-stockpile material; and stockpile and non-stockpile sites.

Specifically, the Dialogue recommends that:

- Successfully demonstrated baseline and alternative technologies should be evaluated at the unit operation level and evaluated (as stated in recommendation 12 of the 1999 NRC report, "Review and Evaluation of Alternative Technologies for Demilitarization of Assembled Chemical Weapons") in combination as required to deploy an integrated destruction system that provides the maximum protection of human health and the environment as required by law.

- Successfully demonstrated alternative technologies should be compared to the baseline system to assess their applicability as potential improvements to existing facilities. Alternative technologies and specific unit operations may be of particular value in the treatment of secondary and dunnage waste streams at baseline incineration sites, but should be evaluated for agent, energetics, and metal parts treatment as well as weapons access. Improvements, if any, should be encouraged for expeditious deployment at those facilities.

[i] Neutralization followed by bioremediation for mustard agent and neutralization followed by supercritical water oxidation (SCWO) for both mustard and nerve agents.
[ii] Transpiring wall supercritical water oxidation and gas phase chemical reduction; electrochemical processing.

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- Successfully demonstrated alternative technologies should be evaluated for applicability to the required destruction of non-stockpile chemical material. Applicable destruction technologies should be moved toward deployment within the context of the non-stockpile program schedule.

- Successfully demonstrated alternative technologies should be evaluated on an ongoing basis as potential solutions to treatment challenges that may emerge within the overall Chemical Stockpile Disposal Program in the future.

Move Forward in an Expeditious Manner with Acquisition in Colorado and Kentucky

Both Colorado and Kentucky have fully assembled chemical weapons (as opposed to agent stored in bulk tanks) and will consider one or more of the technologies demonstrated over the past two years in the ACWA program. The Dialogue recommends that the government should expeditiously pursue acquisition activities for the safe, environmentally sound, and publicly acceptable disposal of chemical weapons at the Colorado and Kentucky stockpile sites. Throughout the acquisition process, the Dialogue group urges the Department of Defense to use a transparent process that is inclusive of all stakeholders.

Explore Convening a Dialogue Group Focused on Broader Chemical Demilitarization Issues of National Significance

The ACWA Dialogue has been successful in dealing with extremely complex and controversial issues. However, the purview of ACWA has been limited to alternative technology demonstration. Many of the issues that arise in ACWA Dialogue meetings go beyond the strict limits of developing and demonstrating non-incineration, alternative technologies. For example, it is clear that the ACWA technologies are applicable to agent stored in bulk as well as to assembled chemical weapons. Yet ACWA is directed solely at the latter group. When one compares life-cycle processes, issues of schedule and cost arise and experiences at baseline incinerator sites become very relevant. While the ACWA Dialogue discusses these issues from time-to-time when they are relevant to the ACWA program, Dialogue members believe that a need exists for a dialogue that would address issues within the broader chemical demilitarization program such as the treatment and disposal of dunnage; secondary waste; non-stockpile material (e.g., old buried weapons); and, facility closure. It would be important to note that an effective national dialogue follow key principles of full stakeholder involvement, open and bilateral communications, active consensus building, and timely and transparent information sharing.

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CRITERIA DEVELOPMENT, CRITERIA APPLICATION AND PUBLIC ACCEPTABILITY

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, Maryland, and Utah. 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 represent the basis for the recommendations below 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

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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, Criterion 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 criterion, 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 before a technology is 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, 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 January 25, 2001. As additional information becomes available, Dialogue members' assessment of potential public acceptability for these

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technologies may change. It should be emphasized that this is only an assessment of potential public acceptability of the alternative technologies demonstrated and is not in comparison to baseline incineration. In keeping with the rest of the Technical Report, this input was NOT by site, but rather a general comment on the likelihood of public acceptability.

The Dialogue agreed to the following summary:

Solvated Electron Technology [Teledyne-Commodore]: The Dialogue agreed by full consensus that the technology solution proposed by Teledyne-Commodore is unlikely to be publicly acceptable.

SILVER II™ Technology [AEA Technology/CH2MHill]: The Dialogue agreed by full consensus that the technology solution proposed by AEA Technology and CH2MHill is likely to be publicly acceptable.

Neutralization/Transpiring Wall Supercritical Water Oxidation (TW-SCWO)/Gas Phase Chemical Reduction (GPCR) [Foster Wheeler/Eco Logic/Kvaerner]: The Dialogue agreed by full consensus that the technology solution proposed by Foster Wheeler/Eco Logic/ Kvaerner is likely to be publicly acceptable.

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 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, or as a parallel stand-alone pilot facility. Assuming the primary acceptability issues as defined above have been adequately addressed, the remaining issues of concern would likely center first, on toxic effluents, if any, (PCBs, etc.) and second 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

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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 objection by the public to an improvement in the baseline process with an alternative component, or with a new alternative process. 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 alternative technology solutions and individual unit operations continue to be assessed for potential application as improvements or additions 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."
- Retrofit segments of the Pine Bluff incineration currently under construction.

The Dialogue members from Arkansas acknowledge that the further along that the Pine Bluff incinerator moves toward completion, the likelihood decreases that either of these two options will be pursued, barring unforeseen circumstances. However, it is noted that some alternative technologies may be able to accommodate retrofit easier than others.

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,
- Schedule, and
- Energy consumption.

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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 four Arkansas Dialogue representatives on the Dialogue have worked on chemical weapons issues for a combined total of 26 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 four representatives agree that to the extent that alternative technology improvements to the baseline are feasible and appropriate, they should be considered.

Specifically, based on the data gathered to date, they commented on additional issues (beyond criteria 1-18) that are likely to raise questions of public acceptability in Arkansas. In sum, they noted that:

- Teledyne-Commodore’s technology is not likely to be publicly acceptable.
- AEA Technology/CH2MHill’s technology is likely to be publicly acceptable.
- Foster Wheeler/Eco Logic/Kvaerner’s technology is likely to be publicly acceptable.

Submitted by: Daniel Clanton, Arkansas Department of Environmental Quality
Wesley Stites, Arkansas Citizens’ Advisory Commission
Evelyn Yates, Pine Bluff for Safe Disposal, a grass roots organization
Don Morrow, Chair, Arkansas Citizens’ Advisory Commission (Alternate to Wesley Stites)

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 the chemical agent HD (mustard); 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:

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- Potential for release of agent and/or toxic by-products during demilitarization and secondary waste processing, 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.

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 regarding a technology decision for Pueblo including the methodology and assumptions used to compare alternative technologies to baseline incineration and modified baseline incineration in terms of:

- Health, safety, and efficacy;
- Cost; and
- Schedule.

If the selected option would take substantially longer than others available, the Colorado Dialogue participants noted there would be particular concerns for:

- 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.

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Recommendations

In October 1999, the Colorado Citizens' Advisory Commission voted on their preference for a disposal method for the Pueblo site. The CAC selected the neutralization/biotreatment process. ACWA Dialogue participants acknowledge this decision and its implications as they relate to Criterion 19.

In addition to the above, Colorado Dialogue participants wish to note that AEA Technology/CH2MHill and Foster Wheeler/Eco Logic/Kvaerner total solutions have been successfully demonstrated and may have the potential for being publicly acceptable. However, Public Law 106-398 requires that only those alternative technologies demonstrated prior to May 2000 may be considered for Pueblo.

The Colorado Dialogue participants encourage the Department of Defense to establish an equitable, reliable, and public analysis of costs and schedule for all of the proposed systems. The lack of such an accurate analysis makes the effective public comparison of systems proposed for Pueblo extremely difficult.

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 life cycle 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 and have the DAE process remain as transparent as possible;
- Colorado Dialogue members urge that Integrated Process Team meetings continue to be open to the public and held in Pueblo to the extent possible; and
- Every consideration should be given to a technology's ability to recycle effluents and by-products.

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Submitted by: 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 are especially important when alternative technologies are considered for their site:

- As stated in our previous report, high temperature or high-pressure treatment of agent is not likely to be acceptable to the public.
- Dialogue members believe the following issues will also be important to the public, regardless of the technology employed:

  -Holding, Testing and Release of Process Effluents

  -Minimizing Gaseous Releases

  -Effluents Disposal Onsite and Offsite

  -Transportation Risks (Outputs and Inputs)

- Scheduling considerations are important however projected differences among the technologies are minor and not a basis for disqualification.
- The technology offered by Teledyne-Commodore did not meet demonstration timelines and could not be validated as a solution.
- Foster Wheeler/Eco Logic/Kvaerner or AEA Technology/CH2MHill would likely be acceptable for Kentucky, based on their ability to handle the total Kentucky stockpile and based on long-term input from the public.

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 Base Realignment and Closure (BRAC) process;
- Real or perceived impact to agriculture from facility effluents;
- Resource usage, consumption, and outputs;
- Impact to the Chemical Weapons Convention 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 other 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 views, opinions, and recommendations expressed in this message from the Dialogue on Assembled Chemical Weapons Assessment do not represent official Army or DOD position.

The Confederated Tribes of the Umatilla Indian Reservation remain concerned about the safe, timely, 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.
Wanda Munn, Oregon Citizens Advisory Commission
Bob Palzer, Sierra Club Air Committee
Wayne Thomas, Oregon Department of Environmental Quality
Rodney Skeen, 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.

Considering input/output data, AEA Technology/CH2MHill and Foster Wheeler/Eco Logic/ Kvaerner would most likely be public acceptable.

Key issues that would need to be addressed would include:

- 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.

The views, opinions, and recommendations expressed in this message from the Dialogue on Assembled Chemical Weapons Assessment do not represent official Army or DOD position.

Submitted by: Dennis Downs, Utah Department of Environmental Quality
Cindy King, Utah Chapter of Sierra Club
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Executive Summary

This *Supplemental Report to Congress* responds to the requirements contained in Title VIII, section 8065 of the Omnibus Consolidated Appropriations Act, 1997 [Public Law 104-208]. In accordance with that law, the mission of the Assembled Chemical Weapons Assessment (ACWA) program is to "demonstrate not less than two alternatives to the baseline incineration process for the demilitarization of assembled chemical munitions." This report presents the results of evaluations of the effectiveness of each alternative chemical munitions demilitarization technology demonstrated by the ACWA program in fiscal year 2000. This report supplements the ACWA 2000 report submitted in December 2000.

Program Evaluation Criteria

The ACWA Program Manager developed Program Evaluation Criteria in concert with the ACWA Dialogue in 1997. **The Implementation Evaluation Criteria, a subset of the Program Evaluation Criteria, were used to evaluate the demonstration results**. These criteria are summarized into four categories:

- Process Efficacy/Process Performance
- Safety/Worker Health and Safety
- Human Health and Environment
- Potential for Implementation

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, specifically asks the ACWA Dialogue, "What is the likelihood of public acceptance?"

Demonstration Planning and Execution

The technology demonstrations consisted of a series of tests on critical unit operations to show their effectiveness and repeatability and to establish confidence that they can be incorporated into an overall system. The unit operation selections were based on information in the technology providers' original proposals and other reports produced during the assessment phase of the program. Unit processes judged to be critical to prove the successful application of each technology being demonstrated and evaluated are listed in Table ES-1.

Testing under the ACWA program was conducted in compliance with all federal, state, Army, local, facility and safety and environmental regulations as well as with the Chemical Weapons Convention. Schedule 2 compounds[i] were also subject to transparency measures by the Organization for the Prohibition of Chemical Weapons Executive Council to verify and document the handling of these materials.

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

Table ES-1. Demonstration II Technologies

Technology	Technology Provider	Primary Destruction	Post Treatment	Unit Operations
SILVER II™	AEA Technology/ CH2MHill	SILVER II™ oxidation of agent and energetics[i] and thermal decontamination of assembled chemical weapons metal parts, dunnage, and solids.	None required	SILVER II™ Agent System SILVER II™ Energetic System
Neutralization/ GPCR/TW-SCWO	Foster Wheeler/ Eco Logic/ Kvaerner	Agent and energetics neutralization by hydrolysis and gas phase chemical reduction (GPCR) thermal decontamination of off-gases, metal parts, and dunnage	Transpiring wall supercritical water oxidation (TW-SCWO) of hydrolysate	Transpiring Wall Supercritical Water Oxidation Gas Phase Chemical Reduction
Solvated Electron System	Teledyne-Commodore	Solvated Electron Technology (SET™) using sodium metal and ammonia	Chemical oxidation	Metal Parts and Dunnage Shredding System Ammonia Fluid Jet Cutting and Washout System SET™/Chemical Oxidation–Agent System SET™/Chemical Oxidation–Energetics System SET™–Dunnage and Metal Parts System

The overall Demonstration Test Program included 9 unit operations and was conducted in six geographical locations over a period of eight months. The Demonstration Test Program resulted in the collection of approximately 1,100 samples for chemical characterization, approximately 8,000 sample analyses, and about 125,000 analytical data results.

ACWA Technology Evaluation Summaries

Summaries and conclusions from the test and evaluation of each of the three technologies are contained in Section II.C of this report and Section C.5.1 of the Technical Evaluation Report (Appendix C). Validation of a technology refers to the completion of the demonstration goals and generation of data to support the technology's ability to meet the Program Implementation Criteria. The conclusions are summarized below.

AEA Technology/CH2MHill

The AEA Technology/CH2MHill process, using an electrochemical oxidation process with silver ions to demilitarize chemical weapons, was validated during demonstration testing. 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.

Foster Wheeler/Eco Logic/Kvaerner

The Foster Wheeler/Eco Logic/Kvaerner process of neutralization followed by Transpiring Wall Supercritical Water Oxidation (TW-SCWO) and Gas Phase Chemical Reduction (GPCR) was validated during demonstration. Based on input from the Dialogue, it is likely that this process

[i] Energetic materials include rocket propellant and high explosives used in bursters, boosters, supplementary charges, fuzes, etc.

will be publicly acceptable. Therefore, it is considered a viable total solution for the demilitarization of all assembled chemical weapons.

Teledyne-Commodore

The Teledyne-Commodore process of Solvated Electron Technology was not validated during demonstration due to the lack of demonstration testing. In addition, based on input from the Dialogue, it is unlikely this process will be publicly acceptable. Therefore, this process is not considered a viable total solution for the demilitarization of chemical weapons at this time.

Certification Of Alternative Technologies

Final results of the life-cycle cost and schedule 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 (Public Law 105-261). Integrated process teams (IPTs) have been established within the Department of Defense as part of the Defense Acquisition Executive Review of the Chemical Demilitarization Program. Among the tasks of these IPTs is to evaluate whether or not alternative technologies described within this report meet certification requirements set forth by Public Law 105-261. The law specifies that 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*
- *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Finally, on May 21, 2001, the Under Secretary of Defense (Acquisition, Technology and Logistics) designated the Chemical Demilitarization Program as a Defense Acquisition Board (DAB) Program, Acquisition Category (ACAT) 1D. This designation means that all acquisition decisions for the program will be made by the USD (AT&L) (i.e., the Defense Acquisition Executive).

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I. INTRODUCTION/BACKGROUND

This report is submitted to the United States (U.S.) Congress in compliance with 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 alternative technologies demonstrated during fiscal year (FY) 2000 under the Department of Defense (DOD) Assembled Chemical Weapons Assessment (ACWA) program to demilitarize assembled chemical weapons.

Pursuant to the direction in the Military Construction Appropriations Act, 2000, Public Law 106-52, section 131, the ACWA program conducted demonstrations of three technologies that did not receive demonstration contracts in July 1998. They were AEA Technology/CH2MHill (SILVER II™), Foster Wheeler/Eco Logic/Kvaerner (Neutralization/Transpiring Wall Supercritical Water Oxidation/Gas Phase Chemical Reduction) and Teledyne-Commodore (Solvated Electron Technology). The demonstrations of these technologies are referred to as Demonstration II. The actual demonstrations of these three alternative technologies took place between July and October 2000. The evaluation of these demonstrations took place between October 2000 and February 2001. The evaluation of the Demonstration II technologies was conducted in a similar manner and using the same criteria to those of the Demonstration I technologies.

The ACWA Program Manager developed Program Evaluation Criteria in concert with the ACWA Dialogue in 1997. **The Implementation Evaluation Criteria, a subset of the Program Evaluation Criteria, were used to evaluate the demonstration results**. These criteria are summarized into four categories:

- Process Efficacy/Process Performance—summarizes performance, maturity, operability, process monitoring and control, and applicability;
- Safety/Worker Health and Safety—summarizes worker safety, normal operations and facility accidents, and public safety during facility accidents as well as off-site;
- Human Health and Environment—summarizes effluent characterization, completeness of effluent characterization, effluent management, permitting and compliance, and resource requirements; and
- 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, specifically asks the ACWA Dialogue, "What is the likelihood of public acceptance?"

This report presents the results of the assessments of the Demonstration II alternative technologies and supplements the ACWA program's December 2000 Report to Congress. This report also builds on the ACWA program's December 1997, December 1998, and September 1999 Reports to Congress. The 1997 and 1998 reports provide complete details of ACWA activities during FY 1997 and 1998, and the September 1999 report provides complete details of the technology selection process and the results of the evaluation of the Demonstration I alternative technologies. All reports are available on the Internet at http://www.pmacwa.org.

II. DEMONSTRATION II

A. Demonstration Preparations

1. Technology Overview

The total technology solutions proposed by the Demonstration II technology providers are summarized in Table 1 and are described in more detail in Appendix C. The unit operations or processes that were selected for demonstration are identified in Table 2.

2. Demonstration Objectives and Planning

The ACWA technology demonstrations were designed to be a series of tests on each technology provider's 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. Due to schedule and budgetary constraints, it was determined at the outset that testing of a fully integrated system would not be feasible. The tests were conducted independently by government personnel in existing government facilities.

The following overall test program objectives were established:

- Independent validation of selected unit operations,
- 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 were developed that were in full alignment with the overall program test objectives. A detailed test program was designed to meet specific test objectives, which were clear, concise, definitive, measurable, and practicable within the ACWA Program schedule, resource, and budget limitations. The specific test objectives were developed with consistency across all technology providers.

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

Offeror	Munitions Access	Agent Treatment	Energetics Treatment	Metal Parts Treatment	Dunnage Treatment
AEA Technology/ CH2MHill	Modified reverse assembly with spray washout	SILVER II™ electrochemical oxidation	SILVER II™ electrochemical oxidation	Metal Parts Treater using 1200°F superheated steam	Batch Rotary Treater using 1200°F superheated steam
Foster Wheeler/ Eco Logic/ Kvaerner	Modified parts of reverse assembly	Caustic hydrolysis followed by transpiring wall supercritical water oxidation (TW-SCWO) and gas phase chemical reduction (GPCR)	Caustic hydrolysis followed by TW-SCWO and GPCR	Caustic hydrolysis followed by treatment in a thermal reactor and GPCR	Caustic hydrolysis followed by treatment in a thermal reactor and GPCR
Teledyne-Commodore	Fluid – abrasive cutting, washing, and mining	Solvated electron treatment (SET™) followed by oxidation	Solvated electron treatment (SET™) followed by oxidation and stabilization	Classifying and shredding followed by SET™	Shredding followed by SET™

Table 2. Summary of Unit Operations Selected for Demonstration

Technology Provider	Unit Operations
AEA Technology/CH2MHill	SILVER II™ Agent System SILVER II™ Energetic System
Foster Wheeler/Eco Logic/ Kvaerner	Transpiring Wall Supercritical Water Oxidation Gas Phase Chemical Reduction
Teledyne-Commodore	Metal Parts and Dunnage Shredding System Ammonia Fluid Jet Cutting and Washout System SET™/Chemical Oxidation–Agent System SET™/Chemical Oxidation–Energetics System SET™–Dunnage and Metal Parts System

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, dunnage, etc.) availability and transport;
- Agent/energetic hydrolysate production;
- Analytical methods identification/validation;
- Test facility standard operating procedure (SOP) requirements;
- Test facility safety (pre-operational survey) requirements;
- Quality Assurance/Quality Control (QA/QC) program development and implementation; and
- Sampling and analysis support coordination.

Detailed information regarding Demonstration II planning and testing can be found in Appendix B.

B. General Demonstration Operations

1. Agent and Energetic Hydrolysate Generation

The Foster Wheeler/Eco Logic/Kvaerner total solution involves hydrolysis of both agent and energetics. Agent hydrolysis was a government technology offered as part of a total solution; therefore, 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 hydrolysis operations if they were to be conducted as part of the technology provider's demonstration. Agent and energetic hydrolysates were also required for Engineering Design Studies.

a. Agent Hydrolysate Generation

The objective of this effort was to produce HD hydrolysates for use as feed material for the demonstration testing of a technology provider's secondary treatment process for both Demonstration II (Foster Wheeler TW-SCWO) and Engineering Design Studies (General Atomics SCWO and Parsons/Honeywell Biotreatment).

Approximately 2,000 pounds of HD were hydrolyzed by the Edgewood Chemical and Biological Center (ECBC) at Aberdeen Proving Ground (APG), Maryland for these purposes. In excess of 3,500 gallons of HD hydrolysate were produced in a campaign of 121 batch runs.

Approximately 50 gallons of GB and VX hydrolysate that remained from Demonstration I testing were used for the Demonstration II testing and Engineering Design Studies, specifically in the SCWO units developed by Foster Wheeler and General Atomics.

b. Energetics Hydrolysate Generation

Approximately 520 pounds of tetrytol, 700 pounds of cyclotol (an acceptable Comp B replacement), and 3,000 pounds of M28 propellant were hydrolyzed to support Demonstration II testing and Engineering Design Studies. This resulted in approximately 420 gallons of cyclotol hydrolysate, over 445 gallons of tetrytol hydrolysate, and 1,850 gallons of M28 hydrolysate, respectively. Hydrolysis of tetrytol and cyclotol were handled by the Pantex Plant, Amarillo, Texas, and M28 hydrolysate was handled by the Radford Army Ammunition Depot, Radford, Virginia.

2. Sampling and Analysis

The primary purpose of the demonstration testing validation sampling and analysis support is 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 9 unit operations conducted in six geographical locations over a period of eight months. It is estimated that the Demonstration II Test Program resulted in:

- The collection of approximately 1,100 samples for chemical characterization,
- Approximately 8,000 sample analyses, and
- About 125,000 analytical data results.

The management of these activities includes the coordination of and support to 14 teams of sample collection personnel, the submittal of samples to 15 analytical laboratories in approximately 800 shipments, and the data processing of the analytical results submitted to the Program Manager by the laboratories for subsequent transmission to the technology providers.

These efforts resulted in verifying and validating most of the sampling and analysis methodologies and obtaining adequate levels of data that were usable for the evaluation of the technologies and the characterization of the effluents.

3. Demonstration Issues

There were several demonstration issues and considerations identified during the demonstration planning process that were generic to all the technologies. 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.

Throughout demonstration testing, problems and issues surfaced that required modification to the Demonstration II Study Plan for each technology provider. There were also changes to the test equipment and test procedures throughout the demonstrations. Changes were submitted in accordance with the Program's Manager's Configuration Management Plan, where each change was developed by the technology provider and reviewed by the ACWA staff and support contractors prior to the change being approved and incorporated.

C. Results and Evaluation

The Program Manager used over two dozen technical evaluators with a wide variety of expertise to assess demonstration and other available data against the program evaluation criteria. The indication that a technology has demonstrated an acceptable level of maturity for proceeding towards implementation denotes that the technology has met the prescribed criteria for maturity as established in the ACWA program at this time.

1. AEA Technology/CH2MHill

a. Demonstration Testing

Two configurations of the SILVER II™ process were used in this demonstration. A 2-kilowatt (kW) system was tested to demonstrate the ability of the process to effectively destroy chemical agents and chemical agent simulants. The plant designed for agent testing was required to be small enough to fit within a toxic chamber for safety and surety reasons. A 12-kW system was tested to demonstrate the ability of the process to effectively destroy energetic compounds and chemical agent simulants. The plant designed for energetics testing was designed larger to model the process closer to full-scale. Chemical agent simulant was tested in both plants in order to provide a comparison between the two plants to address scale-up issues of agent testing.

The SILVER II™ technology is based on the highly oxidizing nature of silver ions, which are generated by passing an electric current through a solution of silver nitrate and nitric acid in a standard industrial electrochemical cell. A more detailed discussion of this technology can be found in Appendix C.

2-kW SILVER II™ System (Agent and Agent Simulant)

The demonstration tests for the 2-kW system were to consist of five, seven-day tests designed primarily to assess the ability of SILVER II™ to destroy organic constituents and operate on a long-term, continuous basis. Five different feed streams were to be introduced to this unit including:

- 2-chloroethyl ethyl sulfide (CEES), an HD simulant – 1 workup and 1 validation run;
- dimethyl methylphosphonate (DMMP), a GB and VX simulant – 1 validation run;
- neat HD – 1 validation run;

- neat VX – 1 workup and 1 validation run; and
- neat GB – 1 validation run.

Due to schedule constraints, however, the CEES run was eliminated and the DMMP and VX runs were shortened. The following objectives were established for the 2-kW SILVER II™ agent and agent simulant demonstration:

- Validate the ability of the SILVER II™ 2-kW unit operation to achieve a destruction and removal efficiency (DRE) of 99.9999% for HD, GB, and VX.
- Determine the impact of operations on materials of construction to be used in a full-scale system.
- Demonstrate the operation and performance of the key process components for future scale-up.
- Develop operational data to allow the SILVER II™ 2-kW agent system to be compared to the 12-kW SILVER II™ system for use in scaling up the SILVER II™ agent system.
- Characterize silver-bearing residuals and determine potential silver recovery and determine disposal options (via characterization) for residuals from silver recovery operation (HD only).[i]
- Characterize gas, liquid and solid process streams from the SILVER II™ process for selected chemical constituents and physical parameters, and the presence/absence of hazardous, toxic, agent, agent simulant, and Schedule 2 compounds.

The 2-kW SILVER II™ system was installed in Building E3566 at the Edgewood Area of APG, Maryland. Delays were incurred with equipment delivery; upgrades of electrical and steam utilities; and installation of analytical and monitoring equipment (including equipment failures, delays in process equipment installation, and changes to analytical methods).

Systemization activities for the 2-kW system began in June and continued until the commencement of demonstration testing on August 17, 2000. Systemization included equipment shakedown and testing, operator training, and safety review or pre-operational surveys. Systemization also took much longer than expected. Delays were due to equipment and installation delays; mechanical equipment problems (including degraded gaskets, burned out pump motors, and software control problems); and analytical equipment problems.

The demonstration tests for the 2-kW system were initiated on August 17, 2000 and were completed on October 1, 2000. Testing included the processing of DMMP, HD agent, VX agent, and GB agent. With the exception of some minor mechanical problems, testing of chemical agents and agent simulants proceeded smoothly. HD, VX, and GB were processed at a higher electrochemical efficiency (>90%) than predicted. However, DMMP was more difficult to process completely than had been anticipated. Although oxidation of the DMMP appeared to be

[i] Solids that require silver reclamation result only from the processing of the chlorinated feeds (i.e., HD and CEES. Note CEES is a simulant and will not be processed at full scale.) VX and GB do not result in a solid that requires 5X and silver reclamation.

complete, unidentified organic material remained in solution. This material is believed to be an intermediate by-product that requires additional time to oxidize. Despite the fact that DMMP was intended to be a simulant for VX and GB, this issue was not seen to the same extent in the VX and GB runs. Therefore, this issue may not be applicable to full-scale operation.

12-kW SILVER II™ System (Energetics and Agent Simulant)

The demonstration tests for the 12-kW system were intended to consist of five, seven-day tests designed to assess the ability of SILVER II™ to destroy organic constituents and operate on a long-term, continuous basis. Feeds to this system were to include:

- CEES (an HD simulant) – 1 workup and 1 validation run;
- DMMP (a GB and VX simulant) –1 validation run;
- M28 propellant – 1 workup and 1 validation run;
- Tetrytol – 1 validation run; and
- Comp B – 1 validation run.

Due to schedule constraints, however, the CEES and Comp B runs were eliminated. The following objectives were established for the 12-kW SILVER II™ energetic and agent simulant demonstration:

- Validate the ability of the SILVER II™ unit operation to achieve a DRE of 99.999% for M28, Comp B, and tetrytol.
- Validate the ability of the SILVER II™ unit operation to achieve a DRE of 99.9999% for DMMP (VX/GB simulant).
- Determine impact of operations on materials of construction to be used in a full-scale system.
- Demonstrate the operation and performance of the key process components for future scale-up.
- Develop operational data to allow the SILVER II™ 2-kW agent system to be compared to the 12-kW SILVER II™ system for use in scaling up the SILVER II™ agent destruction system.
- Demonstrate the ability/inability to recycle, reuse, or dispose of nitric acid.
- Characterize gas, liquid and solid process streams of the SILVER II™ process for selected chemical constituents and physical parameters and for the presence/absence of hazardous and toxic compounds.

The 12-kW SILVER II™ system was installed in the Fire Safety Test Enclosure or "Firebox" at the Aberdeen Test Center, Aberdeen Area of APG, Maryland. Installation of the 12-kW SILVER II™ system took place between March and July 2000. Installation took longer than anticipated primarily as a result of delays in equipment delivery; mechanical equipment failures;

on-site design modifications; problems with the control system software; and problems with the installation of sampling, analytical, and monitoring equipment.

Systemization activities for the 12-kW system began in April and continued until the commencement of demonstration testing on August 13, 2000. A series of process and analytical equipment problems and failures impacted the systemization schedule. Of most concern was a repeated blocking of the energetic feed system due to the "sticky" characteristic of dinitrotoluene, which was being processed during systemization to prove-out the system prior to initiating validation testing. This problem required the reconfiguration of the feed system to include larger-diameter feed lines and valve replacements.

Demonstration testing for the 12-kW system began on August 13, 2000 and was completed on October 3, 2000. The processing of DMMP, M28 propellant, and tetrytol was completed. More time was required to completely process the DMMP than originally expected due to the suspected formation of an intermediate by-product. As discussed above, the same problem was encountered during the DMMP run with the 2-kW plant. Processing of M28 propellant appears to have worked well since the process reached an efficiency of 99% compared to the expected efficiency of 60%. In addition, no major problems were encountered. However, there were significant delays during the processing of tetrytol, and consequently, there was no time to process Comp B before the end of the test program. While processing tetrytol, which contains trinitrotoluene (TNT), numerous blockages occurred throughout the system. These blockages are believed to be a result of trinitrobenzoic acid forming as an intermediate product and precipitating out of solution. In order to prevent formation of the precipitate, the feed rate of tetrytol was reduced, thereby decreasing the efficiency and eliminating the blockages. Thus, the validation run for tetrytol required more than twice the time originally scheduled. Based on the increased processing time for tetrytol and the pre-determined demonstration completion date, the test was terminated prior to processing all of the planned quantity of tetrytol.

A summary of the planned and actual demonstration tests can be found in Appendix B.

b. Technology Evaluation

The AEA Technology/CH2MHill SILVER II™ process to demilitarize chemical weapons was validated during demonstration. Validation refers to the completion of the demonstration goals and generation of data to support the technology's ability to meet the Program Implementation Criteria. In addition, the Dialogue agreed by full consensus that SILVER II™ is likely to be publicly acceptable. Therefore, this process is considered a viable total solution for demilitarization of all assembled chemical weapons. The basis for this conclusion is summarized below.

(1) Process Efficacy/Process Performance

The AEA Technology/CH2MHill process uses SILVER II™ electrochemical oxidation as the primary destruction method for the agent and energetics extracted from chemical weapons. The destruction of agents was validated to 99.9999% destruction efficiency and the destruction of propellant was validated to 99.999% destruction efficiency in government testing. The tetrytol demonstration was curtailed, with destruction validated to 97.5% destruction efficiency. The curtailed tetrytol demonstration and lack of any demonstration data for Comp B prohibit the complete validation of the process. However, destruction of the constituents of Comp B and tetrytol in laboratory experiments indicates the likely effectiveness with these energetic compounds. The thermal treatment of metal parts and other solid wastes has been validated to effectively treat the components of assembled chemical weapons. SILVER II™ was validated not to produce Schedule 1 or significant quantities of Schedule 2 compounds regulated under the Chemical Weapons Convention. Characterization of products from agent and propellant destruction was completed to an acceptable degree. Acceptable treatment of most hazardous intermediates (formed at relatively low levels) was validated for this process; other treatment steps that should effectively destroy the remaining hazardous intermediates were proposed but not demonstrated. Although it poses a manageable technical risk, the incomplete demonstration of energetics destruction in turn leads to incomplete validation of product acceptability. The majority of sampling and analysis methodologies and techniques required were acceptably verified and validated. Optimization of some analytical methods is required, but this is not anticipated to be a problem for full-scale operation.

Although some concerns remain for the integrated process, unit operations demonstrated an acceptable level of maturity for proceeding towards implementation. Two SILVER II™ units were successfully demonstrated for agents and propellant. Newly proposed changes to the SILVER II™ process (after demonstration) to address solids management (tetrytol and Comp B are of particular concern) and the impurities removal systems with continuous operation appear appropriate but they have not been built or tested. Other technical risks are associated with extensive untested modifications to the reverse assembly, the proposed propellant size reduction, and the projectile punch/drain/steam washing systems. These technologies have not been tested in the proposed configuration. To minimize these risks, the conceptual processes can be replaced with existing systems from baseline reverse assembly and from those already being developed by PMACWA.

The overall AEA Technology/CH2MHill SILVER II™ process is complex and has a large number of unit operations. Effective operation of independent semi-batch SILVER II™ units was demonstrated for agents and propellant. However, the proposed continuous operability of SILVER II™ units with impurities removal systems has not been demonstrated. There are concerns about the ability to maintain stability of the complex full-scale system. Operability of SILVER II™ for treatment of burster energetics (tetrytol and Comp B) with proposed changes is undemonstrated; solids management is of particular concern. Most of the proposed unit operations are inherently stable and can be effectively monitored and controlled using commercially available controls and instrumentation. However, the inherent monitoring and control advantages of SILVER II™ are offset by the complexity of continuous operation with many interdependent unit operations.

The proposed process is applicable to all assembled chemical weapons at all sites.

(2) Safety

The process poses minimal risk to workers during normal operations. The SILVER II™ agent and energetics destruction systems operate at ambient pressure and at relatively low temperature; they are energy dependent and cannot cascade out of control. The process requires relatively large quantities of process chemicals, some corrosive, but they are commonly used in industry and can be handled in accordance with well-established industrial safety practices. The process uses fully automated controls as well as highly automated and remote[i] primary destruction operations. Minimal quantities of explosive or flammable gases are produced. However, several accident initiators are associated with various process conditions that could result in worker injury from the accident itself or from the subsequent exposure to agent or hazardous chemicals. The potential to encounter explosive materials represents the most significant, potentially hazardous situation for the worker during maintenance on SILVER II™. This is due to the accumulation of possibly explosive materials within the system and the potential for explosive crystal formation from leaks or in isolated system segments. Size reduction of M28 propellant has not been demonstrated, and the potential for ignition during the process is uncertain. Nevertheless, these risks should be minimized with appropriate engineering design and personal protective equipment and by procedures that ensure the review and approval of maintenance practices.

The process involves relatively large quantities of process chemicals and solid waste, but all have moderate to low toxicity, persistency, and volatility; none are carcinogens. SILVER II™ operates at ambient pressure. All gaseous effluents are processed through catalytic oxidation followed by hold, test, and rework/release. Public impact from potential accidents will be minimized or eliminated through several layers of system and facility secondary containment, which are expected to efficiently mitigate and contain the effects and prevent public exposure. There are no unusual transportation accident response requirements, and risk to the public is minimal.

A formal Hazards Analysis will be performed and included as part of the Engineering Design Package.

(3) Human Health and Environment

All SILVER II™ gaseous effluents undergo hold, test and release (HT&R) prior to discharge, although only a conceptual HT&R plan was provided. Gaseous emissions will be treated to well below regulatory limits. SILVER II™ includes the discharge of liquid effluent, consisting primarily of the dilute nitric acid waste stream. The Agent Impurities Removal System produces an evaporator bottoms solid waste stream with high concentrations of acids, metals, and organics that is containerized and sent to a Resource Conversation and Recovery Act (RCRA) Treatment, Storage and Disposal (TSD) facility. Offsite recycling/recovery is proposed for three effluent streams: 5X[ii] metals, concentrated nitric acid for use in the production of energetics, and silver chloride for silver recovery. Characterization of effluents from demonstration, except those from

[i] Unattended by personnel during operations.
[ii] 5X refers to chemical agent decontamination achieved through treatment at 1000°F for 15 minutes.

processing Comp B, is sufficient to support the proposed effluent management strategy. Effluents have minimal impact on human health and the environment.

SILVER II™'s effluent management strategy is well developed for this stage of the process, although some disposal issues still require resolution. The plan is dependent on the availability of Publicly Owned Treatment Works (POTW) capable of accepting the dilute nitric acid waste stream under a pretreatment exemption. This availability was not confirmed; however, other disposal options for this waste stream were determined to be available. The plan also assumes off-site acceptance of the evaporator bottoms by a RCRA TSD; however, this was not confirmed. Despite these uncertainties, analysis indicates that effluents appear treatable and disposable. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Although there are no unusual issues associated with this technology, the permitting strategy has not yet been fully defined.

(4) Potential for Implementation

The final 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 (Public Law 105-261). Integrated process teams have been established within the Department of Defense as part of the Defense Acquisition Executive Review of the Chemical Demilitarization Program. Among the tasks of these IPTs is to evaluate whether or not the alternative technologies described within this report meet certification requirements set forth by Public Law 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*
- *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.*"

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Therefore, in order to evaluate the cost and schedule portions of the potential for implementation criteria, a preliminary comparison was made between this alternative technology and baseline incineration with respect to total capital cost and schedule.

Life-Cycle Cost—The SILVER II™ estimated total capital cost may be approximately equal to that of baseline incineration. It is likely that the total operating and maintenance (O&M) cost for the SILVER II™ process may be slightly greater than baseline due the expected longer operating period.

Schedule—The schedule estimates developed for the demilitarization of assembled chemical weapons utilizing SILVER II™ indicates completion of Blue Grass, Kentucky, operations in February 2012.

Public Acceptance—Based on input from the ACWA Dialogue, SILVER II™ is likely to obtain public acceptance.

The details of the technical evaluation can be found in Appendix C.

2. Foster Wheeler/Eco Logic/Kvaerner

a. Demonstration Testing

For the demonstration testing, Foster Wheeler and Eco Logic tested the two primary components of their total solution: transpiring wall supercritical water oxidation (TW-SCWO) and gas phase chemical reduction (GPCR). The TW-SCWO process oxidizes the remaining organic compounds from the neutralization process in a high temperature and pressure environment. The GPCR decontaminates dunnage and metal parts in a hydrogen atmosphere. Additional details of these technologies can be found in Appendix C.

Transpiring Wall Supercritical Water Oxidation

The demonstration test program for TW-SCWO consisted of four 100-hour tests designed primarily to assess the ability of Foster Wheeler's design of TW-SCWO (transpiring wall reactor) to destroy organic constituents (including Schedule 2 compounds) and control corrosion and salt plugging on a long-term, continuous basis. The first feed, VX hydrolysate simulant, consisted of the exact recipe utilized by General Atomics in a similar 100-hour test conducted during the Demonstration I Test Program in 1999. The results were intended to directly compare the performance of the Foster Wheeler TW-SCWO system design to that of the General Atomics SCWO system design. The remaining three feeds consisted of mixtures of agent and energetic hydrolysates in proportions set to mimic the ratios of agent and energetics expected from hydrolysis of specific munitions. The feeds that were introduced included the following:

- VX hydrolysate simulant – 1 workup and 1 validation run;
- HD/tetrytol/aluminum hydrolysate and simulant – 1 workup and 1 validation run;
- GB/Comp B/aluminum hydrolysate and simulant – workup and 1 validation run; and,
- VX/Comp B/M28 propellant/aluminum hydrolysate and simulant – 1 workup and 1 validation run.

The following objectives were established for the TW-SCWO demonstration:

- Demonstrate long-term, continuous operability of the TW-SCWO unit with respect to salt plugging, corrosion, integrity of the platelet liner and erosion of the pressure control valve of the SCWO reactor.
- Determine if aluminum from the energetic hydrolysis process can be processed by the SCWO reactor without plugging.
- Demonstrate ability to destroy Chemical Weapons Convention Schedule 2 compounds in the feed to below their detection levels.
- Characterize the gas, liquid and solid process streams from the TW-SCWO process for selected chemical constituents and physical parameters and the presence or absence of hazardous, toxic, agent and CWC Schedule 2 compounds.

The Foster Wheeler TW-SCWO system was installed in Building 4165 at Dugway Proving Ground (DPG) in Dugway, Utah. Installation of the equipment took place during May 2000. Foster Wheeler began its systemization period on May 30, 2000. Systemization included equipment shakedown and testing, operator training, and safety review or pre-operational surveys. Systemization took longer than anticipated because of several problems with the air compressor (which is not part of the full-scale design) and extended training needed for the DPG operators. Systemization of the TW-SCWO equipment was completed by July 25, 2000 with the start of the first validation test.

During demonstration testing, Foster Wheeler tested all planned feeds; however, some validation runs were shortened for various reasons. Each validation run, except for the VX/CompB/M28/aluminum hydrolysate, was preceded by a workup run. One hundred hours of the validation run for VX simulant were completed with two interruptions, both due to problems with the air compressor, which would not be used in the full-scale system. During the workup run for HD/tetrytol hydrolysate, a crack in the upper liner of the TW-SCWO reactor was discovered. The liner section including and surrounding the crack was found to be severely corroded because of the absence of transpiration water protection in that region due to a known fabrication error. The crack was caused by cyclic thermal stresses in the corrosion-weakened liner material. No corrosion was observed in the region of the upper liner that was protected by transpiration water. In the absence of an appropriate spare liner for the cracked upper section, a spare liner, not designed for the upper section, was modified and installed. The modification included the drilling of a bleed hole in the replacement liner, not a desirable solution, to permit use of the “wrong” upper liner for continued testing.

During the 100-hour HD/tetrytol hydrolysate validation run, the run was stopped after 55 hours due to a blister or bulge that formed in a new upper liner, likely from thermal stress caused by the bleed hole. This indicated a limited lifetime remaining for the liner. It was then determined to terminate the HD/tetrytol hydrolysate validation run and reduce the GB/CompB/aluminum hydrolysate validation run to 50 hours instead of 100 hours. It was planned that after these two runs, the 100-hour validation run for VX/CompB/M28/aluminum hydrolysate would be run until the 100 hours or failure was attained.

During the GB/CompB/aluminum hydrolysate run, the system experienced fouling in a low-pressure heat exchanger, downstream of the pressure control valve. Periodic plugs of oxides of aluminum formed in the heat exchanger tubing that required flushing and maintenance. Fifty hours of the GB/CompB/aluminum hydrolysate validation run were completed without any interruption. Several additional problems were experienced throughout the VX/CompB/M28/aluminum hydrolysate validation test. These included trouble achieving ignition, distorted spray pattern from injector ports, and problems with the caustic feed pump. The validation run was terminated after approximately 26 hours of operation because of these problems.

Despite various problems with upstream and downstream system components experienced over the course of testing, the transpiring wall reactor consistently exhibited no salt plugging, relatively minimal salt buildup, and good resistance to corrosion throughout the test program for all feeds.

Gas Phase Chemical Reduction

The demonstration test program for the GPCR system consisted of testing dunnage and chemical agents. The feeds that were to be introduced included the following:

- Carbon trays – 1 workup and 3 validation runs;
- Wood spiked with 4,000 ppm pentachlorophenol (PCP) – 1 workup and 3 validation runs;
- Demilitarization Protective Ensemble (DPE) with 10% butyl rubber by weight to simulate gloves and boots – 1 workup and 3 validation runs;
- Fiberglass firing tubes – 1 workup and 3 validation runs;
- Neat GB – 1 workup and 3 validation runs; and
- M2A1 4.2 inch mortar spiked with simulated 30% HD heel – 1 workup and 3 validation runs.

The following six objectives were established for the GPCR system demonstration:

- Validate the ability of the GPCR process to achieve 5X decontamination condition for metal parts and dunnage.
- Demonstrate the effectiveness of the GPCR process to treat product gases generated during the treatment of metal parts and dunnage.
- Validate the ability of the GPCR process to achieve a DRE of 99.9999 for HD and neat GB.
- Characterize the gas, liquid and solid process streams from the GPCR process for selected chemical constituents and physical parameters and the presence or absence of hazardous, toxic, agent and CWC Schedule 2 compounds.
- Demonstrate the ability of the GPCR process to produce a gas effluent that meets either EPA Syngas or Boiler and Industrial Furnace (BIF) requirements.
- Determine the need for stabilization of residual dunnage solids based on Toxic Characteristic Leaching Procedure results.

The GPCR system was installed in Building E3726 at the Edgewood Area of APG, Maryland. Installation of the GPCR took place during May and June 2000. Although no major problems occurred during installation, several activities required more time than expected. Systemization included equipment shakedown and testing, operator training, and safety reviews or pre-operational surveys. Because of the compressed schedule for these activities, they did not necessarily occur sequentially and there was often considerable overlap. Furthermore, during systemization activities, some problems were encountered and overcome. Systemization activities occurred from June 2000 until the commencement of demonstration testing on July 10, 2000.

The demonstration testing of the dunnage was completed as scheduled. However, the technology provider and test facility encountered some problems while processing neat GB agent. These problems included: blockages in the agent feed line and liquid waste preheater system, test facility carbon filter change-out, high temperatures in test chamber which often prevented operators from entering the chamber, partial melting/corrosion of the product gas burner liner, and difficulties with the agent analytical method in the gas stream. Although these problems were overcome, the agent test schedule was compromised. Therefore, only two of the three runs with an M2A1 4.2-inch mortar and a simulated 30% HD heel were completed. The demonstration tests concluded on October 1, 2000.

A summary of the planned and actual demonstration tests can be found in Appendix B.

b. Technology Evaluation

Neutralization/GPCR/Transpiring Wall-SCWO was validated during demonstration. Validation refers to the completion of the demonstration goals and generation of data to support the technology's ability to meet the Program Implementation Criteria. In addition, the Dialogue agreed by full consensus that Neutralization/GPCR/TW-SCWO is likely to 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/Process Performance

Neutralization/GPCR/TW-SCWO uses modified baseline reverse assembly to access agent and energetics that are neutralized by sodium hydroxide (caustic) or water hydrolysis followed by TW-SCWO. Metal parts, dunnage, and other solids (including secondary wastes), and gases are thermally treated using GPCR. The proposed neutralization processes have been validated effective to 99.9999% destruction efficiency for all agents and to 99.999% destruction efficiency for all energetics as part of this demonstration and previous neutralization demonstrations. Processes used for decontamination of chemical weapons hardware and treatment of contaminated processing wastes were also validated. Validation of GPCR for the destruction of agents was not accomplished due to problems encountered with the process gas sampling and analysis. Agent hydrolysis produces Schedule 2 compounds, but the TW-SCWO effectively destroyed all Schedule 2 compounds to acceptable levels. 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 optimization of the remaining methods appears straightforward. However, agent monitoring in GPCR product gas will require method development for complete product characterization.

Although some concerns remain for the integrated process, unit operations demonstrated an acceptable level of maturity for proceeding towards implementation. Agent neutralization and relevant portions of reverse assembly are well developed. Fluid accessing was successfully demonstrated in Demonstration I, and GPCR and TW-SCWO have been successfully demonstrated in Demonstration II. Fluid systems (mining and dissolution/washing in the Continuously Indexing Neutralization System [COINS™]) and GPCR have commercial industrial history. However, extensive modifications to reverse assembly (projectile punch/drain/steam washing, propellant size reduction, and COINS™) are untested in the proposed configuration and represent a significant technical risk compared to existing systems. There are still technical risks associated with scale-up of batch processing of assembled chemical weapon feeds and generation of carbonaceous material in the GPCR. The TW-SCWO reactor demonstrated promising corrosion resistance and solids management, but the process as a whole is still an emerging technology.

Neutralization/GPCR/TW-SCWO is a complex process and has a large number of unit operations, but appears to have manageable operability characteristics, although some concerns remain. Most unit processes are expected to be inherently stable, robust, and tolerant of moderate changes in operating conditions. The TW-SCWO reactor experienced minimal corrosion and plugging problems during extended, continuous periods of operation during demonstration, but the solids management with feeds containing high aluminum-containing solids content and long-term liner integrity is untested. Modifications to reverse assembly and energetics accessing (COINS™) are complicated and unproven. There are also operability concerns for the coating of the GPCR system with carbonaceous residue during DPE processing.

Most operations can be effectively monitored and controlled using commercially available controls and instrumentation to prevent or minimize process upsets. Segregation steps required for rockets and projectiles will require complex monitoring and control strategies that have not yet been tested. Concerns exist relating to the GPCR system, including agent-monitoring methods for the product gas stream, control of energetic levels in the Thermal Reduction Batch Processor (TRBP) feed, and manual thermal control for TRBP. These issues are expected to be resolved through improvements to design and further development.

The proposed process is applicable to all assembled chemical weapons at all sites.

(2) Safety

The process poses minimal risk to workers during normal operations. Neutralization/GPCR/TW-SCWO incorporates commonly used and well-characterized process materials. Primary destruction operations are remote and operate at low temperature and ambient pressure. Feed or energy shut-off stops all processes, limiting the potential for cascading out of control. Intermediate streams after neutralization and GPCR undergo HT&R. However, there are still inherent risks associated with the process. TW-SCWO and GPCR operate at very high temperature; additionally, TW-SCWO operates at high pressure. The COINS™ solvent energetics detection and quantification system and GPCR generate highly flammable, potentially explosive atmospheres. There are also some areas of uncertainty in the handling and processing of energetics in the system. Agent monitoring of VX hydrolysate and of GPCR process gases needs development. Additional mitigation of these risks needs to be developed, but is expected to be feasible.

The process involves relatively large quantities of process chemicals and solid waste, but most are not highly volatile or flammable or do not present an acute inhalation hazard. However, GPCR uses hydrogen, a highly flammable and potential explosive hazard. The use of potentially large quantities of highly flammable, volatile solvents requires further detail. Nonetheless, even if an accident were to occur during operations, public impact will be minimized or eliminated since several layers of system and facility secondary containment should efficiently mitigate and contain the effects and prevent public exposure. The process also accumulates minimal quantities of agent and energetics. There are no unusual transportation accident response requirements, and risk to the public is minimal.

A formal Hazards Analysis will be performed and included as part of the Engineering Design Package.

(3) Human Health and Environment

Most waste streams, with the exception of GPCR gas effluents from the processing of agents, have been well characterized and the proposed disposal methods minimize impact on human health and the environment. All primary destruction processes and their associated intermediate waste streams undergo HT&R. GPCR product gas is scrubbed with caustic, undergoes HT&R, and is burned in an energy recovery device with the combustion products passed through a catalytic converter. There are no external liquid effluents. The solid products from the total solution include salts from TW-SCWO and solid residue from GPCR. The overall impact on human health and the environment could not be fully ascertained due to the lack of validation for the method for detection of agent in GPCR gas effluents, however the overall impact of effluents is expected to be minimal.

The effluent management strategy for Neutralization/GPCR/TW-SCWO appears sound. All major operations have a history of successful permitting. The evaporator/crystallizer may not process brine salts as proposed, affecting the TW-SCWO effluent management strategy. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. There is a well-developed strategy to ensure compliance with all environmental laws and regulations, including permit conditions. The Army has obtained permits for piloting neutralization/SCWO at Newport, Indiana. GPCR has a history of successful TSCA permitting, although the GPCR agent monitoring issue needs resolution before the effluent management and permitting strategies can be finalized.

(4) Potential for Implementation

The final 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 (Public Law 105-261). Integrated process teams have been established within the Department of Defense as part of the Defense Acquisition

Executive Review of the Chemical Demilitarization Program. Among the tasks of these IPTs is to evaluate whether or not the alternative technologies described within this report meet certification requirements set forth by Public Law 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*
- *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Therefore, in order to evaluate the cost and schedule portions of the potential for implementation criteria, a preliminary comparison was made between this alternative technology and baseline incineration with respect to total capital cost and schedule.

Life-Cycle Cost—Neutralization/GPCR/TW-SCWO estimated total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M costs for the process are comparable to those of baseline.

Schedule—The schedule estimates developed for demilitarization of assembled chemical weapons utilizing Neutralization/GPCR/TW-SCWO indicates completion of Blue Grass, Kentucky, operations in November 2010.

Public Acceptance—Based on input from the ACWA Dialogue, Neutralization/GPCR/TW-SCWO is likely to obtain public acceptance.

The details of the technical evaluation can be found in Appendix C.

3. Teledyne-Commodore

a. Demonstration Testing

The demonstration test program for Teledyne-Commodore's Solvated Electron Technology (SET™) was to test all seven primary components of their total solution. The demonstrations were to be conducted at DPG in Dugway, Utah, and at Deseret Chemical Depot (DCD) at the Chemical Agent Munitions Disposal System (CAMDS) in Tooele, Utah. The agent systems were to be tested at CAMDS and the energetics and dunnage systems were to be tested at DPG. The components to be tested are listed below.

- Ammonia Fluid Jet Cutting and Washout System (AFJC&W)
- SET™/Energetics System
- SET™/Energetics Chemical Oxidation System
- SET™/Agent System
- SET™/Agent Chemical Oxidation System
- Metal Parts and Dunnage Shredding System
- SET™/Dunnage System for Metal Parts and Dunnage

As discussed in the following paragraphs, the following components were not (completely or partially) tested as planned.

- Ammonia Fluid Jet Cutting and Washout System (AFJC&W)
- SET™/Energetics System
- SET™/Energetics Chemical Oxidation System
- SET™/Agent System
- SET™/Agent Chemical Oxidation System

The primary treatment process is a solvated electron reaction (dissolved sodium in anhydrous liquid ammonia) to destroy agent and energetics. A more detailed discussion of this technology can be found in Appendix C.

Provided below is a summary of the demonstration program. It is divided into the three areas of testing: (1) AFJC&W and SET™/Energetics with oxidation (conducted at DPG); (2) SET™/Dunnage spiked with agent simulant (conducted at DPG); and (3) SET™/Agent with oxidation (conducted at CAMDS).

AFJC&W and SET™/Energetics with Oxidation

The SET™ energetics destruction system was installed inside of the Suppressive Shield Facility at DPG. The following feeds were planned to be processed:

- M60 (inert) rockets (cutting only) – 2 workup and 15 validation runs;
- M61 (energetic only) rockets (cutting and processing) – 4 workup and 3 validation runs;
- Comp B processing in SET™ (from M61s) – 4 workup and 3 validation runs;
- M28 processing in SET™ (from M61s) – 4 workup and 3 validation runs; and
- Bulk tetrytol processing in SET™/Oxidation – 2 workup and 3 validation runs.

The test objectives for the AFJC&W included:

- Demonstrate the ability of the Fluid Jet Cutting/Washout to prepare a suitable feed to the SET™/Oxidation Reactors.
- Demonstrate the ability of Fluid Jet Cutting/Washout to separate the burster and propellant from the rockets.
- Demonstrate the accuracy and precision with which the fluid jet cutting system can position and cut the rockets using manual placement of the rockets.
- Determine the impact of fluid jet cutting and fluid washout operations on chamber components (e.g., integrity of the chamber seals).

The test objectives for the SET™/Energetics and Oxidation included:

- Validate the ability of the SET™/Oxidation Reactors to achieve a DRE of 99.999% for the following:
- Comp B (RDX and TNT)
    - Tetrytol (tetryl and TNT)
    - M28 propellant (NC and NG)
- Demonstrate the operation and performance of the key process components to support future scale-up.
- Demonstrate the ability to produce a gas effluent that meets either the EPA Syngas or BIF requirements.
- Demonstrate the effectiveness of the solidification and stabilization process for treatment of the solids from the SET™/Oxidation Reactor (M28 propellant runs only).
- Characterize gas, liquid, and solid process streams from the SET™/Oxidation Reactors for selected chemical constituents and physical parameters, and the presence/absence of hazardous and toxic compounds.

No major problems occurred during the installation and systemization phase. However, several activities required more time than expected causing program delays. It took approximately two months longer than planned to install the equipment at DPG. Systemization was therefore delayed and also took longer than planned. Due to the delays, the only validation test runs conducted were the cutting of the M60 (inert) rockets from September 8-13, 2000. On September 18-19, 2000, two M61 workup runs were conducted. On September 19, 2000, an energetic ignition of the M61 rocket was observed. Although there were no health or safety-related issues, the impact this event had on schedule prevented any further testing.

SET™/Dunnage

The SET™/Dunnage System was installed inside of the Suppressive Shield Facility at DPG. There were two steps involved with processing and decontaminating dunnage materials and metal parts: 1) Shredding and size-reducing; and 2) SET™ treatment in the SET™/Dunnage Reactor.

Five dunnage feed types were used for the ACWA Program; they are listed below. All materials were spiked with agent simulants in the DPG Laboratory prior to testing. No agent was used for this demonstration.

- DPE suits (shredded);
- Wood pallets (shredded);
- Fiberglass from rocket firing tubes of inert rockets such as M60s, without polychlorinated biphenyl (PCB) contamination (shredded);
- Carbon (supplied granulated – not shredded); and
- Metal parts from inert 4.2-inch mortars (shredded).

The test objectives for the SET™/Dunnage unit operations included:

- Validate the ability of the shredder to adequately prepare the dunnage and metal parts for downstream processing in the SET™/Dunnage Reactor.
- Demonstrate the ability to handle and feed the shredded dunnage and metal parts into the SET™/Dunnage Reactor.
- Validate the ability of the SET™/Dunnage Reactor to meet a 3X condition[i] or equivalent for agent simulants for metal parts and dunnage.
- Demonstrate the operation and performance of the key process components to support future scale-up.
- Relate the characterization of SET™/Dunnage Reactor offgas to produce a total facility gas effluent that meets either the EPA Syngas or BIF requirements.
- Characterize gas, liquid, and solid process streams from the SET™ process for selected chemical constituents and physical parameters, and the presence or absence of hazardous and toxic compounds including residual agent simulants.

The feed preparation step was conducted from May 3-4, 2000 at a commercial facility. There were no installation or systemization requirements because all equipment was existing at the facility. There were no major problems with any of the shredding activities and all feed types were successfully size-reduced for subsequent processing in the SET™/Dunnage system.

Due to the delays in the installation and systemization of the SET™/Energetics system, it was determined that Teledyne-Commodore would be allowed to test the SET™/Dunnage system first. There were no major problems observed during the installation, systemization, or testing activities. The validation tests began on August 15, 2000 and ended on August 28, 2000. The

[i] 3X decontamination indicates an item has been surface decontaminated, bagged, or contained and that appropriate tests have verified that vapor concentrations do not exist above 0.0001 mg/m^3 for GB,
and 0.00001 mg/m^3 for VX.

system processed all five dunnage feeds as planned and all necessary validation data were collected.

SET™/Agent

The SET™/Agent system was installed inside the Chemical Test Facility at CAMDS. The original Teledyne-Commodore schedule allowed for approximately three months of testing. The following three dunnage feeds were planned to be processed:

- GB – 2 workup and 3 validation runs;
- VX – 2 workup and 3 validation runs; and
- HD – 2 workup and 3 validation runs.

The program objectives for the SET™/Agent system are provided below:

- Validate the ability of the SET™/Oxidation Reactors to achieve a DRE of 99.9999% for VX, GB, and HD.
- Demonstrate the operation and performance of the key process components to support future scale-up.
- Demonstrate the effectiveness and accuracy of the ambient monitoring equipment for agent in the presence of ammonia.
- Validate the ability of the oxidation reactor to eliminate Schedule 2 compounds present in the feed to the Oxidation Reactor.
- Demonstrate the ability to produce a gas effluent that meets either the EPA Syngas or BIF requirements.
- Characterize gas, liquid, and solid process streams from the SET™/Oxidation Reactors for selected chemical constituents and physical parameters, and the presence/absence of hazardous and toxic compounds including residual agent and Schedule 2 compounds.

There were significant delays in the installation and systemization phases. The primary cause of these delays was that Teledyne-Commodore underestimated the time required to conduct all the necessary installation and systemization activities.

In addition to installation and systemization delays, on July 6, 2000, several workers were exposed to a small sulfuric acid spill that occurred during systemization activities. This incident required an investigation by both Teledyne-Commodore and test facility personnel. Some minor corrective actions were identified and incorporated to reduce the risk of similar events from happening in the future. The process of determining and implementing the necessary corrective measures delayed the program further. In addition, substantial cost growths occurred. On August 24, 2000, it was determined that agent testing could not be conducted within the PMACWA demonstration test window, and as a result, PMACWA terminated all Teledyne-Commodore operations at CAMDS. Consequently, there were no agent tests conducted for Teledyne-Commodore. The schedule delays resulted in a test end date that went far beyond the timelines that were established for the Demonstration II test program. The AMC Acquisition

Center (Procurement) sent a letter to Teledyne-Commodore on August 24, 2000 to cease work under their contract with ACWA. This decision was discussed with the CATT. Teledyne-Commodore was authorized to complete testing at DPG with the SET™ Energetics/Dunnage and Fluid Jet Cutting/Washout at their own expense as long as testing was completed by September 27, 2000, and a final report was delivered. PMACWA was willing to fund the test facility and analytical support.

During the Fluid Jet Cutting/Washout testing of an M61 rocket on September 19, 2000, a fire occurred inside a pressure vessel located inside a chamber that was specifically designed to safely handle events of this nature. The DPG emergency response team was notified immediately and responded. All operations were conducted remotely in accordance with standard safety procedures. No personnel were injured and no damage to the test facility was reported. The cause of the fire was the ignition of energetic components in the rocket. Teledyne-Commodore reported that there was an incompatibility between the ammonia vapors and the M28 propellant that led to the ignition of the propellant.

Subsequent to this incident, it was decided that no further testing of the Teledyne-Commodore Fluid Jet Cutting/Washout or SET™/Energetics unit operations would be conducted.

A summary of the planned and actual demonstration tests can be found in Appendix B.

b. Technology Evaluation

The Teledyne-Commodore Solvated Electron System (SES) to demilitarize chemical weapons was not validated for agent or energetics destruction during the ACWA Demonstration Test Program. Therefore, this process cannot be considered a viable total solution at this time. The basis for this conclusion is summarized below.

(1) Process Efficacy/Process Performance

The SES uses fluid-abrasive cutting and fluid mining to access agent and energetics, which are then destroyed by SET™ using sodium metal and ammonia; the SET™ reaction products are subsequently oxidized with a chemical reagent. Metal parts and dunnage are 3X decontaminated with SET™ reagent. Although prior small-scale laboratory testing by the technology provider indicates the likely effectiveness with agent and energetics, agents and energetics destruction has not been independently verified and validated in ACWA demonstration testing. Demonstration of both the Agent SET™/Oxidation and Energetics SET™/Oxidation systems was terminated by PMACWA before any validation testing was conducted. Due to the failure to complete required demonstration tests, products from processing agent and energetics were not validated. There is information available indicating that SET™ effectively decontaminates metal parts to 3X, but demonstration data for 3X decontamination of metal parts and dunnage were inconclusive. Sampling and analysis methodologies were validated, but their performance was not verified for agent and energetics processing.

SES has an unacceptable level of maturity for proceeding towards implementation. Demonstration was required to provide information on the transport and segregation of materials, the control of the overall extraction and treatment systems, and the ability to demonstrate scale-up and to accumulate experience with working with agents and energetics at larger-than-laboratory quantities. Three of the four proposed major unit operations were not demonstrated, and information required on the performance of this technology was not available. Although fluid accessing systems have historical commercial industrial basis, the PET considers the level of maturity of SES inadequate for timely implementation. Although previous testing conducted by the technology provider generally supports the stability of SET™ reactions, the SES process for assembled chemical weapons is complex with undemonstrated operability characteristics. There are numerous concerns about the reliability and stability of using Isopar-L (a hydrocarbon solvent) for fluid accessing and its effect on downstream SET™ and oxidation processes.

Proposed monitoring and control technologies are commercially available. Most of the critical process units are operated in batch mode and there are many HT&R points. However, no process monitoring or control data were obtained during demonstration for the Energetics SET™/Oxidation and Agent SET™/Oxidation operations. Minimal process monitoring and control data were obtained during demonstration for Dunnage SET™ operations. Thus, there are insufficient data to prove that SES can be monitored and controlled.

Based on previous testing conducted by the technology provider, SES could be applicable to all agents and energetics. However, SES was not validated by demonstration for treatment of agents and energetics. Treatment of metal parts and dunnage contaminated with agent simulant was demonstrated, but removal of the simulant was inconclusive. The use of Isopar-L for fluid accessing at sites with rockets remains undemonstrated, which represents a significant uncertainty in the applicability of SES.

(2) Safety

There appears to be a sound risk mitigation strategy. SES utilizes process materials that are commonly used in industry and which can be handled in accordance with established industrial safety standards. The remote primary destruction operations protect workers from chemical and physical hazards. SET™ destruction of agent and energetics is essentially immediate at ambient temperature and low pressure. There are HT&R points throughout the process. However, concerns remain relative to energetics, reducing confidence in the inherent safety of SES. The technology provider states that ammonia, a major process chemical, is incompatible with M28 propellant. The effectiveness of the proposed mitigation strategy (use of Isopar-L rather than ammonia) has not been demonstrated. Because insufficient data supporting the assumption that the use of Isopar-L would prevent propellant ignition were provided, there is still an undefined element of risk associated with the process. Energetics residue is potentially present during maintenance. There are several hazardous materials used in large quantities and the process generates hazardous intermediates (including cyanide salts and flammable gases). Use of sodium presents unique risks because of its reactivity with water.

This technology minimizes the risk of a serious accident affecting the public because exposure to agent is reduced by the immediate destruction of agent and energetics and containment is provided at the equipment and facility level. However, accidents involving ammonia storage could require establishing large protective action zones, a significant public impact even though the safety risk is minimal. Overall, the technology poses minimal risk to the public.

(3) Human Health and Environment

Critical issues associated with impact on human health and environment, effluent characterization, the effluent management strategy, and the environmental compliance and permitting approach could not be assessed. Demonstration of both the Agent SET™/Oxidation and Energetics SET™/Oxidation systems was terminated by PMACWA before any validation testing was conducted. Because these two test programs were not conducted, the data that are available on the effluent characterization are based on limited testing by the technology provider conducted prior to the ACWA demonstration. The effluents from the Metal and Dunnage SET™ Reactor were characterized; however, the demonstration system is not entirely representative of the proposed full-scale system and modifications to the unit may change the characterization of the effluents.

SES utilizes HT&R for gaseous streams at several stages of treatment. Synthesis gas produced is proposed for use as supplemental fuel for heating, reducing the need for boiler fuel. There are no external liquid effluents proposed in the technology provider's final report. The process will generate a large volume of RCRA waste that will require off-site disposal, some of which may require stabilization, which has not yet been demonstrated. A general effluent management plan with stated goals and commercial applications was provided. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Similarly, a qualitative assessment of the permitting strategy indicates that no unusual issues are anticipated. However, treatment and disposal options for all wastes could not be verified.

(4) Potential for Implementation

By agreement with the ACWA Dialogue, life-cycle cost, schedule, and public acceptance were not evaluated because the SES demonstration was severely curtailed. These criteria were included in the Implementation Evaluation Criteria in anticipation of the availability of demonstration data. However, there was insufficient information generated at demonstration to allow a detailed assessment of the life-cycle cost and schedule for this process. The lack of demonstration data related to the technical criteria precludes judging public acceptance of this technology.

The details of the technical evaluation can be found in Appendix C.

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 AEA Technology/CH2MHill, Foster Wheeler/Eco Logic/Kvaerner, and Teledyne-Commodore. They 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 C.5.1.1 of the Technical Evaluation Report (Appendix C), the AEA Technology/ CH2MHill SILVER II™ is considered a viable total solution for the demilitarization of all assembled chemical weapons.

- Based on the technical findings summarized in Section II.C.2 of this report and in Section C.5.1.2 of the Technical Evaluation Report (Appendix C), the Foster Wheeler/Eco Logic/Kvaerner process of neutralization followed by TW-SCWO and GPCR 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 C.5.1.3 of the Technical Evaluation Report (Appendix C), the Teledyne-Commodore SET™ process cannot be considered a viable total solution for the demilitarization of assembled chemical weapons at this time.

IV. NEXT STEPS

Engineering Design Studies (EDS) are planned for 2001 on the alternative technologies that were validated under the ACWA Demonstration II Test Program. These technologies include AEA Technology/CH2MHill (SILVER II™) and Foster Wheeler/Eco Logic/Kvaerner (Neutralization followed by TW-SCWO and GPCR). The objectives of EDS II will be the same as EDS I and are identified below. EDS I refers to the Engineering Design Studies for General Atomics and Parsons/Honeywell.

- Support the certification decision of the Under Secretary of Defense for Acquisition, Technology, and Logistics as directed in Public Law 105-261 for a full-scale facility with respect to:
  - Total life-cycle cost,
  - Schedule, and
  - Safety; and
- Support the contract Request for Proposals for a full-scale pilot facility.

In accordance with Public Law 105-261, the alternative technologies must be validated under the ACWA Program and must be certified in cost, schedule, and safety by the Under Secretary of Defense for Acquisition, Technology and Logistics. The Notice of Intent (NOI) for Pueblo, Colorado, was published in April 2000; therefore, the ROD is expected in late 2001. Because Public Law 106-398, section 151, precludes consideration of technologies demonstrated after May 1, 2000, and Demonstration II occurred from July to October 2000, these technologies cannot be considered in the NEPA process for the Pueblo Chemical Depot.

The NOI for Blue Grass, Kentucky, was published in early December 2000. The ROD for Blue Grass is expected in April/May 2002. It is expected that the certification process will take approximately four to six months after delivery of the Final Engineering Design Package. In order to meet the April/May 2002 ROD date and requirements for certification, the Final Engineering Design Package must be submitted no later than December 2001. The Final Engineering Design Package includes engineering drawings and documents, life-cycle cost estimates, life-cycle schedules, and a preliminary hazards analysis.

PMACWA has initiated planning for the EDS II testing and engineering design packages based on the projected ROD date for Blue Grass. AEA Technology/CH2MHill, Foster Wheeler and Eco Logic submitted proposals in November 2000 on what they felt should be tested during the EDS II phase. Based on the technical evaluation and these proposals, PMACWA decided what parts of the proposal should be tested under EDS II. Pre-contract costs were authorized in December 2000 to allow the technology providers to procure long lead equipment and begin any long lead engineering. It is anticipated that the task order contract for EDS II testing will be awarded in March 2001. The technology providers submitted draft study plans for the EDS II tests in February 2001. In most cases, the test equipment from Demonstration II will be used in EDS II with some modification and optimization. Some of the EDS II tests are anticipated to begin in March 2001. All EDS II tests will be completed by November 2001.

In addition, PMACWA received Technical/Cost Proposals for the preparation of an Engineering Design Package for Blue Grass in February 2001 from AEA Technology/CH2MHill, Foster Wheeler and Eco Logic. PMACWA is currently reviewing these proposals. It is anticipated that the task order contracts for the Blue Grass Engineering Design Package will be awarded in March 2001. The Final Engineering Design Package will be delivered in December 2001.

Appendix A

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Appendix B

Summary of Demonstration II Test Program

Demonstration II Test Program

Demonstration II Planning

The primary product of the demonstration planning process was a Demonstration Test Matrix for each technology provider. These matrices were carefully developed so that the technology demonstrations could meet requirements of Public Law 104-208 and the Conference Report accompanying Public Law 106-79 (House Report 106-371), 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,
- Quality Assurance/Quality Control (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. Several demonstration issues and considerations 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 that would have added considerably to the cost and difficulty of the demonstration.
- Pentachlorophenol (PCP). PCP was spiked onto all wood used for the demonstration tests for all dunnage treatment technologies to simulate wood preserved with PCP.
- Baseline Operations. It was determined that processes used in the baseline operations such as reverse assembly, brine reduction, condensers, gas scrubbers, and carbon filtration were not 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 standard operating procedure (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 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 to prevent the hydrolysate from being considered a hazardous waste by the U.S. Environmental Protection Agency.
- Treaty Compliance. All related testing conducted under the Assembled Chemical Weapons Assessment (ACWA) Demonstration Program was done in compliance with the Chemical Weapons Convention 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 Executive Council.

Test 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 the 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: Aberdeen Proving Ground, Maryland; Deseret Chemical Depot, Utah; and Dugway Proving Ground, 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 B-1. 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 standard operating procedures and test plans, as required by the installation. The test sites were also responsible for the collection and shipment of analytical samples (with the exception of gas samples, which were collected by ACWA contractors).

Table B-1. Summary of Test Facilities for ACWA Demonstrations

Test Site	Unit Operation (Technology Provider)	Test Facility
Aberdeen Proving Ground, MD—Aberdeen Test Center	SILVER II™ – 12 kW Energetics System (AEA Technology/CH2MHill)	Fire Safety Test Enclosure
Aberdeen Proving Ground, MD—Edgewood Chemical and Biological Center	SILVER II™ – 2 kW Agent System (AEA Technology/CH2MHill)	Toxic Test Chamber (Building E3566)
	Gas Phase Chemical Reduction (Eco Logic)	Toxic Test Chamber (Building E3726)
	Neutralization Reactor System for HD (generated by Program Manager)	Chemical Transfer Facility
Deseret Chemical Depot, UT—Chemical Agent Munitions Disposal System	Solvated Electron Technology/Chemical Oxidation - Agent (Teledyne-Commodore)	Chemical Test Facility
Dugway Proving Ground, UT—West Desert Test Center	Rocket Cutting and Washout System (Teledyne-Commodore)	Suppressive Shield Facility (Building 8321)
	Solvated Electron Technology/Chemical Oxidation - Energetics (Teledyne-Commodore)	Suppressive Shield Facility (Building 8321)
	Solvated Electron Technology - Dunnage (Teledyne-Commodore)	Suppressive Shield Facility (Building 832l)
	Transpiring Wall Supercritical Water Oxidation Unit (Foster Wheeler)	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

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 their 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 78 analytical method evaluation studies were conducted. Twenty of these studies, undertaken by government laboratories, involved the analysis of energetics, agents, and associated breakdown products in various matrix solutions prepared to represent the solutions expected from the demonstration tests. The U.S. Army Center for Health Promotion and Preventive Medicine conducted six evaluations; five for the analysis of energetic materials in different mixtures, and one for the analysis of chromium IV in one matrix. The analytical laboratories at Edgewood Chemical and Biological Center and Chemical Agent Munitions Disposal System conducted 14 method evaluation studies for the analysis of agents and Schedule 2 compounds. The remaining 58 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.

Summary of Demonstration II Testing

AEA Technology/CH2MHill

Unit Operation: **2-kW SILVER II™ System**
Test Location: Edgewood Chemical and Biological Center - Building E3566

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Simulants				
CEES (HD simulant)	44 lbs	1 (10 days)	Not Conducted[2]	Not Conducted[2]
DMMP (VX simulant)	31 lbs	1 (7 days)	31 lbs[3]	1 (5 days) [3]
Agent				
HD Agent	35 lbs	1 (7 days)	35 lbs	1 (7 days)
VX Agent	22 lbs	1 (7 days)	9 lbs[3]	1 (4 days) [3]
GB Agent	35 lbs	1 (7 days)	35 lbs	1 (7 days)

1. Workup (practice) runs were also planned for CEES and VX. However, the VX workup run was not conducted due to schedule constraints and chlorobenzene was substituted for CEES as the HD workup run.
2. CEES was not conducted due to projected schedule constraints.
3. The quantity of VX agent was reduced due to schedule constraints.

Unit Operation: **12 kW SILVER II™ System**
Test Location: Aberdeen Test Center - Fire Safety Test Enclosure

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Agent Simulants				
CEES (HD simulant)	220 lbs	1 (9 days)	Not Conducted[2]	Not Conducted[2]
DMMP (VX simulant)	220 lbs	1 (8 days)	88 lbs[3]	1 (7 days)
Energetics				
M28 Propellant	440 lbs	1 (8 days)	308 lbs[3]	1 (8 days)
Tetrytol	220 lbs	1 (8 days)	220 lbs	1 (18 days)
Comp B	220 lbs	1 (8 days)	Not Conducted[2]	Not Conducted[2]

1. Workup (practice) runs were also planned for CEES and M28 propellant; however, the CEES workup run was not conducted due to schedule constraints.
2. CEES and Comp B were not conducted due to schedule constraints.
3. The quantity of DMMP and M28 propellant was reduced due to schedule constraints.

Foster Wheeler/Eco Logic/Kvaerner

Unit Operation: Foster Wheeler Transpiring Wall Supercritical Water Oxidation
Test Location: Dugway Proving Ground - Building 4165

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Agent & Energetic Hydrolysates				
VX Simulant	6,000 lbs	1 (100 hrs)	6,000 lbs	1 (100 hrs)
HD/Tetrytol/Aluminum Hydrolysate	6,000 lbs	1 (100 hrs)	3,300 lbs	1 (55 hrs)[2]
GB/Comp B/Aluminum Hydrolysate	6,000 lbs	1 (100 hrs)	3,000 lbs	1 (50 hrs)[3]
VX/Comp B/M28/ Aluminum Hydrolysate	6,000 lbs	1 (100 hrs)	1,560 lbs	1 (26 hrs)

1. Workup (practice) runs were also conducted for all feeds.
2. HD/Tetrytol Hydrolysate Validation Run was terminated at 55 hours due to schedule limitations and reactor issues. HD hydrolysate was used for the first 19 hours followed by 36 hours with HD hydrolysate simulant. It was necessary to use simulant to maximize use of actual hydrolysate under environmental permit restrictions and obtain long-term runs.
3. GB/Comp B/Aluminum Hydrolysate Validation Run was shortened to 50 hours due to schedule limitations and reactor issues. GB hydrolysate was used for the first 28 hours followed by 22 hours with GB hydrolysate simulant. It was necessary to use simulant to maximize use of actual hydrolysate under environmental permit restrictions and obtain long-term runs.

Unit Operation: Eco Logic Gas Phase Chemical Reduction
Test Location: Edgewood Chemical and Biological Center - Building E3726

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Dunnage				
Carbon Trays	50 lb tray	3 (36 hrs ea.)	50 lb tray	3 (9 hrs ea.)
Wood spiked w/ PCP	22 lbs	3 (38 hrs ea.)	22 lbs	3 (24 hrs ea.)
DPE/Butyl Rubber/Bags	18 lbs	3 (46 hrs ea.)	18 lbs	3 (36 hrs ea.)
Fiberglass Firing Tubes	4 lbs	3 (28 hrs ea.)	4 lbs	3 (6 hrs ea.)
Agent				
GB Agent	11 lbs	3 (16 hrs ea.)	8-11 lbs[2]	3 (12 hrs ea.)
Mortar w/ simulated 30% HD Heel	16 lbs metal, 2 lbs HD	3 (25 hrs ea.)	16 lbs metal, 2 lbs HD	2 (9 hrs ea.)[3]

1. Workup (practice) runs were also conducted for all dunnage and GB agent. A workup run was planned for the mortar w/ simulated 30% heel, but it was not conducted due to schedule constraints. Validation runs were shorter than planned due to better than expected system performance.
2. For the GB Validation Runs, approximately 8 lbs were fed for Run #1, >9 lbs for Run #2, and 11 lbs for Run #3.
3. One Validation Run of a mortar with simulated 30% HD Heel was not performed due to schedule constraints.

Teledyne-Commodore

Unit Operation: **Ammonia Fluid Jet Cutting/Washout**
Test Location: Dugway Proving Ground – Suppressive Shield Facility

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Munitions				
M60 INERT Rocket (no energetics; no agent; ethylene glycol removed)	1 rocket	15 (1 hour – cutting only)	1 rocket	15
M61 Rocket (contained Comp B and M28; no agent; ethylene glycol was removed)	1 rocket	3 (4 hours – cutting and washout)	Not Conducted[2]	Not Conducted[2]

1. Workup (practice) runs were also conducted for M60 rockets (4) and M61 rockets (2)
2. Validation runs for the M61 rocket were not conducted due to the energetic ignition of the M28 propellant during Workup Run #2 and schedule constraints.

Unit Operation: **SET™/Oxidation - Energetics**
Test Location: Dugway Proving Ground – Suppressive Shield Facility

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Energetics				
Comp B from M61 rockets	3.14 lbs	3	Not Conducted[2]	Not Conducted[2]
M28 Propellant from M61 rockets	19.1 lbs	3	Not Conducted[2]	Not Conducted[2]
Bulk Tetrytol	15 lbs	3	Not Conducted[2]	Not Conducted[2]
Cement Stabilization of Oxidation Products of M28 Processing	2 gallons	3	Not Conducted[2]	Not Conducted[2]

1. One workup (practice) run was conducted for the Comp B and M28 Propellant.
2. Energetics were not conducted due to the energetic ignition of the M28 propellant during Workup Run #2 and schedule constraints.

Unit Operation: **SET™ – Dunnage/Metal Parts**
Test Location: Dugway Proving Ground – Suppressive Shield Facility

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Dunnage/Metal Parts – Feed Preparation				
DPE/Butyl/Bags	500 lbs	1 (as req'd)	518 lbs	1
Wood Pallets	30 lbs	1 (as req'd)	52 lbs	1
Fiberglass Firing Tubes	40 lbs	1 (as req'd)	54 lbs	1
M42A1 4.2-inch Mortars	350 lbs	1 (as req'd)	362 lbs[2]	1
Dunnage/Metal Parts – Process Operation				
Shredded DPE/Butyl/Bags spiked with Simulant	5 lbs	3 (8 hours)	5 lbs	3 (<8 hours)
Shredded Wood Pallets spiked with Simulant & Pentachlorophenol (PCP)	5 lbs	3 (8 hours)	5 lbs	3 (<8 hours)
Carbon spiked with Simulant	5 lbs	3 (8 hours)	5 lbs	3 (<8 hours)
Shredded Fiberglass Firing Tubes spiked with Simulant	5 lbs	3 (8 hours)	5 lbs	3 (<8 hours)
Shredded M42A1 4.2-inch Mortars spiked with Simulant	5 lbs	3 (8 hours)	5 lbs	3 (<8 hours)

1. No workup (practice) runs were planned nor conducted.
2. The quantity of mortars was reduced to 350 lbs since the weight of 40 mortars was lower than expected.

Unit Operation: **SET™/Oxidation - Agent**
Test Location: Chemical Agent Munition Disposal System – Chemical Test Facility

FEED	PLANNED		ACTUAL	
	Quantity per Validation Run	**# of Validation Runs (Duration)**	**Quantity per Validation Run**	**# of Validation Runs (Duration)[1]**
Agent				
GB Agent	10 liters (24 lbs)	3 (~5 hrs SET™, ~4 hrs Oxidation)	Not Conducted[2]	Not Conducted[2]
VX Agent	10 liters (22 lbs)	3 (~5 hrs SET™, ~4 hrs Oxidation)	Not Conducted[2]	Not Conducted[2]
HD Agent	5 liters (14 lbs)	3 (~5 hrs SET™, ~4 hrs Oxidation)	Not Conducted[2]	Not Conducted[2]

1. Two workup (practice) runs were planned for each agent but not conducted.
2. No agent testing was conducted due to cost overruns and schedule constraints.

Appendix C

Technical Evaluation Report

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Program Evaluation Team

Final Technical Evaluation:

AEA Technology/CH2MHill SILVER II Electrochemical Oxidation
Foster Wheeler/Eco Logic International/KvaernerNeutralization/GPCR/TW-SCWO
Teledyne-Commodore Solvated Electron System

Program Evaluation Team (PET) Chair: Joseph J. Novad — Joe Novad — 16 Feb 01 — Date

Technical Evaluation Committee (TEC) Chair: Jim Richmond — Jim Richmond — 16 Feb 01 — 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 munitions configured with fuzes, explosives, propellant, chemical agents, shipping and firing containers, and packaging materials.

The PMACWA established three teams (Technical Team, Environmental Team, and Business 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 for technology demonstration testing—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 three technology providers selected for the first round of demonstration testing in 1999 were Burns and Roe, General Atomics, and Parsons/Honeywell.[i] The recommendations made by the Program Evaluation Team (PET) to the PMACWA are shown in Table C.ES-1. Following Demonstration I, PMACWA began conducting Engineering Design Studies (EDS) with neutralization[ii] followed by supercritical water oxidation (SCWO) and neutralization followed by biotreatment. EDS were conducted concurrently with and separate from Demonstration II, and the results of the EDS will be reported in a separate document.

Table C.ES-1. Demonstration I Technologies and Recommendations

Technology	Provider	PMACWA Recommendation
Plasma Waste Converter (PWC)	Burns & Roe (B&R)	Not viable for any ACW
Neutralization/SCWO	General Atomics (GA)	Viable for all ACW
Neutralization/Biotreatment	Parsons/Honeywell (PH)	Viable for mustard ACW Not viable for nerve ACW

[i] Previously known as Parsons/AlliedSignal (PAS)
[ii] Neutralization is destruction of agent and energetics by hydrolysis.

Congress provided funding in fiscal year 2000 for a second round of ACWA demonstration tests. PL 106-79 directed the Army to conduct demonstration testing (Demonstration II) of the three technologies that were not selected for the initial demonstration testing. The technology providers selected to conduct Demonstration II tests are shown in Table C.ES-2.

Table C.ES-2. Demonstration II Technologies

Technology	Provider	Primary Destruction	Post Treatment
SILVER II™	AEA Technology/ CH2MHill	SILVER II oxidation of agent and energetics[i] and thermal decontamination of ACW metal parts, dunnage, and solids.	None required
Neutralization/ GPCR/ TW-SCWO	Foster Wheeler/ Eco Logic Int'l/ Kvaerner	Agent and energetics neutralization by hydrolysis and gas phase chemical reduction (GPCR) thermal decontamination of offgases, metal parts, and dunnage	Transpiring wall supercritical water oxidation (TW-SCWO) of hydrolysate
Solvated Electron System	Teledyne-Commodore	Solvated Electron Technology (SET™) using sodium metal and ammonia	Chemical oxidation

The PET developed the evaluation and recommendations described in this report. 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.

Findings

AEA Technology/CH2MHill SILVER II

SILVER II uses modified baseline reverse assembly to access agent and energetics. The agent and energetics are then mineralized by SILVER II oxidation to produce an effluent containing insignificant concentrations of organic compounds; SILVER II is an electrochemical oxidation process using silver nitrate in concentrated nitric acid. Metal parts, dunnage, and other solids are thermally treated with steam to meet the 5X decontamination level.[ii]

[i] Energetic materials include rocket propellant and high explosives used in bursters, boosters, supplementary charges, fuzes, etc.
[ii] 5X (XXXXX) indicates that an item has been decontaminated completely of agent and may be released for general use or sold to the public.

Demonstration validated agent and M28 propellant[i] destruction using SILVER II, and thermal treatment of metal parts and dunnage. However, validation of energetics destruction using SILVER II is incomplete, although previous data from laboratory experiments indicate the likely effectiveness with energetic compounds. Demonstration provided acceptable characterization of products from the process, with the exception of Composition B (Comp B).[ii] The process produces no significant quantities of Schedule 2 compounds, which are regulated under the Chemical Weapons Convention (CWC). Sampling and analysis methodologies for developing the mass balance and for measuring agent, energetics, and most other compounds of concern have been verified and validated.

SILVER II has demonstrated an acceptable level of maturity for proceeding towards implementation, although there are concerns with untested modifications made to SILVER II after demonstration testing. Effective operation of SILVER II was demonstrated for agent and propellant. Concerns remain about the operability of the continuous SILVER II units with impurity removal systems, and the management of solids while processing explosives; i.e., Tetrytol[iii] and Comp B. The inherent monitoring and control advantages of SILVER II are offset by the complexity of continuous operation with many interdependent unit operations. The SILVER II process is capable of demilitarizing all ACWs at all sites.

The process poses manageable risks for worker safety. The SILVER II agent and energetics destruction systems are energy-dependent and cannot cascade out of control. Remote operations minimize exposure to workers. The potential to encounter explosive materials represents the most significant, potentially hazardous situation for the worker during maintenance on SILVER II. This is due to the accumulation of possibly explosive materials within the system and the potential for explosive crystal formation from leaks or in isolated system segments. The proposed strategies to mitigate or eliminate these risks appear sound, but they have not been verified. Several layers of system and facility secondary containment are expected to effectively prevent public exposure in the event of an accident. Risk to the public is minimal.

Effluents have minimal impact on human health and the environment. Most waste streams were characterized, except those from processing Comp B. Effluent management strategy is well developed, however some disposal issues still require resolution. Limited resource requirement data are available; however, no unusual resource requirements are anticipated. Although SILVER II has no U.S. permits, no exceptional permitting issues are expected.

In the area of potential for implementation, the final 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). Integrated Process Teams have been established within the Department of Defense as part of the Defense Acquisition Executive (DAE) Review 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:

[i] The M55 rocket's M28 propellant grain: A double-base propellant composition of 60% nitrocellulose (NC), 23.8% nitroglycerin (NG), 9.9% triacetin, 2.6% dimethylphthalate, 2.0% lead stearate, 1.7% 2-nitrodiphenylamine (2-NDPA).

[ii] Comp B (Composition B) is a high explosive composition of 60% RDX, 39% TNT, 1% wax.

[iii] Tetrytol is a high explosive composition of 70% tetryl and 30% trinitrotoluene (TNT).

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*
>
> *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Therefore, in order to evaluate the cost and schedule portions of the Potential for Implementation criteria, a preliminary comparison between this alternative technology and baseline incineration with respect to total capital cost and schedule was made. SILVER II's estimated total capital cost may be approximately equal to that of baseline incineration. In addition, a qualitative assessment of operating and maintenance cost was conducted and was compared to those of baseline incineration. It is likely that the total operating and maintenance (O&M) cost for SILVER II will be slightly greater than those for baseline. The schedule estimates developed for the demilitarization of ACWs utilizing SILVER II indicate completion of operations for Blue Grass in February 2012.

In summary, the AEA Technologies/CH2MHill SILVER II process was validated during demonstration. In addition, the Dialogue agreed by full consensus that SILVER II is likely to be publicly acceptable. Therefore, this process is considered a viable total solution for demilitarization of all ACWs.

Foster Wheeler/Eco Logic/Kvaerner Neutralization/GPCR/TW-SCWO

Neutralization/Gas Phase Chemical Reduction (GPCR)/Transpiring Wall Supercritical Water Oxidation (TW-SCWO) uses modified baseline reverse assembly to access agent and energetics that are neutralized by sodium hydroxide (caustic) or neutral hydrolysis followed by TW-SCWO. Metal parts, dunnage, and other solids (included secondary wastes), and gases are thermally treated to meet the 5X decontamination level using the GPCR.

Neutralization has been validated for agent destruction and energetics deactivation. GPCR was validated for the treatment of metal parts and dunnage. Products from the process have been acceptably characterized, with the exception of GPCR process gases during agent operations. Although agent hydrolysis produces CWC Schedule 2 compounds, the TW-SCWO effectively destroyed all Schedule 2 compounds to acceptable levels. Sampling and analysis methodologies for neutralization and SCWO have been generally verified and validated. However, GPCR requires development of agent detection methods for process gas steams.

Neutralization, GPCR, and TW-SCWO unit operations have demonstrated an acceptable level of maturity for proceeding towards implementation. However, some accessing systems have not been used in the proposed configuration and TW-SCWO requires additional development.

Although complex, the process has manageable operability characteristics. Concerns remain about operability and monitoring and control for several unit operations. Effective control of most critical unit operations was demonstrated to prevent or minimize process upsets. Concerns remain for monitoring and control of TW-SCWO to maximize organic destruction, segregation steps required for rockets and projectiles, GPCR for agent monitoring and thermal control, and control of energetic levels in the Thermal Reduction Batch Processor feed. However, these concerns are considered manageable. Neutralization/GPCR/TW-SCWO is capable of demilitarizing all ACWs at all sites.

The process poses manageable risks for worker safety. Remote operations limit potential worker exposure. Feed or energy shut-off stops all processes, limiting the potential for cascading out of control. The most significant concerns relate to energetics accessing and propellant processing. Additional mitigation of these risks needs to be developed, but is expected to be feasible. Several layers of system and facility secondary containment are expected to effectively prevent public exposure in the event of an accident. Risk to the public is minimal.

Effluents have minimal impact on human health and the environment. Sufficient characterization of the effluent process streams was achieved with the exception of the effluent gas stream associated with processing agent in GPCR. Appropriate and proven methods for monitoring process effluents were demonstrated, with the exception of agent in GPCR product gas. The proposed waste management strategy appears sound. Limited resource requirement data are available; however, no unusual resource requirements are anticipated. There is a well-developed strategy to ensure compliance with all environmental laws and regulations, including permit conditions.

In the area of potential for implementation, the final 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). Integrated Process Teams have been established within the Department of Defense as part of the DAE Review 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*
>
> *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Therefore, in order to evaluate the cost and schedule portions of the Potential for Implementation criteria, a preliminary comparison between this alternative technology and baseline incineration with respect to total capital cost and schedule was made. Neutralization/GPCR/TW-SCWO's estimated total capital cost may be approximately equal to that of baseline incineration. In addition, a qualitative assessment of operating and maintenance cost was conducted and was compared to those of baseline incineration. It is likely that the total O&M cost for Neutralization/GPCR/TW-SCWO will be comparable to baseline. The schedule estimates developed for the demilitarization of ACWs utilizing Neutralization/GPCR/TW-SCWO indicate completion of operations for Blue Grass in November 2010.

In summary, the Foster Wheeler/Eco Logic International/Kvaerner Neutralization/GPCR/TW-SCWO was validated during demonstration. In addition, the Dialogue agreed by full consensus that Neutralization/GPCR/TW-SCWO is likely to be publicly acceptable. Therefore, this process is considered a viable total solution for demilitarization of all ACWs.

Teledyne-Commodore Solvated Electron System

The Solvated Electron System (SES) uses fluid-abrasive cutting and fluid mining to access agent and energetics, which are then destroyed by SET using sodium metal and ammonia; the SET reaction products are subsequently oxidized with a chemical reagent. Metal parts and dunnage are 3X decontaminated[i] with SET reagent. Due to the failure to complete required demonstration tests, the following were not validated:

- Agent and energetics destruction
- Products from processing agent and energetics

Demonstration data for 3X decontamination of metal parts and dunnage were inconclusive. Sampling and analysis methodologies were validated, but their performance was not verified for agent and energetics processing.

SES does not have an acceptable level of maturity for timely implementation. SES for ACWs has undemonstrated operability characteristics. The capability to effectively monitor and control SET and oxidation reactions has not been demonstrated. The process could potentially be feasible for demilitarizing all ACWs at all sites. However, the untested change of the fluid used for accessing munitions at sites with rockets represents a significant uncertainty in the applicability of SES.

There appears to be a sound risk mitigation strategy. However, concerns remain relative to energetics, which reduces confidence in the inherent safety of SES. The technology provider states that ammonia is incompatible with propellant and the proposed use of an alternative fluid for energetics accessing to eliminate this hazard has not been demonstrated or validated. Several layers of system and facility secondary containment are expected to effectively prevent public exposure in the event of an accident. The process poses minimal risk to the public. However, an

[i] 3X (XXX) indicates that the item has been surface decontaminated, then contained and the headspace air verified to contain agent concentrations below the airborne exposure limits for unmasked workers. Access to 3X material is generally restricted to government personnel and contractors.

accident involving large amounts of ammonia could have public impact, although the safety risk is minimal.

The impact of SES on human health and environment could not be assessed. No effluent characterization data are available from the demonstration of energetics and agent. Qualitative assessments of the waste management plan and the permitting strategy indicate that no unusual requirements are anticipated. However, treatment and disposal options for all wastes could not be verified due to the lack of demonstration data. Limited resource requirement data are available; however, no unusual resource requirements are anticipated.

By agreement with the Dialogue, the evaluations of the cost, schedule, and public acceptance factors for SES were not performed due to the incomplete demonstration of the technology.

In summary, the Teledyne-Commodore SES was not validated during demonstration. Therefore, this process is not considered a viable total solution for demilitarization of any ACW.

Recommendations

The following recommendations to the PMACWA are based on the technical findings detailed in this report.

The AEAT/CH2MHill SILVER II process is considered a viable total solution for 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 EDS focus on the following:

- Modifications to and longer-term testing of a large-scale (e.g., 12-kW) SILVER II system including ancillary systems such as the impurities removal and energetics feed systems
- Lab scale testing to address cell membrane performance, fluoride-containing feeds, hydrocyclones, high shear mixing, and organic transfer
- Review literature data and prepare reports to address projectile burster wash and energetics slurry concentration

The Foster Wheeler/Eco Logic/Kvaerner Neutralization/GPCR/TW-SCWO process is considered a viable total solution for 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 EDS focus on the following:

- Optimization of systems related to the GPCR unit operation, including method development for agent detection in the process gases
- Longer-term testing of agent and energetics hydrolysates or simulants with a new TW-SCWO reactor, including optimization of upstream and downstream solids handling (i.e., aluminum compounds), liner integrity, and organic destruction

- Testing of methods for M28 propellant size reduction

The Teledyne-Commodore SES process for demilitarization of ACWs is not considered a viable total solution at this time. Therefore, the PET recommends that PMACWA not consider this process for future pilot testing.

C.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 assembled chemical weapons. Assembled chemical weapons for this purpose represent the chemical weapons stockpile munitions configured with fuzes, explosives, propellant, chemical agents, shipping and firing (S&F) containers, and packaging materials.

The PMACWA established three teams (Technical Team, Environmental Team, and Business 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 for technology demonstration testing—Phase 1, Criteria Development; Phase 2, Technology Assessment; and Phase 3, Demonstration. In Phase 1, criteria were developed by PMACWA and DACWA 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 C-B. Phase 2, Technology Assessment, was divided into four steps and is discussed in Section C.2. The purpose of Phase 2 was to select technologies for Phase 3, Demonstration Testing. Final technical evaluations of the technologies were then conducted at the conclusion of Phase 3.

Since resource constraints originally prevented the testing of all six technologies that had passed the technical 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 the first round of demonstration testing in 1999 were Burns and Roe, General Atomics, and Parsons/Honeywell (now referred to as Parsons/Honeywell[i]).[1] The final technical evaluation pertaining to the three "Demonstration I" tests can be found in the 30 September 1999 *Supplemental Report to Congress*.[2] As a result of Demonstration I testing, PMACWA reached the following conclusions:

- 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

[i] Honeywell merged with AlliedSignal effective 2 December 1999.

process will be publicly acceptable. Therefore, this process was not considered a viable total solution for demilitarization of ACW.

- The General Atomics process of neutralization followed by supercritical water oxidation (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 Parsons/Honeywell process of neutralization of mustard followed by biotreatment 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 was not considered a viable total solution for the demilitarization of chemical weapons with nerve agent.

Following that determination, PMACWA decided to conduct Engineering Design Studies (EDS) with the General Atomics and Parsons/Honeywell technologies.[3] Those studies were designed to provide information for a preliminary full-scale design for the construction of a demilitarization facility with the associated cost, schedule, and preliminary hazard analysis. EDS were conducted concurrently with and separate from Demonstration II; the evaluation of the EDS will be reported in a separate document. Following Demonstration II, PMACWA may elect to conduct additional EDS activities for those technologies considered viable total solutions.

Congress provided funding in fiscal year 2000 for a second round of ACWA demonstration tests. PL 106-79 directed the Army to conduct demonstration testing (Demonstration II) of the three technologies that were not selected for the initial demonstration testing. The technology providers selected to conduct Demonstration II tests were:

- AEA Technology Engineering Services Inc.
  241 Curry Hollow Road
  Pittsburgh, PA 15236-4696
  Point of Contact: Mr. Robert Boylston
  (412) 655-1200

- Foster Wheeler Development Corp., and
  John Blizard Research Center
  12 Peach Tree Hill Road
  Livingston, NJ 07039
  Point of Contact: Mr. K. S. Ahluwalia
  (973) 535-2346

  ELI Eco Logic International, Inc.
  835 Cumberstone Road
  Harwood, MD 20776
  Point of Contact: Mr. Fred T. Arnold
  (301) 261-5381

- Teledyne-Commodore
  Cummings Research Park
  300 Sparkman Drive
  P.O. Box 070007
  Huntsville, AL 35807-7007
  Point of Contact: Mr. Peter McGrath
  (256) 726-2600

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

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

Offeror	Munitions Access	Agent Treatment	Energetics Treatment	Metal Parts Treatment	Dunnage Treatment
AEA Technology CH2MHill	Modified reverse assembly with spray washout	SILVER II electrochemical oxidation	SILVER II electrochemical oxidation	Metal Parts Treater using 1200°F superheated steam	Batch Rotary Treater using 1200°F superheated steam
Foster Wheeler Eco Logic International Kvaerner	Modified parts of reverse assembly	Caustic hydrolysis followed by supercritical water oxidation (SCWO) and gas phase chemical reduction (GPCR)	Caustic hydrolysis followed by SCWO and GPCR	Caustic hydrolysis followed by treatment in a thermal reactor and GPCR	Caustic hydrolysis followed by treatment in a thermal reactor and GPCR
Teledyne-Commodore	Fluid – abrasive cutting, washing, and mining	Solvated electron treatment (SET) followed by oxidation	Solvated electron treatment (SET) followed by oxidation and stabilization	Classifying and shredding followed by SET	Shredding followed by SET

The Program Evaluation Team (PET) developed the evaluation and recommendations described in Sections 4 and 5 of this report. The PET consists of members of the Technical Evaluation Team (TET), the Demonstration Working Group (DWG),[i] 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 C-A. The evaluation was conducted in close association with the Citizens Advisory Technical Team (CATT), appointed by the DACWA 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.

[i] The DWG worked with test installation representatives, technology providers, support contractors, and members of the CATT in planning and coordinating demonstration activities.

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 C.2, ACWA Technical Assessment.

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

C.2 Final Technical Evaluation Methodology

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. Section C.2.1 explains the technical assessment process previously used to evaluate these technologies. Section C.2.2 describes briefly the information sources and the overall process used in the final technical evaluation.

C.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 C.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.[4]

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 C-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.

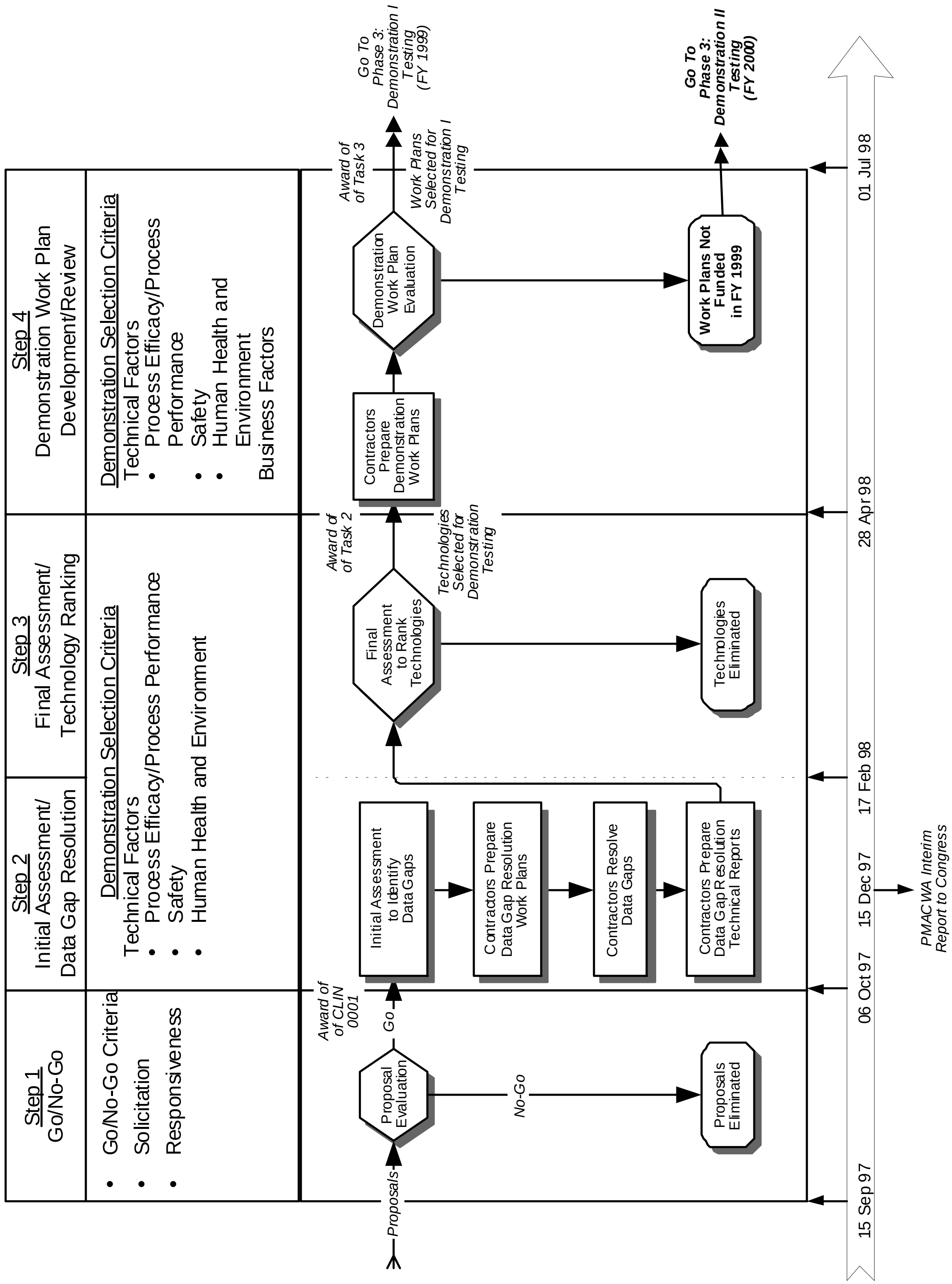

Figure C.2-1. The Four Steps of the ACWA Phase 2 Technology Assessment

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,[i] Parsons/Honeywell, and Teledyne-Commodore.[5] 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; 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 I testing. The three remaining technology providers were later awarded tasks in February 2000 to perform a second round of demonstration testing. Descriptions of the three Demonstration II technologies are provided in Section C.4.

C.2.2 Information Sources and Final Evaluation Process

C.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 C.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.

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.

[i] Foster Wheeler, Eco Logic International, and Kvaerner were originally part of a larger team under the coordination of Lockheed Martin and were retained after the formal Lockheed Martin teaming agreement dissolved; see Section C.4.2.

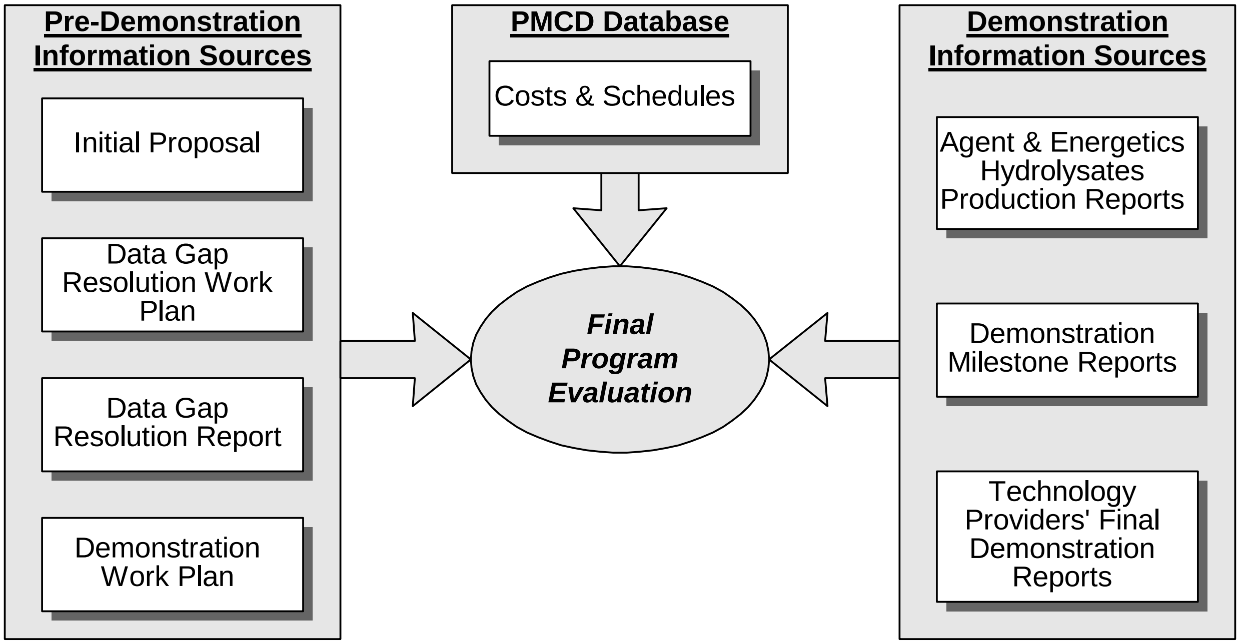

Figure C.2-2. Sources of Information for the ACWA Evaluation Process

C.2.2.2 Final Evaluation Process

For the Final Evaluation, the PMACWA continued the process that was used successfully during Phase 2 and at the conclusion of Demonstration I (see Figure C.2-3). The PET (see Attachment C-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 C-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 DACWA provided input for factor 19 regarding Public Acceptability on a site-specific basis during the Dialogue meeting in Lexington, Kentucky on 25-26 January 2001.

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.

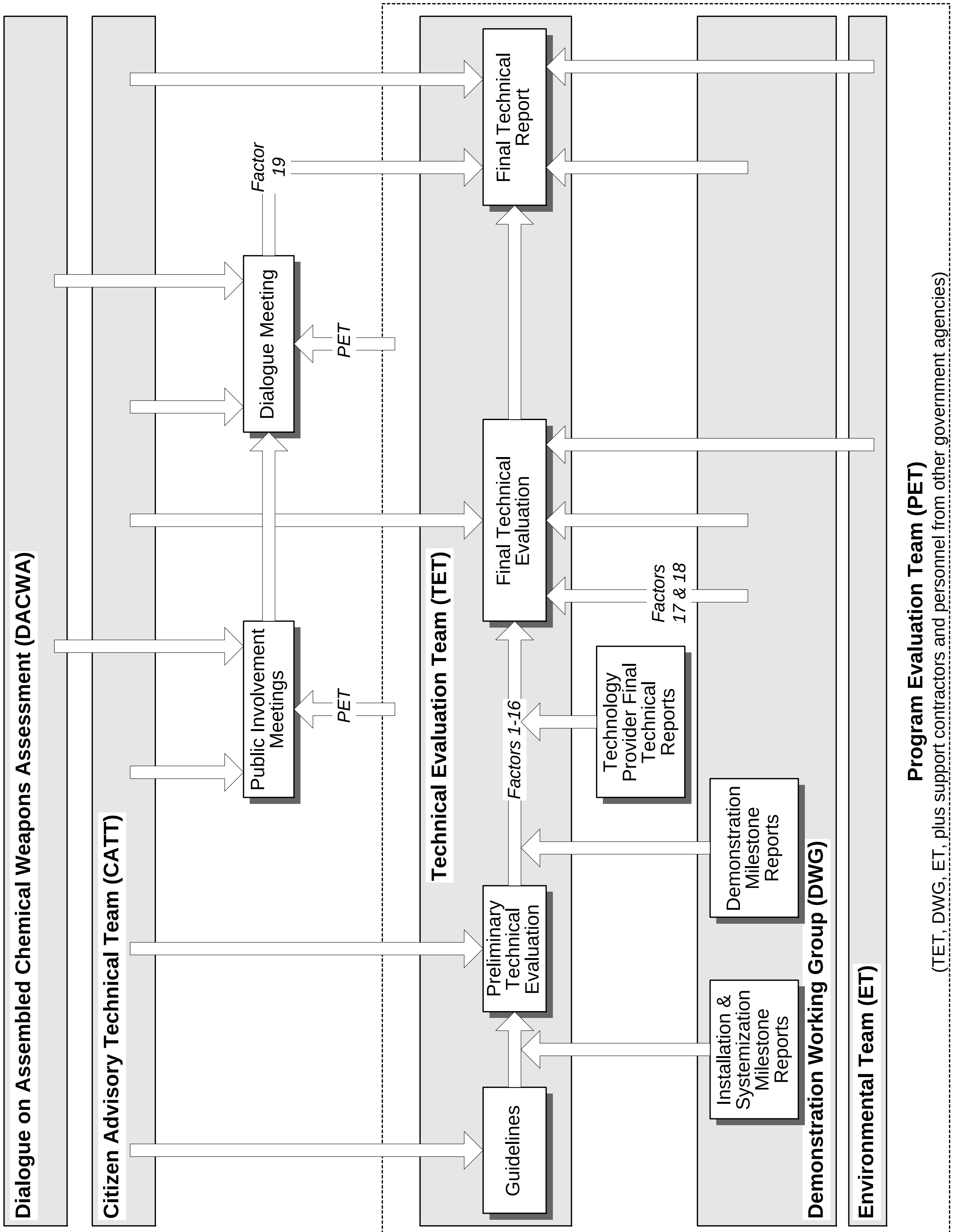

Figure C.2-3. Final Evaluation Process for ACWA Technologies

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C.3 Demonstration II Preparations and Testing

The Demonstration II testing phase of the ACWA program began with the authorization of pre-contract costs on long lead activities and equipment to teams led by AEA Technology and CH2MHill; Foster Wheeler, Eco Logic International, and Kvaerner; and Teledyne-Commodore in October 1999 for demonstration planning activities. Because of the constrained program schedule, the planning was begun prior to the award on February 25, 2000 of the Demonstration II task, task order 3. During the planning phase, Demonstration Work Plans from May 1998 were revised to reflect current conditions. Equipment installation began in the spring of 2000 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 U.S. Army Soldier Biological and Chemical Command (SBCCOM) and the Aberdeen Test Center, both at Aberdeen Proving Ground (APG), MD. Demonstration testing started in early July 2000 and was completed on October 3, 2000.

C.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
- Verification of the maturity and operability of the tested unit processes

C.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

C.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 it had to 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 could not 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. One of the three technologies chosen for demonstration as well as the EDS 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 the technology providers conducted operations separately.

- **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 (TSCA) 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 (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.

C.3.4 Demonstration II Testing

Equipment installation and systemization began at each of the test sites in the spring of 2000. The actual demonstration tests were conducted from early July 2000 to October 3, 2000. Figure C.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, five of the seven unit operations were tested substantially as planned. The two unit operations that were not tested were associated with the same technology. In addition, most of the planned analytical samples were taken for the five unit operations tested. In all, the demonstration test resulted in:

- The collection of approximately 1,100 samples for chemical characterization,
- Approximately 8,000 sample analyses, and about 125,000 analytical data results.
- Analytical samples were sent to one of fifteen 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.

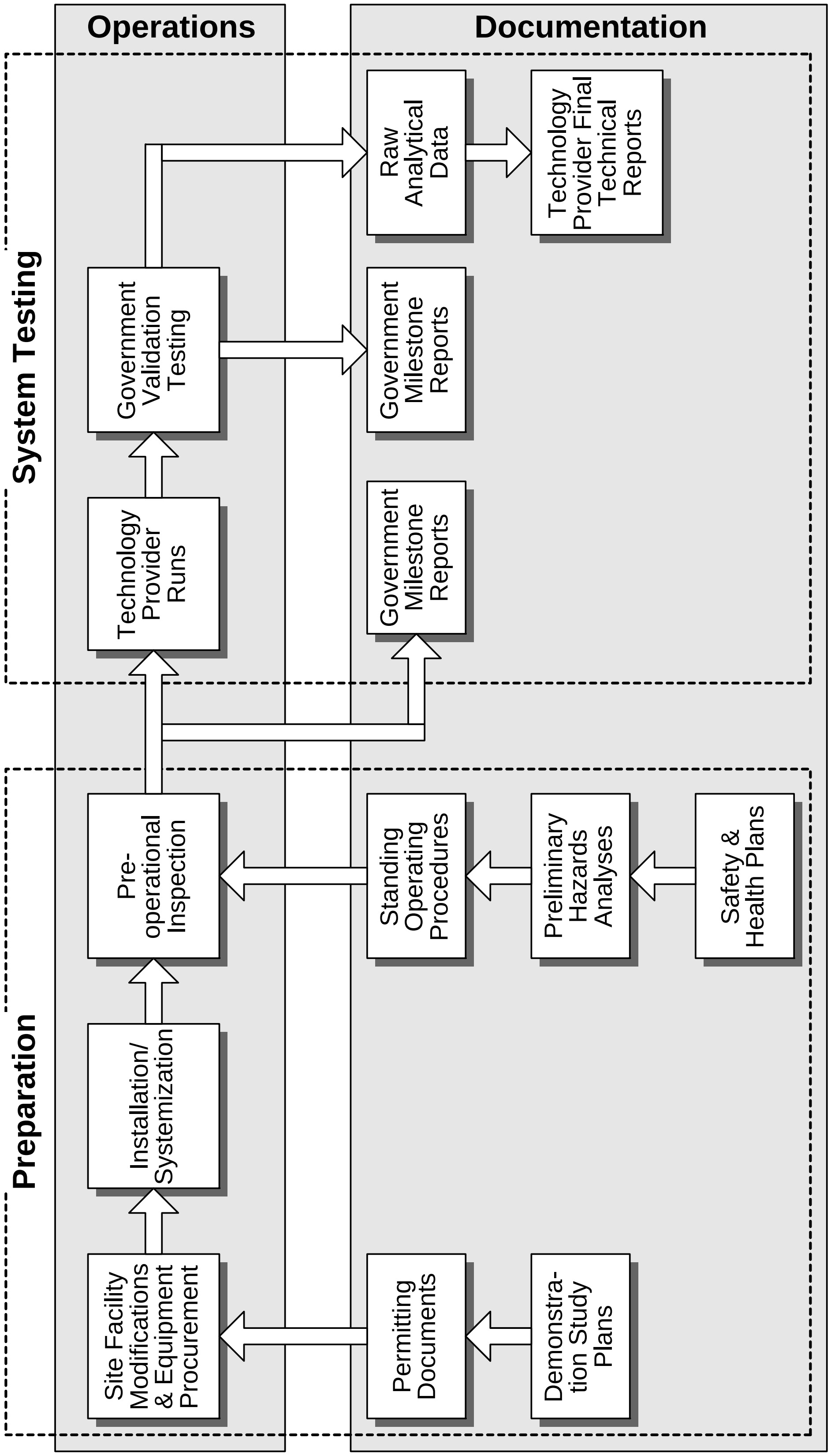

Figure C.3-1. Demonstration Testing Activities and Documentation Included in Evaluation

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C.4 Technical Evaluations

The final evaluation process used for the three technologies of Demonstration II is the same as the process used for the three technologies of Demonstration I, and based on the process used successfully for Phase 2 of the ACWA Program. The principal differences between the Demonstration I and II evaluations on the one hand and the previous Demonstration Selection evaluations on the other are:

- The use of the Program Implementation Criteria (see Attachment C-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. Effectiveness was evaluated based on destruction efficiency or ability to meet performance conditions, as appropriate.[i] Some extrapolation was required for the evaluation of the Process Maturity and Process Operability criteria. The Sampling and Analysis evaluation (see Attachment C-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 the method worked in practice or not. For purposes of evaluating applicability, all assembled chemical weapons (ACWs) refers to chemical rockets, mortars, and projectiles, and all sites refers to Pueblo, Blue Grass, or any other site where chemical rockets, mortars, and projectiles are stockpiled.

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

[i] In its evaluation of effectiveness, PMACWA has elected to evaluate the amount of agents and energetic compounds in all effluent streams. Thus, for purposes of this report, PMACWA has defined destruction and removal efficiency (DRE) as $(M_{fi}-M_{fo})/M_{fi}$, where M_{fi} is the mass flow of the hazardous constituent entering the unit and M_{fo} is the mass flow rate emitted from the unit, summed over gaseous, liquid, and solid effluents. This definition is synonymous with EPA's definition of destruction efficiency (DE).

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. Standard risk mitigation measures such as use of cascading heating, ventilation, and air conditioning systems and double-walled piping are not discriminators between technologies because these measures will be implemented in any chemical demilitarization facility no matter what technology is implemented; the evaluation of the Worker Health and Safety criteria does not consider these non-discriminating measures.

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 mass 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 Blue Grass, Kentucky, an independent cost and schedule analysis was performed. An independent analysis was conducted in order to ensure consistency with the Demonstration I evaluation and to allow for comparisons when appropriate. 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 C-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 January 2001 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.

C.4.1 AEAT/CH2MHILL SILVER II Electrochemical Oxidation

This section of the technical evaluation report covers the description and evaluation of the SILVER II process proposed to PMACWA by the AEA Technology/CH2MHill team.

C.4.1.1 Description of the Proposed Technology

The process uses modified baseline reverse assembly to access agent and energetics, which are then mineralized[i] using SILVER II, an electrochemical oxidation process using silver nitrate in concentrated nitric acid. Hardware and solids are thermally decontaminated.

The current process has notably different pre-treatment and post-treatment from that proposed during the initial ACWA demonstration selection phase (see *Assembled Chemical Weapons Assessment Program, Annual Report to Congress*, December 1997) because of subsequent technology development and enhancement.

C.4.1.1.1 ACWA Total Solution

SILVER II incorporates a combination of three major operations—reverse assembly modified with projectile punching and fluid accessing, SILVER II electrochemical oxidation, and thermal treatment. See Figure C.4-1 for a process flow diagram of the SILVER II total solution.

Pre-Treatment

SILVER II uses baseline reverse assembly and fluid accessing (fluid-abrasive cutting and fluid mining using water) for ACW pre-treatment. Spent grit is filtered from the water and sent to thermal treatment; the water is reused for fluid-abrasive cutting. The explosive train is removed from projectiles by using the baseline projectile/mortar disassembly (PMD) machine. In a separate station, projectile bursters are fluid mined to remove the explosive burster charge. Other explosive components are sent to a Detonation Chamber.

A Punch/Drain/Washout Machine (PDWM) accesses the agent cavities in projectiles and drains/washes them. First, two, 1-inch holes, 180° apart at each end, are punched through the sidewall into the agent reservoir of the projectile. Then the agent is gravity drained from the projectile and steam is used to wash the agent reservoir.

A Rocket Demilitarization Machine (RDM) replaces the baseline Rocket Shear Machine (RSM). The RDM punches and drains rockets by using the drain station of the RSM and then additionally steam washes the agent reservoir. Fluid cutting/mining systems access the energetic components. The RDM radially cuts in three places simultaneously—separating the fuze, warhead, motor, and fin assembly. The fuze portion is transported to the Detonation Chamber. Bursters, while in the warhead, are fluid mined to remove the explosive charges. The M28 propellant grain is pulled out of the motor case in its entirety and size reduced with a two-stage grinder into a slurry. The rocket S&F container is transferred to thermal treatment.

[i] "Mineralize" refers to complete oxidation of organic material.

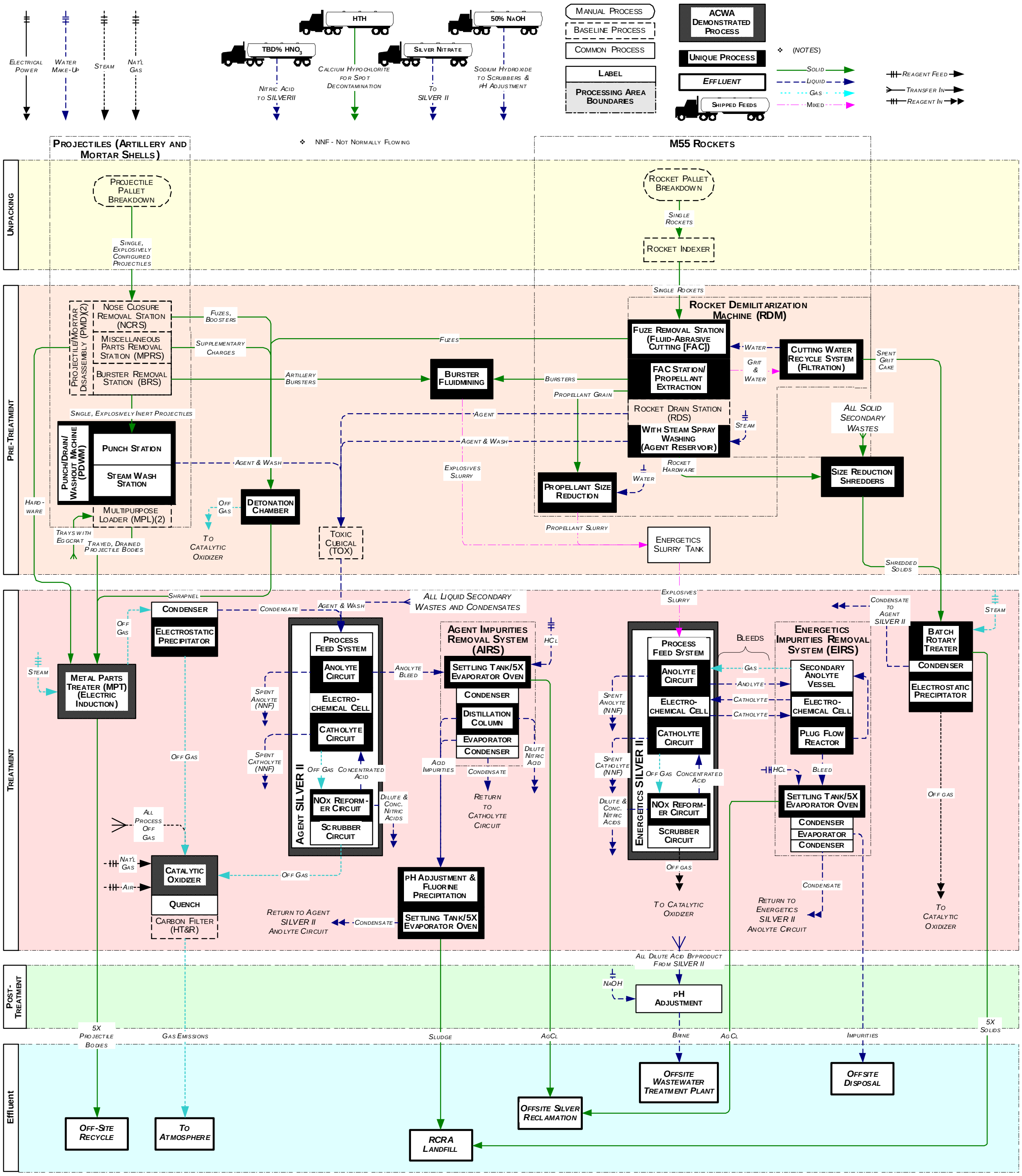

Figure C.4-1. AEAT/CH2MHill SILVER II Process Flow Diagram

The Detonation Chamber is a thermally initiated, contained detonation device that accesses explosive components (i.e., fuzes/boosters, supplementary charges, and igniters) by exposing them to heat.

Slurried explosive material from the ACW (20% by weight) is sent to a number of holding tanks for feed to the SILVER II reactor circuit. Agent is pumped to tanks in a buffer area similar to the baseline toxic cubicle (TOX). Solid secondary wastes (e.g., dunnage) are size reduced in 2-stage shredders.

Treatment

Drained agent, along with liquids condensed from the Batch Rotary Treater (BRT) and Metal Parts Treater (MPT) (see below), are destroyed in the Agent SILVER II[i] unit. Propellant and high explosives (from bursters) are destroyed in the Energetics SILVER II unit. Each SILVER II unit consists of a Feed System, an Anolyte Circuit, and a Catholyte Circuit integrated with an impurities removal system. SILVER II, originally a semi-continuous batch process, is made continuous through a "bleed" to impurities removal systems and the use of an additional hydrocyclone, both on the anolyte circuit. The Agent Impurities Removal System (AIRS) evaporates liquids (mostly aqueous acid) from solids in a 5X[ii] evaporator oven (thermal soak for at least 15 minutes at 1,000°F) and separates acid offgas for reuse (nitric) or disposal (hydrofluoric [HF], hydrochloric [HCl], phosphoric, and sulfuric). The slurry from the agent SILVER II is treated with HCl to precipitate silver as silver chloride (AgCl) before heating in the 5X evaporator oven. The Energetics Impurities Removal System (EIRS) has an additional, smaller SILVER II unit followed by a 5X evaporator oven and nitric acid recovery. Offgas from the BRT and MPT (mostly steam and nitric acid) is condensed for recovery or disposal.

Metal parts (projectile bodies and hardware; rocket metal hardware; and scrap from the Detonation Chamber) are placed on trays and thermally treated in batches in the MPT, an electrically heated oven with a steam atmosphere. The BRT thermally treats fluid cutting grit and size-reduced, solid (mostly non-metallic) secondary wastes (dunnage and rocket S&F containers). The BRT is similar in structure to the baseline DFS, but is operated in batch mode. Offgas from the MPT and the BRT (mostly steam) is condensed and sent to SILVER II for treatment.

All process offgas is mixed with air and is treated with a catalytic oxidation system, followed by Hold, Test, & Release/Rework (HT&R).

SILVER II includes a nitric oxide/nitrogen dioxide (NOx) Reformer Circuit, a Caustic Scrubber Circuit, and continuous stirred tank reactors (CSTRs) for pH adjustment. NOx in the offgas is collected by a NOx absorber column and reformed to nitric acid using oxygen in a packed bed distillation column. The remaining offgas from the NOx reformer goes to a caustic scrubber for acid neutralization.

[i] SILVER II is mediated electrochemical oxidation using silver^{2+} ions in aqueous nitric acid (formed by an electrochemical cell) that is circulated through CSTRs (anolyte and catholyte circuits).
[ii] Toxic Chemical Agent Safety Standards, Army Pamphlet 385-61, 31 March 1997. 5X (XXXXX) indicates that an item has been decontaminated completely of agent and may be released for general use or sold to the public.

Post-Treatment

Acids distilled by the AIRS are neutralized with lime in a CSTR. Similarly, dilute nitric acid waste is pH neutralized with caustic.

Effluent Management

The system offgas is processed through carbon filters and undergoes HT&R, using a carbon filter for rework as necessary, before exhausting to the atmosphere. Liquids are separated by evaporator/ condensers and are reused (on or off site) or sent offsite for disposal. Evaporator bottoms from the impurities removal systems are disposed of off site. The pH adjusted acid streams will undergo wastewater treatment either on or off site. Solids from HF neutralization are collected in a filter press and landfilled. 5X metals are recycled and 5X solids are landfilled.

C.4.1.1.2 Unit Operations Not Demonstrated in Demonstration II

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

- **Shredder (Size-Reduction)—**This is common commercial equipment used for marginal size reduction of solid secondary wastes for feed to the BRT. Extensive size reduction capabilities were previously validated by PMACWA (Demonstration I and EDS).

- **Rocket Demilitarization Machine—**The RDM is a new addition to the proposed full-scale process, incorporated after Demonstration II was conducted. The punch and drain stations are based on the existing baseline RSM.

    - **Cutting Station—**These fluid-abrasive cutting and fluid mining operations are substantially similar to the rocket cutting and fluid mining technology previously validated by PMACWA.[6]

    - **M28 Propellant Grinding—**Several ACWA technologies require size reduction of M28 propellant. PMACWA has therefore elected to conduct a single design study to address this requirement.

- **Punch/Drain/Washout Machine—**The PDWM for projectiles is a new addition to the proposed full-scale process, incorporated after Demonstration II was conducted.[7] In addition, punching of projectiles was done at full-scale at Crane Army Ammunition Plant.

    - **Projectile Burster Washout—**This operation is substantially similar to the burster washout technology previously validated by PMACWA.[8]

    - **Steam Spray Wash—**Water spray washout of ton container vessels and steam washing of ton container eductor tubes was demonstrated at Edgewood Chemical and Biological Center (ECBC).

- **Detonation Chamber—**This contained blast chamber is a commercially available, indirect, electrically heated vessel.

- **Metal Parts Treater and Batch Rotary Treater—**The MPT and BRT are similar to the Metal Parts Treater previously validated by PMACWA.[9]

- **Catalytic Oxidation System—**The catalytic oxidation system is commercially available; it is also similar to the CATOX previously validated by PMACWA.[10]

- **Agent Impurities Removal System and Energetics Impurities Removal System—** These are new additions to the proposed full-scale process, incorporated after Demonstration II was conducted.[11]

C.4.1.1.3 Unit Operations Demonstrated

This section explains the rationale for selecting the SILVER II demonstration unit operations, the objectives of testing, and significant deviations from the planned testing. Demonstrations with a 2-kW SILVER II Unit and a 12-kW SILVER II Unit are discussed below.

C.4.1.1.3.1 2-kW SILVER II Unit (Agent)

A 2-kW SILVER II Unit was demonstrated to validate destruction of the agents contained in ACW and to correlate with the 12-kW SILVER II Unit through testing with agent simulants. The 2-kW SILVER II unit was demonstrated at Building E3566 at the Edgewood Area of APG, Maryland. The demonstration system was an integrated unit consisting of the following:

- **Feed System—**The agent for each run is pumped from a steel container into two premix vessels for metering into the anolyte vessel at an appropriate rate, according to the destruction efficiency of the particular organic material.

- **Electrochemical Process—**The electrochemical cell contains titanium electrodes that are electroplated with platinum. It is designed to operate at a maximum current of 1,000 amps per electrode face, with the power supply voltage automatically varied to maintain the set current. The electrochemical cell comprises two cathodes flanking an anode. The electrodes are separated into anolyte and catholyte compartments by membranes made of a perfluoro ion exchange polymer. The organic feed is metered into the anolyte vessel that contains 8 M nitric acid and 10% silver nitrate. Fluids from the anolyte circuit flow through the channels with exposure to the anode in the cell. When the current is turned on, the Ag^{2+} ions generated oxidize the organic feed. Some Ag^{+} ions and water (as hydrated protons) pass through the electrochemical cell membrane and flow into the catholyte vessel, which contains 4 M nitric acid. The cathodic reaction reduces the nitric acid to NOx and water in the catholyte vessel.

- **Particulate Removal and Treatment—**AgCl precipitates when chlorinated feeds (*i.e.*, HD) are exposed to nitric acid and silver nitrate. The particulate removal process is integrated into the electrochemical process unit; a hydrocyclone on the anolyte circuit removes the AgCl before it reaches the electrochemical cell. The AgCl accumulates in a separate evaporator oven for 5X treatment to confirm that it is agent-free. The vapor from the oven passes to a condenser and the condensate is returned to the anolyte vessel. The AgCl is then removed as a solid cake for silver reclamation.

- **NOx Reformer Circuit—**The reactions with Ag^{2+}, that occurs in the anolyte circuit, release carbon dioxide (CO_2), carbon monoxide (CO), and NOx. The reactions occurring in the catholyte circuit release NOx. Offgas from both circuits passes through a condenser to remove some of the NOx vapors and then travels to the NOx reformer. Due to facility size restrictions, the 2-kW plant included a less efficient than optimal NOx reformer with a single column for absorption and distillation. As the gas travels up the column, water running down the column reacts with NOx in the gas, forming dilute nitric acid. The dilute nitric acid is heated to evaporate water and produce concentrated nitric acid. The evaporated water is condensed, producing very dilute nitric acid, which is recycled to the anolyte vessel or disposed of as waste. The concentrated nitric acid is recycled to the catholyte vessel or used commercially.

- **Caustic Scrubber Circuit—**Offgas from the NOx reformer is sent to the caustic scrubber tower to remove any residual NOx before release of the gas to the facility ventilation system.

Laboratory scale testing of a SILVER II agent unit had previously been performed with GB; destruction of HT and VX had previously been tested at a scale similar to that of the demonstration unit. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives of this demonstration unit included the following:

- Validate the ability of the 2-kW SILVER II Unit to achieve a DRE of 99.9999% for HD, GB, and VX.

- Determine the impact of operations on materials of construction to be used in a full-scale system.

- Demonstrate the operation and performance of the following key process components for future scale-up:

    - Instrumentation, valves, pumps, etc.

    - Hydrocyclone (to determine its ability to deal with solids in the anolyte circuit)

    - Electrochemical cell (electrodes and membranes)

- Develop operational data to allow comparison of the 2-kW SILVER II Unit to the 12-kW SILVER II Unit for use in scaling up SILVER II.

- Characterize silver-bearing residuals. Determine potential silver recovery and determine disposal options (via characterization) for residuals from silver recovery operation (HD only).

- Characterize gas, liquid, and solid process streams from SILVER II for selected chemical constituents and physical parameters, and the presence/absence of hazardous, toxic, agent, agent simulant, and Schedule 2 compounds.

The 2-kW SILVER II Unit was tested with the following:

  - 31 lb dimethyl methylphosphonate (DMMP)
  - 35 lb HD
  - 9 lb VX
  - 35 lb GB

Significant deviations from the planned demonstration testing included:

- Reduction in the VX validation run quantity (from 22 lb to 9 lb) and duration due to schedule constraints
- Elimination of the chloroethyl ethyl sulfide (CEES) validation run due to difficulty in obtaining CEES in the quantity needed and schedule constraints

C.4.1.1.3.2 12-kW SILVER II Unit (Energetics)

A 12-kW SILVER II Unit was demonstrated to validate destruction of the energetics contained in ACW and to correlate with the 2-kW SILVER II Unit through testing with simulants. The 12-kW SILVER II Unit was demonstrated at the Fire Safety Test Enclosure at the Aberdeen Test Center, Aberdeen Area of APG, Maryland. The demonstration system was an integrated unit consisting of the following:

- **Feed System—**The energetics feed system is designed to maintain the energetics material in a 20% slurry with water by storing it in a continuously mixed feed vessel. Two forms of agitation ensure the energetics remain in the slurry: an air-driven mixer and a recirculation loop. The energetics slurry is fed to the anolyte vessel by bleeding off a slipstream from the recirculation loop.
- **SILVER II System—**The SILVER II system of the 12-kW unit is the same as that for the 2-kW SILVER II Unit but without the particulate removal and treatment system[i] and with a complete NOx Reformer Circuit. The complete NOx reformer circuit included separate absorption and distillation columns. As gas travels up the absorption column, water running down the column reacts with the NOx in the gas, forming dilute nitric acid. The dilute nitric acid leaves the bottom of the absorption column and enters the distillation column, where it is heated to evaporate water and produce concentrated nitric acid.

[i] No chlorinated feeds were processed in this unit, so the particulate removal and treatment system was removed from the unit.

Energetics testing in a laboratory scale SILVER II unit was previously performed with RDX, TNT, tetryl, and a double-base propellant similar to M28. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives of this demonstration unit included the following:

- Validate the ability of the 12-kW SILVER II Unit to achieve a DRE of 99.999% for Comp B (RDX and TNT), Tetrytol (tetryl and TNT), and M28 propellant (NC and NG).
- Validate the ability of the 12-kW SILVER II Unit to achieve a DRE of 99.9999% for DMMP (dimethyl methyl phosphonate, a VX/GB simulant).
- Determine the impact of operations on materials of construction to be used in a full-scale system.
- Demonstrate the operation and performance of the following key process components for future scale-up:
  - Instrumentation, valves, pumps, etc.;
  - Electrochemical cell (electrodes and membranes);
  - Full-height NOx reformer/silver recovery boiler (ability to maintain H_2O balance);
  - Offgas scrubber operating in conjunction with NOx reformer.
- Develop operational data to allow comparison of the SILVER II 2-kW agent system to the 12-kW SILVER II system for use in scaling up the SILVER II agent system.
- Demonstrate the ability/inability to recycle, reuse, or dispose of nitric acid.
- Characterize gas, liquid, and solid process streams of SILVER II for selected chemical constituents and physical parameters and for the presence/absence of hazardous and toxic compounds.

The 12-kW SILVER II Unit was tested with the following:

- 88 lb DMMP
- 308 lb M28 propellant
- 220 lb Tetrytol

Significant deviations from the planned demonstration testing included the following:

- Elimination of the CEES validation run due to difficulty in obtaining CEES in the quantity required and schedule constraints.

- The quantity of M28 propellant was reduced (from 440 lb to 308 lb) due to schedule constraints.
- Planned Comp B testing was not conducted due to schedule constraints.

C.4.1.2 Technical Evaluation

C.4.1.2.1 Process Efficacy/Process Performance

C.4.1.2.1.1 Effectiveness

The effectiveness of SILVER II destruction of chemical agents was validated during the demonstration. HD was not detected in any effluent sample, with detection limits of 11 µg/L for liquid streams and 15.2 $\mu g/m^3$ for the offgas, indicating a destruction efficiency of >99.999996% for HD.[12] GB was not detected in any effluent sample, with detection limits of 10 µg/L for liquid streams and 1.3 $\mu g/m^3$ for the offgas, indicating a destruction efficiency of >99.999996% for GB.[13] VX was not detected in any effluent sample, with detection limits of 10 µg/L for liquid streams and 1.2 $\mu g/m^3$ for the offgas, indicating a destruction efficiency of >99.999988% for VX.[14] The destruction of vesicants H and HT was not part of the planned demonstration test program. However, destruction of H is expected to be essentially identical to that of HD. Based on the results of the HD testing and previous testing for the U.S. Army with HT,[15] there is a high degree of confidence that SILVER II can adequately destroy H and HT agents.

The MPT and BRT use technology demonstrated previously by the Army and validated for the destruction of residual agents HD, GB, and VX on munition hardware.[16] A catalytic oxidation unit (the CATOX) was also demonstrated previously by the Army and validated to destroy HD, GB, and VX in the gaseous effluent. The MPT alone destroys at least 99.9998% of GB and with the CATOX it validated greater than 99.999998% destruction of GB. The MPT unit alone destroys at least 99.998% of VX and with the CATOX was validated to greater than 99.9999993% of VX. The MPT unit alone destroys at least 99.98% of HD, and with the CATOX was validated to 99.9995% destruction with HD. One observation of HD breakthrough at levels below the HD screening level occurred during CATOX agent spike testing.[17] Based on all available data, the overall SILVER II process was effective for destruction of the chemical agents of concern.

Destruction of M28 propellant with SILVER II was validated. NC was not detected in anolyte, catholyte, the concentrated nitric acid product or the scrubber liquid at a detection limit of 130 µg/L or in scrubber filter solids; it was detected at 160 µg/L in the dilute nitric acid product and quantitated at 0.94 g in the anolyte filter solids, indicating a destruction efficiency of >99.9990%. NG was not detected in anolyte, catholyte, the concentrated nitric acid product or the scrubber liquid at a detection limit of 25 µg/L; it was detected at 190 µg/L in the dilute nitric acid product, indicating a destruction efficiency of >99.9996%.[18]

Complete destruction of Tetrytol components (tetryl and TNT) by SILVER II was not validated. Tetryl was not detected in the dilute nitric acid product or the scrubber liquid at a detection limit of 125 mg/L; it was detected at 800 mg/L in the anolyte, 920 mg/L in the catholyte, and 420 mg/L in the concentrated nitric acid product and 26.2 mg of tetryl was found in the scrubber filter, indicating a destruction efficiency of only 98.6% for tetryl. TNT was not detected in the anolyte, the dilute nitric acid product, or the scrubber liquid at a detection limit of 125 mg/L; it was detected at 690 mg/L in the catholyte, and 320 mg/L in the concentrated nitric acid product, and 400 µg of TNT was found in the scrubber filter and 280 µg of TNT was found in the anolyte filter, indicating a destruction efficiency of only 97% for TNT.[19] However, laboratory testing by the technology provider indicates destruction of 100 g quantities of TNT to >99.99997% after 40-42 hours and tetryl to >99.99993% after 31 hours when the process is allowed to run to completion.[20] Modifications to the process have been proposed that should improve the effectiveness of the demonstration unit towards the level observed in the laboratory.

Destruction of Comp B (composed of RDX and TNT) was not validated during demonstration testing due to schedule constraints. However, laboratory testing by the technology provider indicates destruction of 100 g quantities of RDX to >99.99999% after 19 hours and TNT to >99.99997% after 40-42 hours when the process is allowed to run to completion.[21]

The MPT is based on a technology[22] that was previously validated effective for (5X) decontamination with munitions spiked with HD, VX, and GB during Demonstration I. No detectable agent remained on any of the tested parts.[23] No energetic decontamination was validated, however 5X performance conditions were met. The BRT is based on a technology that was previously validated for (5X) decontamination with charcoal, wood, fiberglass, and demilitarization protective ensemble (DPE). Although no agent testing was planned, the material achieved a 5X condition based on time and temperature.[24] Solids removal and thermal treatment of AgCl (collected during the HD run) to 5X conditions were validated during Demonstration II.

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. In addition, weapons-grade VX,[25] HT,[26] and “tarry mustard,”[27] chemical agents representative of stockpiled munitions were processed in previous tests conducted by the technology provider with a 4-kW SILVER II unit. These materials are likely to contain most of the impurities that will be encountered in U.S. stockpile munitions.[i] Based on all available data, the confidence in the effectiveness of the process in the presence of impurities and additives is high.

In summary, SILVER II is effective in destroying agents and propellant. However, the curtailed Tetrytol demonstration and lack of any demonstration data for Comp B prohibits the complete validation of the process. The technology includes operations to effectively process metal parts and dunnage. Although Comp B has not been demonstrated, greater than 99.999% destruction of the constituents of Comp B and Tetrytol in laboratory experiments indicates the likely effectiveness with these energetic compounds.

C.4.1.2.1.2 Products

The overall characterization of the proposed SILVER II process is well defined based on data obtained during demonstration.[28] In general, the major products from SILVER II treatment of organic materials are CO_2, water, and mineral acids including HCl, HF, nitric acid, sulfuric acid, and phosphoric acid. However, some areas of the proposed process were not addressed during

[i] M55 rockets have different materials of construction than other ACW (e.g., aluminum warheads) and, therefore, they are expected to have different impurities.

demonstration, most notably incomplete characterization for Comp B. However, laboratory testing of Comp B components by the technology provider supports the mass balance that was provided.[29]

It was validated that there was no agent reformation in SILVER II once the agent was initially destroyed. HD, GB, and VX were not detected in any process stream exiting the SILVER II unit.[30] Subsequent HD reformation is extremely unlikely because chloride is precipitated as AgCl, sulfate remains in the anolyte solution, and carbon from the agent is converted to gaseous CO and CO_2.[31] Subsequent GB and VX reformation is extremely unlikely because phosphate and sulfate remain in the anolyte solution, whereas carbon from the agent is converted to gaseous CO and CO_2.[32]

SILVER II was validated not to produce Schedule 1 compounds or significant quantities of Schedule 2 compounds. No thiodiglycol was detected at 5 µg/mL in any samples during the HD run.[33] After GB processing, no Schedule 2 compounds were detected in any process waste stream except for isopropyl methylphosphonic acid (IMPA), which was detected in the scrubber solution in insignificant quantities (0.60 mole percent of agent input). After VX processing with SILVER II, no Schedule 2 compounds were detected in any process waste stream except for ethyl methylphosphonic acid (EMPA) and methylphosphonic acid (MPA). EMPA was detected in anolyte offgas and in the concentrated nitric acid in insignificant quantities. MPA was detected in the catholyte, anolyte offgas prior to the scrubber, and in scrubber offgas in insignificant quantities (total Schedule 2 production in SILVER II VX process waste streams of 0.004 mole percent of agent input).

SILVER II does not form dioxins, furans, and other chlorinated organics in significant quantities. No EA2192 was detected during VX processing, as expected. 1,2-dichloroethane is present in HD as a contaminant (2.4 percent by weight), but was reduced to estimated mg/L levels in dilute acid from the reformer, µg/L levels in the scrubber solution, and PPMV levels in scrubber offgas. Other hazardous substances are effectively treated; wood dunnage spiked with PCP was treated during Demonstration I in a prototype unit representative of the rotary dunnage treater with no detectable PCP in the effluent.[34]

However, data from demonstration testing show that the following hazardous substances were produced:

- Alkyl nitrates were produced during SILVER II operations. These included:
    - Isopropyl nitrate from GB estimated at 44 mg/L in dilute acid from reformer
    - Methyl nitrate from GB estimated at µg/L levels in concentrated and dilute acid from reformer and in scrubber solution
    - Alkyl nitrates from M28 estimated at mg/m^3 levels in anolyte offgas and scrubber offgas
    - Decyl- and nonyl- nitrates or other alkyl nitrates from M28 and Tetrytol were tentatively identified at $\mu g/m^3$ levels in anolyte offgas and scrubber offgas

- Unknown organic compounds from processing of Tetrytol, M28, GB, HD, and VX estimated at:
    - Up to g/L levels in the anolyte
    - Up to mg/L levels in the catholyte, in the dilute acid from reformer, in the concentrated acid from reformer, and in the scrubber solution
    - Up to mg/m^3 levels in the anolyte offgas and in the scrubber offgas
- Low levels of total dioxins/furans (up to 160 ng/m^3) were produced during Demonstration I tests of DPE processing in a prototype unit representative of the BRT, but were reduced in the catalytic oxidation unit to single digit ng/m^3 levels of total dioxins/furans (100 pg/m^3 toxic equivalency).[35] These are levels at which minimal health effects would be expected,[36] and are below typical incinerator effluent limits.[i,ii] Additionally, the charcoal filters downstream of the catalytic oxidation unit would further reduce these emissions. However, quantifying the effectiveness of the filters was not within the scope of the demonstration testing.
- Tetrytol processing produced significant quantities of a crystalline solid containing 30% by weight tetryl and reported to include 1,3,5-trinitrobenzene (TNB).[37] TNB is considered a flammable solid when wetted and an explosive when dry or when wetted with less than 30% water by weight.[38] Proposed process modifications to manage this material, including a high shear mixer and dual hydrocyclones, were not demonstrated.
- During previous testing with HD heel in a prototype unit representative of the BRT and MPT, vinyl chloride was produced at up to hundreds of $\mu g/m^3$; no data were presented on the ability of catalytic oxidation to remove low molecular weight compounds, especially chlorinated organics.[39] These levels, while lower than acceptable workplace levels,[40] still exceed concentrations associated with an elevated cancer risk.[41]

There are little data from demonstration testing to support adequate treatment of some hazardous intermediates:

- GB processing produces HF as an intermediate.[42] The AIRS should separate HF from the process streams and precipitate it as calcium fluoride, but it has not been demonstrated.
- Tetrytol processing produces, nitrobenzene, 2,4-dinitrophenol, 2,4- and 2,6-dinitrotoluene, and 2,4,6-trinitroaniline at mg/L levels in the catholyte circuit and in dilute acid from the NOx reformer. The capability of the additional hydrocyclone (on the anolyte circuit) to return these materials to the anolyte vessel for destruction was not demonstrated. The capability of the EIRS to remove these materials from the anolyte circuit for destruction was not demonstrated. (It is unclear whether some of these compounds were a carry-over from the dinitrotoluene [DNT] systemization runs or whether they were produced during Tetrytol processing.)

[i] *cf.*, 40 CFR 60.52e, which limits emissions from new medical waste incinerators to 25 ng/m^3 total dioxin.
[ii] The US Environmental Protection Agency has recently announced a final rule that will modify 40 CFR 63.1203(b)(1) to limit emissions levels from hazardous waste incinerators to 200 pg/m^3 TEQ.

In summary, demonstration data provided an acceptable characterization of the products of the process for agents and propellant. Non-reformation was validated for all agents, and SILVER II was validated not to produce Schedule 1 or significant quantities of Schedule 2 compounds. Dioxins, furans, and other hazardous chlorinated organics are not formed in significant quantities in this process. Acceptable treatment of most hazardous intermediates (formed at relatively low levels) was validated for this process; other treatment steps that should effectively destroy the remaining hazardous intermediates were proposed but not demonstrated. Although it poses a manageable technical risk, the incomplete demonstration of energetics destruction in turn leads to incomplete validation of product acceptability

C.4.1.2.1.3 Sampling and Analysis

Prior to the start of SILVER II testing, most non-standard sampling and analysis methodologies passed validation testing. These included analysis for the following types of chemical substances:

- Anions in both AgCl and in acidic process liquid[43]
- Residual agent for SILVER II process matrices[44]
- Residual energetics for SILVER II process matrices[45]
- Residual NG and NC[46]
- Metals, mercury, dioxins/furans, semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs), and total organic carbon (TOC) for SILVER II process matrices[47]

Modified standard gas sampling techniques (based on a previously tested prototype unit that was representative of the MPT and BRT) were implemented with minimal difficulty and expected impacts on data usability. Most of the data generated were deemed usable for evaluation of the technology and characterization of the process effluents. The gas-sampling set-up (with carbon steel ductwork) caused difficulties with the collection of representative samples for metals. These difficulties were judged easy to overcome in future testing.[48]

Several non-standard sampling and analysis methodologies 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:

- NG results for high concentrations may not be representative, likely due to low solubility in nitric acid matrix[49]
- Results for acidic SVOC phenol derivatives were biased significantly low
- Cadmium, lead, and thallium recoveries and results are likely biased low
- Poor recovery of surrogates, e.g., 1,4-difluorobenzene, chlorobenzene-d_5, and styrene-d_8, during VOC analyses indicates that some results are likely biased low

During the SILVER II demonstration, most of the data generated have been deemed usable for evaluation of the technology and characterization of the process effluents.[50] 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, as reflected in the amount of usable data obtained during demonstration, is given in Table C.4-1.

In summary, demonstration showed that the vast majority of sampling and analysis methodologies and techniques for mass balance purposes and for determining residual levels of agent, energetics, and other compounds of concern in the process matrices are acceptably verified and validated. The commercial laboratories contracted to analyze the samples generated during the demonstration effort validated twelve analytical methods. The challenges encountered with sample analysis were overcome and are not anticipated to be a problem for full-scale operation; however, recoveries of cadmium, thallium, and lead will likely remain low.

Table C.4-1. Level of Verification for SILVER II Analyses

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

C.4.1.2.1.4 Process Maturity

In general, the unit operations that comprise the SILVER II total solution have an acceptable level of maturity adequate for implementation, with completion of most of the demonstration objectives.

The SILVER II process incorporates a combination of three major operations—reverse assembly modified with fluid accessing, SILVER II electrochemical oxidation, and thermal treatment. Most of these operations have been demonstrated at the bench scale or greater, they are based on common industrial processes, or they are being developed under ACWA EDS. This constitutes a major benefit of the proposed process. However, untested modifications proposed to SILVER II after the completion of the ACWA demonstration tests increase the technical risk.

<u>Pre-Treatment</u>

The baseline reverse assembly operations (PMD and RSM/rocket drain station [RDS]) have had extensive use for ACW. The proposed fluid accessing systems have historical commercial industrial bases and they have been validated by the PMACWA during Demonstration I. It must be noted that extensive integration with fluid accessing will be difficult and reuse of the cutting water after filtration has been shown to be problematic due to materials transport.

The technology provider has proposed some changes in rocket processing with the RDM that are not beneficial. These differences pose only small technical risks, but they have also already been resolved by PMACWA by using other techniques. The operations of concern are pulling the propellant grain from rocket motors and grinding the grain whole. The proposed method of pulling the M28 propellant grain from the rocket motor differs somewhat from that shown during Demonstration I. The technology provider proposes to leave the anti-resonance rod in place, which is likely to interfere with the pulling mechanism. Although propellant grinding has been commercially developed, shearing the grain into smaller pieces prior to grinding would be desirable.

The projectile punching portion of the PDWM is well-developed,[51] but the overall process has never been built or tested with ACW and is expected to pose a much higher technical risk than techniques currently available under baseline reverse assembly and being developed by PMACWA. Use of the baseline Multipurpose Demilitarization Machine (MDM) Pull and Drain Station (PDS) and the Projectile Washer being developed under EDS[52] would provide better access and cleaning (i.e., less residual agent) than the PDWM while reducing the uncertainty and technical risk. The complex manipulations required for the PDWM inevitably present greater problems than those observed with the MDM/PDS, contrary to the technology provider's claims.[53]

The fuze detonation chamber is a contained blast chamber, a commercially available unit, but no details were provided.[54] Finally, generating and maintaining a 20 PBW energetics slurry throughout the storage and transfer system is expected to be somewhat difficult.

<u>Treatment</u>

Extensive testing of SILVER II has been conducted at laboratory, bench, and pilot scale (up to a 12-kW system) with a wide variety of materials in large quantities, including energetics and many different agents. The major components used in SILVER II are well developed and demonstrated in industrial applications. Electrochemical cells have many years of operating experience in the chlor-alkali manufacturing industry. The hydrocyclone is a common media separation method and CSTRs are used commonly in the chemical process industry. Varieties of silver reclamation processes are also standard in the industry. SILVER II has been successfully and, for the most part predictably, scaled from lab to pilot size.[55] Two SILVER II units were successfully built and operated during Demonstration II and there was good correlation between 2- and 12-kW units, which indicates an understanding of scale-up issues. Certain portions (such as the anolyte circuits) require special materials of construction, but all are commercially available.[56]

Determining the ability of SILVER II to process solids was a specific test objective. Although many of the solids of concern are now thermally treated, solids and impurities continue to challenge SILVER II and have instigated the untested process changes (impurities removal systems). As such, the proposed SILVER II system differs in equipment and operating strategy from all previously tested systems.[57] Changes were made to improve the destruction of TNT-based energetics and to remove impurities from the SILVER II circuits. Past testing used a semi-continuous batch mode. The proposed process includes additional solids management devices and new impurities removal systems to improve effectiveness and to allow operation on a continuous basis. Although the principles of this approach appear sound, these untested modifications represent a significant technical risk.

The thermal treatment systems have commercial, industrial bases—the MPT is a basic oven, the BRT is a rotating drum oven, and the 5X ovens are evaporators—but the use of a steam atmosphere makes these thermal treatments somewhat less mature. The MPT and BRT are based on thermal treatment systems being developed by the PMACWA (EDS).[58] All process offgas is mixed with air and treated by a commercial catalytic oxidation system similar to that being developed by the PMACWA (EDS).[59] There is a lack of definition about how the thermal treatment condensate is treated, and although treatment with SILVER II seems feasible, there are no data on the effectiveness or products of the resulting oxidation of condensate organics.

Post-Treatment

A number of recycle and recovery systems are built into SILVER II (with more off site), so post-treatment for the most part involves only pH adjustment using commercial packaged systems, which reflects adequate maturity. Liquids are treated in common, industrial scrubbers and reformers (NOx).

Effluent Management

The effluent management systems consist predominately of physical separation units (i.e., distillation columns, evaporators, and condensers), primarily for recovery and reuse of nitric acid. These systems, although numerous, are common industrial operations. There is limited detail on the HT&R system (strategy only).

Summary

A number of the unit operations of the proposed SILVER II total solution are sufficiently mature for full-scale. The baseline systems have extensive full-scale experience. The fluid accessing systems and thermal treatment systems are also based on commercial operations with some ACW experience, including some from ACWA testing. The provider proposes thermal treatment systems similar to that validated by PMACWA during Demonstration I, which have matured during the ACWA EDS. Most of the equipment used to construct the SILVER II solution is commonly used in industry and is considered mature.

Although extensive development and testing was conducted on the SILVER II technology, there continues to be significant technical "surprises" that indicate a lack of process maturity in certain areas. Newly proposed changes to overcome problems observed during Demonstration II appear appropriate but they have not been built or tested. Overcoming the technical issues associated with SILVER II is critical to successful use of this system and still poses a technical risk.

Other technical risks are associated with the proposed incorporation of other technology providers' processes into the SILVER II process. These technologies have not been tested in the proposed configuration and in some cases may be inappropriately employed.

C.4.1.2.1.5 Process Operability

There are several advantages of process stability of SILVER II. Modest temperature changes have a modest effect on the SILVER II destruction rate and modest changes in feed rate and purity are tolerated by the control system. Changes in plant pressure should not be a problem during normal operations since the system operates at atmospheric pressure and it is fully vented to HT&R to relieve pressure buildup. Variations in many reaction conditions (e.g., anolyte silver concentration) only reduce electrochemical efficiency.[60] The HT&R monitoring approach supports the stability of the total solution. While SILVER II is a continuous operation, liquid effluent streams are pulled off periodically in batches for offsite disposal or recycling. In regards to safe operation of the system, the SILVER II agent and energetic demonstrations had no stability problems.

Rocket cutting and energetics (burster) hydromining by another technology provider during Demonstration I and EDS had no stability problems and they are expected to be stable operations at full-scale. The effectiveness and robustness of the MPT and the BRT are based on high temperature operating environments. Both these units are similar to thermal treatment systems being industrialized under ACWA EDS.[61] While stability limits for the MPT and BRT are not fully investigated, it is anticipated that this concern can be mitigated. A concern for the MPT is the possibility of bursters not being completely washed out and entering the MPT. The stability of the MPT would be compromised if enough burster material entered the MPT and reacted explosively.

The most serious concern in regards to process operability is the treatment of burster energetics (Tetrytol and Comp B) in the SILVER II system. A limitation of SILVER II was exposed when Tetrytol was fed to the 12-kW SILVER II demonstration unit at the originally planned feed rates.[62] Since SILVER II had problems decomposing an intermediate product, material began to precipitate within the anolyte circuit. Consequently, the system had to be shut down to clear the lines. It was clear that SILVER II required more time than expected to complete oxidation of Tetrytol. The subsequent reduction of the feed rate in the demonstration to minimize precipitation also lowered electrochemical efficiency. In addition, there was evidence that precipitation of material increased when SILVER II process streams cooled, which could be problematic during any shutdown of the system during high energetics feed rates. The technology provider’s solution to the precipitation problem is to add a hydrocyclone and a high-speed mixer in the anolyte circuit.[63] There was also a buildup of organics in the catholyte, possibly due to an ineffective or leaky membrane or to the increased concentration gradient resulting from buildup of organic material in the anolyte circuit. The catholyte circuit was periodically drained, and the drained catholyte solutions were never reintroduced into the anolyte; thus, there is a possibility that the intermediate product that was concentrating within the catholyte and was only partially treated in the demonstration. A catholyte-to-anolyte recycle stream is proposed to reduce the buildup of organics within the catholyte. Upon incorporation of these changes, the technology provider believes that feed rates can be increased to the originally planned values, which would then improve electrochemical efficiency. While these proposed improvements all have merit, optimization studies at smaller scales would be required. The major unknown is whether the solids problem can be resolved by treating energetics processing as a mass transfer limited reaction, allowing energetics to be fed at the planned rates.

There are some additional concerns regarding process operability of the SILVER II process. The operation of SILVER II as a continuous process with AIRS and EIRS has not been demonstrated. The overall total-solution has numerous solid and chemical separation requirements that taken individually are quite feasible, but will be difficult to control simultaneously. The interdependencies of the many unit operations could ultimately hamper the overall operability of the total solution. Sufficient size reduction of energetics and propellant must occur in order for SILVER II to readily process these materials. Salts forming in the process could also challenge the stability of the system. There was evidence of some solids buildup in the electrochemical cell and the formation of lead oxide during demonstration.[64] Specifically, plating of the anode or cathode or plugging of the cell is of concern and buildup of salts could affect the chemistry of the process, although the impurities removal system is supposed to remove these compounds. The long-term corrosion resistance of polytetrafluoroethylene (PTFE)-lined stainless steel, proposed as the material of construction for much of the SILVER II piping and reactors, also has not been demonstrated.

The system has unknown reliability, availability, and maintainability (RAM) characteristics at this time and the confidence required to predict RAM characteristics for full-scale will depend on the success of EDS. Baseline reverse assembly has known (poor to average) RAM characteristics while the punch-and-drain is expected to have poor RAM characteristics based on the present immaturity of design. The new accessing technologies (RDM and PDWM) are expected to have poor to average RAM characteristics based on their maturity. While fluid-abrasive cutting (with water) as an accessing technology is relatively simple, RAM of the entire process is negatively impacted based on the high number of operations required involving numerous manipulations of the munitions. The interconnectedness of the SILVER II units with immature and untested downstream impurities removal and pollution abatement systems is a significant concern with respect to RAM characteristics. RAM of the MPT and BRT is expected to be average, based on difficulties in controlling solids flow, numerous robotics controls in moving the projectiles, and because it is a batch high-temperature operation.

There are manageable demands for startup/shutdown, idle, upset recovery, and campaign changeover activities. The system can run in "idle" mode with the cell and the NOx reformer off but with all other systems operating.[65] However, cooldown or shutdown modes may be problematic, as cooling could result in crystallization of material in pipes and reactors.[66] There will also be poor efficiencies at low organic input to SILVER II when the system needs to be emptied for scheduled or unscheduled maintenance.

The design of the system as a whole is very complex. The complexity of SILVER II is increased by complex munition disassembly processes and untested downstream pollution abatement options. The unit operations for the SILVER II system concept are discussed in Section C.4.1.1. Nitric acid and silver recovery operations are required offsite. In regards to complexity of SILVER II operation alone, government personnel with no prior experience of SILVER II were able to run the 2-kW and 12-kW systems with the technology provider's supervision, demonstrating the operability of the system by properly trained operators (see however, operational complexity described in Section C.4.1.2.1.6). An average number of operators with average skills is needed. The complexity of the overall system with interdependent unit operations could result in greater than average maintenance requirements.

In summary, the operability of independent semi-batch SILVER II units was demonstrated for agents and M28 propellant. The operability of the proposed continuous, SILVER II units with impurities removal systems has not been demonstrated and there are concerns about the ability to maintain stability of the complex full-scale system. A major concern relates to the undemonstrated stability for treatment of burster energetics (Tetrytol and Comp B), several major modifications to the original SILVER II design are proposed to address this issue.

C.4.1.2.1.6 Process Monitoring and Control

For the full-scale system, primarily off-the-shelf instrumentation will be used to monitor and control SILVER II operations, to include agent flow, chemical analysis, oxygen flow, pressure, temperature, voltage, and current. Silver concentration and pH are measured in both the anolyte and catholyte. Anolyte and scrubber offgas are measured for oxygen, CO_2, CO, sulfur dioxide, nitrogen, and NOx. Specific parameters that are monitored during operation of SILVER II also include the rate of increase for anolyte CO_2 and anolyte TOC, periodic electrochemical efficiency, NOx reformer efficiency, pH in the caustic scrubber, and catholyte fluid level.[67] Steady state is indicated when the ratio of CO_2/O_2 is constant and the TOC has reached a steady concentration. The process monitoring requirements for both 2-kW (agent) and 12-kW (energetics) demonstration plants were very similar, indicating the commonality of monitoring and control for SILVER II.

Liquid effluent streams should be in small enough quantities to allow for HT&R for agents and other compounds of concern. Relatively small gas effluent streams can also undergo HT&R and those that contain agent are reworked through a set of carbon filter banks. Cleared gases are released through the plant HVAC carbon filter banks.

There are several advantages of the process for monitoring and control. SILVER II responds at an inherent, slow pace at which the system can react to changing conditions. The process is stable and can be immediately shut down to control any runaway reactions by stopping electrical current to the cell. Fully automatic control maintains all processes within established limits, and returns processes to normal operation after minor process upsets. On several occasions during demonstration, the plant was shut down at short notice for planned or unplanned maintenance and remained in a safe mode. Under normal operating conditions, TOC, acidity (pH), and silver concentration change slowly, which allows operators time to adjust to changing variables.

There are a several concerns in regards to monitoring and control instrumentation. In the 12-kW demonstration, the IONICS 3400 series system for silver determination, the IONICS Model T1800 analyzer for TOC, and the on-line continuous emissions monitoring equipment in the gas stream entering the NOx reformer did not operate correctly, but it is believed that improvements could be made for monitoring using these or other units during EDS.[68] There is also some concern in using TOC for determination of the destruction efficiency because these values did not always correlate during demonstration. There is a meaningful difference between the SILVER II demonstration units and the full-scale system in that the operators of the full-scale system must fully rely on instrumentation for monitoring and control. During demonstration, the operators were able to quickly determine the locations of solids buildup (due to glass piping), and the removal and inspection of the electrochemical cell was rather simple with only 1-6 cells. With stainless steel piping and up to 55 cell pairs, the operators of the full-scale system will not have the liberties that smaller demonstration units provide. There is some concern in the ability to manage energetic slurries at up to 20% energetics concentration. During demonstration, energetics slurry concentrations up to 30% may have been added to the anolyte vessel, clearly showing that accidental energetics feeds of greater than 20% are possible. Effective process control is also critical to the success of the MPT/BRT/condensate recycle/catalytic oxidation operation, but it is understood that operability and control issues are being resolved in the existing EDS.

The greatest concern for this factor is the predicted troubles in controlling the overall process, potentially jeopardizing the stable treatment of all process feeds. Although the control software for the SILVER II demonstration units was designed as operator-friendly and was clearly labeled, it was still quite complicated. The complexity was simply due to the sheer number of items to be checked and controlled on each screen, and it was difficult to operate the system without significant training and hands-on experience. Extensive complexity will be involved with operating multiple simultaneous SILVER II units at full scale. All flow rates must be stabilized at optimum set points so as to not imbalance the steady-state system. The SILVER II units alone require careful control between the anolyte, catholyte, and NOx reformer circuits. Operation of the generic SILVER II processes will be complicated by addition of the AIRS and the EIRS, catholyte to anolyte recycles, and SILVER II treatment of BRT and MPT condensates. While the slow reacting system has some advantages in regard to safe, stable reaction conditions, the changing of just one or two independent parameters at any point within the interdependent process has the potential of producing changing conditions at multiple locations, making the system difficult to restabilize.

In summary, off-the-shelf instrumentation is available for monitoring and control of SILVER II. The process operates at an inherent slow pace where the system can react to changing conditions. However, the complexity of the full-scale system, requiring simultaneous operation of many interdependent units, may make the system difficult to monitor and control.

C.4.1.2.1.7 Applicability

The proposed process is capable of demilitarizing all ACWs at all sites.

C.4.1.2.2 Safety/Worker Health and Safety

C.4.1.2.2.1 Design or Normal Facility Occupational Impacts

The SILVER II system operation for processing agent and energetics occurs at ambient pressure and at relatively low temperature (190°F), thus minimizing hazards associated with high pressure or high temperature operations.[69] All process materials for SILVER II are commonly used in industry and can be handled in accordance with well-established industrial safety practices. SILVER II also forms some hazardous intermediate products, including TNB (which is explosive when dry or less than 30% water by weight) and HF (formed during GB processing), which is acutely toxic and corrosive to the skin. The remote nature[i] of SILVER II operations generally protects workers from chemical and physical hazards associated with normal operations. Worker exposure to process materials and equipment is primarily associated with maintenance activities. Some maintenance activities could take place in areas subject to strong electromagnetic fields, presenting a hazard to workers with pacemakers. The technology provider's Draft Final Technical Report provided very little information regarding maintenance activities anticipated to support process operations.[70] SILVER II is energy-dependent, and it is not likely to cascade out of control during upset conditions. The compounds associated with the process did not interfere with standard monitoring techniques for chemical agent.

There are seven major hazardous process chemicals used in large quantities: sodium hydroxide, nitric acid, sodium hypochlorite, HCl, calcium oxide, silver nitrate, and liquid oxygen. All of

[i] Unattended by personnel during operations

these chemicals pose some routine exposure risk to workers during feed preparation and maintenance of process equipment. The corrosive nature of sodium hydroxide, nitric acid, and HCl increases the likelihood for leakage within the system. Normal SILVER II operations involve a modest accumulation of chemical agent (up to 150 gal.) and a very large accumulation of energetics (up to 1,500 lb of M55 rocket propellant).[71] This buffering of large quantities of energetics is to allow for munitions disassembly operations to take place 12 hours per day, yet allowing agent and energetics processing to continue 24 hours per day. In the full-scale plant design, the energetics holding tanks will be located within an explosive containment. The composition of the energetics slurry needs to be monitored and controlled to ensure a slurry consistency that can be held and transported safely within the system, and to preclude any settling or accumulation of energetic materials within the system piping. The risks of handling hazardous materials are minimized with appropriate engineering design, remote operations, and process monitoring and control.[72]

In summary, the inherent risks associated with the hazardous chemicals in the process and the very large accumulation of energetic materials impact the safety of normal facility operations. Nevertheless, these risks should be minimized with appropriate engineering design and personal protective equipment.

C.4.1.2.2.2 Facility Accidents with Worker Impact

Agent and energetics destruction systems operate at ambient pressure and at relatively low temperature (190°F), thus minimizing hazards associated with high pressure or high temperature operations. All process materials are commonly used in industry and can be handled in accordance with well-established industrial safety practices. Since the remote nature of SILVER II protects workers from chemical and physical hazards associated with accidents during operation, worker exposure to process materials and equipment is generally limited to maintenance. SILVER II is energy-dependent, and it is not likely to cascade out of control during upset conditions. SILVER II forms some hazardous intermediate products, including TNB and HF. However, minimal amounts of explosive or flammable gases are produced. Hydrogen is produced at levels of 0.01–0.2%, resulting in a gas stream well below explosive limits.

Several accident initiators are associated with various process conditions that could result in worker injury from the accident itself or from the subsequent exposure to agent or hazardous chemicals. Processing of GB produces HF as an intermediate product, which is acutely toxic and corrosive to the skin if contacted during maintenance or repair activities.[73] Some maintenance activities could take place in areas subject to strong electromagnetic fields, presenting a hazard to workers with pacemakers.[74] The water pump for the fluid-abrasive cutting process operates at very high pressure (50,000 PSI). The MPT and the BRT operate at extremely high temperature (>1,000°F),[75] and could result in contact burns to operators unloading the treaters if not allowed to cool down properly prior to maintenance. Similarly, stored liquid oxygen represents a thermal (cold) hazard and it should not be allowed to contact organic substances because of increased combustion risk. However, these risks are minimized with appropriate engineering design and personal protective equipment and by procedures that ensure the review and approval of maintenance practices.

Although propellant grinding operations have been successfully demonstrated industrially for some types of propellant, the ability to safely grind M28 propellant has not yet been safely demonstrated.

There are seven major hazardous process chemicals used in SILVER II in large quantities: sodium hydroxide, nitric acid, sodium hypochlorite, HCl, calcium oxide, silver nitrate, and liquid oxygen. The corrosive nature of sodium hydroxide, nitric acid, and HCl increases the likelihood for leakage within the system. Leakage and subsequent drying/evaporation of process streams containing explosive materials could lead to formation of sensitive explosive crystals. Normal SILVER II operations involve modest accumulation of chemical agent (up to 150 gal.) and a very large accumulation of energetics (up to 1,500 lb of M55 rocket propellant). The composition of the energetics slurry needs to be monitored and controlled to ensure a consistency that can be held and transported safely within the system, and to preclude any settling or accumulation of energetic materials within the system piping. Proposed modifications to eliminate settling and enhance control of energetic concentrations could significantly mitigate this risk. The demonstration testing of SILVER II has identified the possible formation of solid intermediate products, some of which may be difficult to further degrade, and which could lead to blockages within the system.

In summary, the possible accumulation of explosive materials within the system, coupled with the potential for explosive crystal formation from leaks or isolated system segments, represents a potentially hazardous situation for the worker during maintenance on the SILVER II system. Nevertheless, these risks should be minimized with appropriate engineering design and personal protective equipment and by procedures that ensure the review and approval of maintenance practices.

C.4.1.2.2.3 Facility Accidents with Public Impact

Although SILVER II uses large quantities of hazardous chemicals, these materials are not highly volatile and only have low to moderate toxicity and persistency. All of the process materials are commonly used in industry and can be handled in accordance with well-established industrial safety practices. Proposed use of a catalytic oxidation system, followed by HT&R to monitor for agents in the process gas effluent, should significantly reduce the potential for release of agents or other hazardous materials to the public.[76] Commercial monitoring equipment for agents and other hazardous materials can be used in SILVER II. Agent and energetics destruction systems operate at ambient pressure, eliminating hazards associated with high-pressure operations. The primary destruction process is not likely to cascade out of control during upset conditions. Total containment[i] in the event of an accident or explosion is provided, mostly at the facility level.

In general, the safeguards, monitoring, and controls that minimize worker impact in the event of a facility accident are similarly beneficial with respect to public impact. These provisions mitigate the risk of accidental release of process chemicals that are stored in large quantities and could otherwise be dispersed to the public. SILVER II does include the accumulation of very large quantities of energetics (up to 1,500 lb of M55 rocket propellant) to allow for munitions disassembly operations to take place 12 hours per day, yet allowing agent and energetics processing to continue 24 hours per day. However, in the full-scale plant design, the energetics

[i] Total containment is both vapor and explosion containment. Explosion containment is achieved by explosive hardened structures.

holding tanks will be located within an explosive containment structure to ensure public safety. Energetics accessing and propellant grinding operations will also take place within the explosive containment structure. For energetics being fed into the process, the composition of the energetics slurry needs to be monitored and controlled to ensure a consistency that can be held and transported safely within the system, and to preclude any settling and accumulation of energetic materials within the system piping. Even if an accident were to occur during operations, public impact would be minimized or eliminated since several layers of system and facility secondary containment should efficiently mitigate and contain the effects and prevent public exposure.

C.4.1.2.2.4 Off-Site Transportation Accidents

SILVER II uses eight hazardous process chemicals: sodium hydroxide, nitric acid, sodium hypochlorite, HCl, calcium oxide, silver nitrate, liquid oxygen, and liquid nitrogen. Silver nitrate is classified by the Department of Transportation (DOT) as an oxidizer;[77] liquid oxygen is an oxidizer and forms a non-flammable gas;[78] nitric acid, sodium hypochlorite, HCl, calcium oxide, and sodium hydroxide are corrosive;[79] and liquid nitrogen forms a non-flammable gas.[80] Of these chemicals, none are carcinogenic. The chemicals pose relatively low hazard to nearby populations or workers in the event of a transportation accident. However, the total volume of both process and waste-stream materials is expected to be high relative to the amount of agent being processed. Proposed off-site recycling of AgCl would additionally increase the volume of waste stream materials transported.

All solids are treated to 5X (indicates that an item has been decontaminated completely of agent and may be released for general use or sold to the general public) before shipment offsite for disposal or recycle/recovery.

Standard hazardous materials (HAZMAT) and fire department PPE, containment equipment, and techniques should be sufficient to contain any spills. Evacuation zones would be less than 100 yards for spills involving HCl or calcium oxide, while spills of the remaining materials used in the process would require evacuation areas of only 30-50 yards.[81] No special training beyond Occupational Safety & Health Association (OSHA) HAZMAT and DOT requirements is needed. In summary, this technology poses very little risk of a serious accident affecting the public.

C.4.1.2.3 Human Health and Environment

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

All waste streams generated during demonstration were characterized and proposed full-scale disposal options were specified for all waste streams. Comp B waste streams were not characterized because Comp B demonstration testing was eliminated due to schedule constraints. SILVER II produces multiple waste streams with high concentrations of acids, metals, and organics that are to be disposed of by highly specific disposal methods. These methods include discharge to a Publicly Owned Treatment Works (POTW) for the water effluent and a RCRA approved Treatment, Storage, and Disposal (TSD) facility for various solid wastes. The availability or acceptability of these disposal methods was not identified by the technology provider and uncertainties regarding the implementation of these plans were identified.

All process gaseous effluents undergo HT&R prior to discharge,[82] however only a conceptual HT&R plan was provided.[83]

Emission estimates for NOx, SOx, and CO were provided[84] and based on the estimates it does not appear that the total solution will be classified as a Major Source under the Clean Air Act. CO emissions (based on demonstration data) are estimated at 180 tons per year before treatment by catalytic oxidation, which is expected to oxidize most of the CO to CO_2. Hazardous Air Pollutants (HAPS) emissions are well below regulatory limits for Major Source classification under the National Emissions Standards for Hazardous Air Pollutants (NESHAPS).[85] HD, VX, and GB were not detected in any scrubber off gas sample above detection limits. Based on demonstrated equipment, permits will be required for final discharge streams, but anticipated discharge limitations can be met with demonstrated controls.

The proposed total solution includes the discharge of liquid effluent, consisting primarily of the dilute nitric acid waste stream. The characterization of this stream during demonstration indicated that there are low concentrations of some organics in this effluent. HD, VX, and GB were not detected in the dilute acid from the reformer above the detection limit. The technology provider's plan is to discharge this effluent into a POTW capable of accepting the dilute nitric acid waste stream under a pretreatment exemption. The availability of such a POTW with a pretreatment program in place was not identified for either installation; however, other disposal options for this waste stream were determined to be available. Further water treatment would be required for NPDES permitted discharge of this waste stream; this exigency was not discussed.

Offsite recycling/recovery is proposed for two effluent streams. Concentrated nitric acid is stated to be acceptable to Ensign-Bickford[86] for use in the production of energetics. AgCl precipitate (produced during mustard destruction) is collected and treated to 5X. This waste stream is then shipped offsite for silver recovery. The technology provider's report states that Ames Goldsmith[87] will accept this waste stream. Additionally, the technology provider states that significant volume reductions are achieved, solid wastes requiring offsite disposal are 1/10th of the weight of waste treated.[88] These solid wastes include dunnage, spent carbon, garnet grit, DPE, and S&F containers, and will be treated to 5X in the MPT or BRT and then disposed of off-site in a RCRA TSD facility. The anolyte and scrubber filters and the 5X solids were analyzed for Toxicity Characteristic Leaching Procedure (TCLP) characteristics (SVOC, VOC, and metals) and the results reported to date do not indicate any target compounds at or above their regulatory threshold limits.

The AIRS produces an evaporator bottoms solid waste stream that is to be containerized and sent to a RCRA TSD. The AIRS was not tested during demonstration. The unit operations for treating this process stream and resultant wastes were not tested and data representative of these waste streams could not be collected. The proposed full-scale design of the AIRS will draw process fluids from the anolyte vessel. During demonstration, agent was detected in mid run samples from the anolyte vessel at low PPM concentrations. Therefore, there will be low concentrations of agent entering the AIRS. It is not known where the agent decomposition and destruction will be among the various processes in the various unit operations (two 5X units, distillation, evaporation).[89] While no agent will remain in the evaporator bottoms waste stream, treatment and disposal options for this waste stream are not fully resolvable at this time.

Sampling and analysis methodologies for determining residual compounds of concern (energetic breakdown products and regulated toxic substances) were generally validated and verified. This included metals, mercury, dioxins/furans, SVOCs, VOCs, and TOC. All methods used for determining residual levels of energetics were verified to perform adequately during demonstration by providing a high proportion of usable data.[90]

C.4.1.2.3.2 Completeness of Effluent Characterization

The composition of all demonstrated effluents was sufficiently validated and verified, including a mass balance as well as residual compounds of concern (energetic breakdown products and regulated toxic substances). This included metals, mercury, dioxins/furans, SVOCs, VOCs, and TOC. All methods used for determining residual levels of energetics were verified to perform adequately during demonstration by providing a high proportion of usable data.[91]

The mass balance for Comp B was not validated during demonstration. However, laboratory testing of Comp B components by the technology provider does support the mass balance that was provided.

C.4.1.2.3.3 Effluent Management Strategy

The technology provider presents a detailed plan with specific disposal or recycling strategies for each of the waste streams. The plan is dependent on the availability of a POTW capable of accepting the dilute nitric acid waste stream under a pretreatment exemption. This availability was not confirmed. The plan also assumes off-site acceptance of the evaporator bottoms by a RCRA TSD, however this was not confirmed.

The AIRS produces an evaporator bottoms solid waste stream that is to be containerized and sent to a RCRA TSD. The AIRS was not tested during demonstration. The unit operations for treating this process stream and resultant wastes were not tested and data representative of these waste streams could not be collected. The proposed full-scale design of the AIRS will draw process fluids from the anolyte vessel. During demonstration, agent was detected in mid run samples from the anolyte vessel at low PPM concentrations. Therefore, there will be low concentrations of agent entering the AIRS. It is not known where the agent decomposition and destruction will be among the various processes in the various unit operations (two 5X units, distillation, evaporation).[92] While no agent will remain in the evaporator bottoms waste stream, treatment and disposal options for this waste stream are not fully resolvable at this time.

Solid wastes including dunnage, spent carbon, garnet, DPE, and S&F containers will be treated to 5X in the MPT or BRT and then disposed of off-site in a RCRA TSD facility. AgCl is to be processed off-site for silver recovery.[93] The technology provider's report states that Ames Goldsmith will accept this waste stream.[94] Concentrated nitric acid is stated to be acceptable to Ensign-Bickford[95] for use in the production of energetics. However, the predicted near azeotropic concentrations were not produced during demonstration.

All process gaseous effluents undergo HT&R,[96] however only a conceptual HT&R plan was provided.[97]

The technology provider proposes to route treated effluent from a packaged batch fluoride treatment system, cooling tower blowdown, water softener, boiler blowdown, and sanitary wastewater to either a POTW or an on-site wastewater treatment plant.[98] At the sites being considered for an ACWA facility, a sanitary wastewater plant is neither provided nor planned to support a demilitarization facility. Generally, processing industrial wastewater treatments has not been considered in this technical evaluation; additional investigation on the ability to receive SILVER II wastewaters is needed. This may be a particular problem (though the fluoride waste stream will not be an issue) at Pueblo, where a zero-discharge wastewater treatment plant is currently planned.

AEAT has experience in handling a wide variety of munitions but not the entire weapon configurations found in the U.S. chemical stockpile. However, CH2MHill has a high degree of familiarity with the chemical demilitarization program. AEAT has no experience with the management of waste streams from chemical weapons destruction in the US; however, CH2MHill has extensive relevant permit writing experience with the Stockpile Disposal Program.[99] At the present time, AEAT has no commercial applications of SILVER II.[100]

Gases undergo HT&R. The proposed design of this system could not be fully evaluated due to a lack of details.[101]

In summary, the technology provider presented a very detailed effluent management strategy with all waste streams characterized and proposed disposal specified. However, dependence on POTW and RCRA TSD acceptance of wastes was not confirmed and uncertainties in the implementation of these plans were identified. The AIRS and the EIRS were not demonstrated and could not be conclusively evaluated due to lack of detail. Despite these uncertainties, analysis indicates that effluents appear treatable and disposable.

C.4.1.2.3.4 Resource Requirements

The design included order of magnitude estimates for resource consumption. The proposed total solution uses the same footprint as the baseline plant. No other special land use requirements are proposed. Specific water and energy requirements could not be quantitatively verified from the technology provider’s report; however, a qualitative assessment has determined that no unusual requirements are anticipated.

C.4.1.2.3.5 Environmental Compliance and Permitting

SILVER II is expected to meet regulatory acceptance, however SILVER II has no U.S. permits. CH2MHill has extensive chemical demilitarization permitting experience. The permitting strategy includes discussion of air effluent HT&R. Most liquid wastes are proposed to meet standards for discharge into a POTW. Silver salts are expected to have the silver content recovered for reuse and all 5X metal is recycled. Evaporator bottoms may need neutralization/stabilization.

Although there are no unusual issues associated with this technology, the permitting strategy has not yet been fully defined. Unlike the other alternative treatment technologies, the SILVER II technology provider proposes to discharge liquid to a POTW, which requires additional permitting not addressed by the technology provider.

C.4.1.2.4 Potential for Implementation

In order to evaluate the cost and schedule portions of the Potential for Implementation criteria, the total capital cost and schedule for Blue Grass were developed using the approach discussed in Attachment C-D. Using this same approach and information obtained from PMCD, the total capital cost and schedule were estimated for baseline incineration at Blue Grass. A preliminary comparison between this alternative technology and baseline incineration with respect to total capital cost and schedule was made. In addition, a qualitative assessment of operating and maintenance cost was conducted and was compared to those of baseline incineration. Cost and schedule were not evaluated for Pueblo due to Public Law 106-398, which precludes consideration of technologies at Pueblo that were demonstrated after 1 May 2000.

The final 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). Integrated Process Teams have been established within the Department of Defense as part of the Defense Acquisition Executive 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*
>
> *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

The potential for Public Acceptance was evaluated by the ACWA Dialogue and the results presented to PMACWA at the Dialogue meeting in Lexington, KY on 25-26 January 2001.

C.4.1.2.4.1 Cost

The estimated total capital cost for SILVER II as proposed by the technology provider for Blue Grass is comparable to that for baseline incineration:

- Blue Grass: SILVER II total capital cost is approximately equal to that of baseline incineration.

Table C.4-2. Total Capital Cost Estimate for SILVER II—Blue Grass

SILVER II	Blue Grass Total Capital Cost ($Millions)
Installed Core Process Equipment	186
Installed Baseline Equipment Additions	54
Total Installed Equipment Cost	**240**
Buildings and Support Facilities	269
Total Capital Cost	**509**

It is interesting to note that nearly 55% of the total capital cost for SILVER II is attributed to equipment and buildings common to baseline incineration and the other alternative technology demonstrations evaluated in Section C.4.2 of this report.

Sufficient information currently does not exist to make a reasonable estimate of SILVER II operating and maintenance (O&M) cost. However, based upon a review of SILVER II, it was independently estimated that the O&M labor requirements for this alternative technology would be slightly greater than for baseline incineration. This is because the operating time for demilitarization of the stockpile at Blue Grass is nearly 33 months verses 22 months for baseline incineration. Furthermore, since O&M labor requirements account for 65 to 70% of the total O&M cost for baseline, it is likely that the total O&M cost for SILVER II will be slightly greater than that for baseline. Since no extraordinary chemical usage or utility requirements are anticipated for SILVER II, the increased O&M cost for this technology over baseline incineration is due primarily to maintaining a considerable labor force onsite for nearly a year of operation longer than baseline incineration.

C.4.1.2.4.2 Schedule

The basic schedule assumptions, key milestone activities, and key activity duration periods are given in Attachments B-D and summarized below:

- The Kentucky Statute (revised in July 2000) allows for alternative technologies demonstrated under the PMACWA program to be considered at Blue Grass.

- The Demonstration II technologies must be validated by PMACWA in order to enter the EDS Phase. The objectives of the EDS are to:

    - Support the certification decision of the Under Secretary of Defense for Acquisition, Technologies & Logistics as directed in PL 105-261 with respect to a Full-Scale Facility Total Life Cycle Cost, Schedule, and Safety

    - Support NEPA documentation and RCRA permit application

    - Support contract RFP for a full-scale pilot plant facility.

- PMACWA and PMCD are preparing separate Environmental Impact Statements (EIS) and each will have a Record of Decision (ROD). The PMACWA Programmatic EIS will be comparing the PMACWA-validated alternative technologies. The PMCD Site Specific EIS for Blue Grass will be evaluating the incineration technologies along with the PMACWA-validated alternative technologies. The Department of Defense (DOD) will review both RODs and approve a Technology Decision for Blue Grass.

- The draft acquisition strategy for alternative technologies at Blue Grass utilizes a "Dual Contract Approach"[i]:

  - Contractor A, from an initial solicitation, is responsible for completing the facility design, constructing, operating and closing the facility and providing support to Contractor B during training, systemization and pilot testing.

  - Contractor B, from a follow-on solicitation, is responsible for completing the core process technology design, procuring/fabricating core process technology specific equipment, training, systemization, pilot testing and providing support to Contractor A during facility operations and closure.

- Contracting:

  - Contract A RFP Release occurs prior to DOD Technology Decision.

  - Contract A Award occurs immediately following DOD Technology Decision.

  - Contract B RFP Release occurs as soon as possible after DOD Technology Decision (allowing 6 months for proposal preparation and evaluation).

- Permitting:

  - The RCRA Part B Application can be submitted within four months of DOD Technology Decision (based on current experience that EDS Engineering Packages are sufficient for preparing RCRA Part B Application).

  - The RCRA Part B Permit will be issued 15 months after submittal of the application.

- Construction/Operations:

  (1) Munitions Demilitarization Building (MDB) construction (the single most important critical path item) begins upon RCRA Part B approval.

  (2) 16-month Initial Systemization

  (3) 5-month Pilot Testing

  (4) 5-month Design/Equipment Modifications

[i] Subsequent to this analysis, the Dual Contract Approach was eliminated; this change in contracting approach is not expected to substantially alter the estimated completion date.

(5) 6-month Final Systemization

Based on the above, the key milestones and corresponding dates are summarized in Table C.4-3 for Blue Grass.

As indicated in the table, the schedule developed for the demilitarization of ACWs utilizing SILVER II estimates the following date for completion of operations:

- Blue Grass: February 2012

The implementation schedule for SILVER II indicates that demilitarization operations are not completed until after the CWC date of 29 April 2007; however, demilitarization operations for SILVER II are estimated to likely be completed within the possible 5-year CWC Treaty extension.

C.4.1.2.4.3 Public Acceptance

As discussed in the report to which this evaluation is appended, based on the full consensus of the Dialogue, the SILVER II process was deemed likely to obtain public acceptability.

C.4.2 Foster Wheeler/Eco Logic/Kvaerner Neutralization/GPCR/TW-SCWO

This section of the technical evaluation report covers the description and evaluation of the technology proposed to PMACWA by the Foster Wheeler (FW)/Eco Logic International (ELI)/Kvaerner team (FW-ELI-K).

Foster Wheeler, Eco Logic, and Kvaerner were originally part of a larger team, under the coordination of Lockheed Martin, when the original Neutralization/GPCR/TW-SCWO process was submitted in 1997. Foster Wheeler and Eco Logic contributed the two unique individual components to the Lockheed Martin total solution package; namely, the transpiring-wall supercritical water oxidation (TW-SCWO) and Gas-Phase Chemical Reduction (GPCR™) systems respectively. After PMACWA chose the three other technology providers for the Demonstration I in 1999, the formal Lockheed Martin teaming agreement dissolved. When PMACWA received additional funding and the Congressional mandate to test the three remaining technology providers in 2000, Foster Wheeler and Eco Logic were both willing to demonstrate their respective technologies without Lockheed Martin's involvement. They also agreed to retain their original association and the combination of their individual technologies as part of an overall total solution package. To help in this effort, another former Lockheed Martin team member, Kvaerner Process Services, Inc. (Kvaerner), was retained to continue its original role of developing the overall total solution design. Kvaerner is responsible for incorporating test data from the demonstration of Foster Wheeler and Eco Logic's unit operations into the total solution design. Thus, Foster Wheeler, Eco Logic, and Kvaerner together represent a single technology provider.

Table C.4-3. Implementation Schedule for SILVER II–Blue Grass

Key Milestones	Date
Publication of Notice of Intent–PMACWA	April 2000
Publication of Notice of Intent–PMCD	December 2000
Start of EDS Testing	April 2001
DOD Technology Certification	March 2002
PMACWA Programmatic EIS Submittal	July 2001
PMACWA Programmatic ROD Submittal	August 2001
PMCD Site-Specific EIS Submittal	March 2002
PMCD Site-specific ROD Submittal	April 2002
DOD Technology Decision	April 2002
Contract A (Site Infrastructure and Non-Technology Specific Buildings) RFP Release[i]	September 2001
Contract Award for Contract A[i]	June 2002
Contract B (Core Process Technology) RFP Release[i]	April 2002
Contract Award for Contractor B[i]	October 2002
RCRA Part B and Clean Air Act Permits Submittal	August 2002
RCRA Part B and Clean Air Act Permits Approval	November 2003
MDB Construction Start	November 2003
MDB Construction Completion	September 2006
Systemization/Pilot Test Start	September 2006
Systemization/Pilot Test Completion	June 2008
Design and Equipment Modification/Final Systemization Start	June 2008
Design and Equipment Modification/Final Systemization Completion	May 2009
Operations Start	May 2009
Operations Completion	February 2012

[i] Subsequent to this analysis, the Dual Contract Approach was eliminated; this change in contracting approach is not expected to substantially alter the estimated completion date.

C.4.2.1 Description of the Proposed Technology

The process uses modified baseline reverse assembly to access agent and energetics that are neutralized by sodium hydroxide (caustic) or water hydrolysis followed by SCWO. Hardware, solids (included secondary wastes), and gases are thermally treated.

The current process has somewhat different pre-treatment operations from that proposed during the initial ACWA demonstration selection phase[102] because of subsequent technology development and enhancement.

C.4.2.1.1 ACWA Total Solution

See Figure C.4-2 for a process flow diagram of Neutralization/GPCR/TW-SCWO.

<u>Pre-Treatment</u>

Neutralization/GPCR/TW-SCWO uses parts of baseline reverse assembly, but modified, for ACW pre-treatment. The explosive train is removed from projectiles and the explosive components are accessed using the baseline PMD. Bursters are sheared into 1-inch long sections by the baseline Burster Size Reduction machine (modified RSM). The Projectile Punch Machine (PPM) accesses projectile agent cavities by punching 1-inch holes, 180° apart, one at each end, through the sidewall into the agent reservoir of the projectiles. The agent is gravity drained from the projectiles and a water spray washes the agent reservoir. The projectiles are then placed in a bin for thermal treatment.

Rockets are accessed using a modified baseline RSM (MRSM). The baseline RDS punches and drains rockets, one rocket shear station (RSS) shears the fuzes, and another RSS then shears the rocket body into sections. Following punch and drain, a tube cutter cuts off the S&F container and the fin assembly is unscrewed from the rocket motor to access the propellant grain. The M28 propellant grain is pulled out of the motor case in its entirety and size reduced with a wet grinder into a slurry. Slurried energetic material from the ACW (20% by weight) transfers to a number of holding tanks for feed to neutralization. Agent and spray wash water transfer to a buffer area is similar to the baseline TOX.

Energetics, any residual agent, and aluminum in the ACW hardware are partially hydrolyzed and dissolved in the Continuously Indexing Neutralization System (COINS™)[i]. COINS transfers hardware in hanging baskets through an agitated caustic dip tank followed by spray washing. The washed hardware is dumped into bins for thermal treatment. COINS liquid effluent is screened, with undissolved solids sent to thermal treatment and the liquid continuing to neutralization.

[i] Although some hydrolysis occurs in the COINS, it is considered a pre-treatment operation because verification of destruction occurs in the neutralization process.

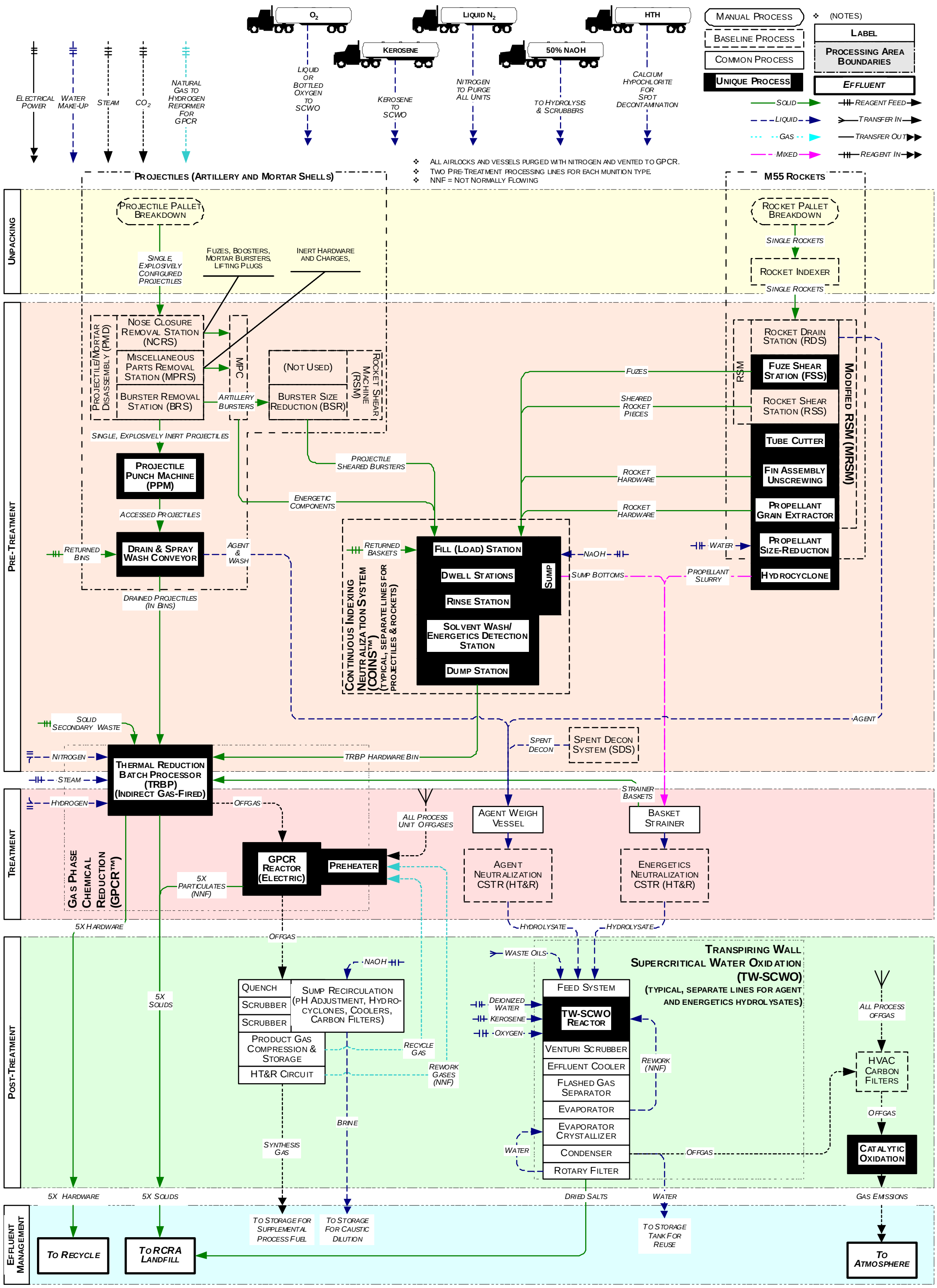

Figure C.4-2. FW-ELI-K Neutralization/GPCR/TW-SCWO Process Flow Diagram

Treatment

Hydrolysis (reaction with water or sodium hydroxide), similar to the Army's Alternative Technologies & Approaches Project (ATAP) process, neutralizes agents and energetics in CSTRs. Drained agent and wash water are treated in the Agent Hydrolysis process, liquid from the COINS is treated in the Energetics Hydrolysis process, and slurried propellant is treated in the Propellant Hydrolysis process.

GPCR treats all solids (from pre-treatment and secondary wastes) and all pre-treatment and treatment offgas. GPCR is a thermal (1,560°F [850°C]) system, using hydrogen in a steam atmosphere to reduce organics into methane, CO_2, CO, and acid gases. GPCR consists of the Thermal Reduction Batch Processor (TRBP) integrated with a reactor. The TRBP is an indirect, flame heated batch evaporator oven that volatilizes material to the main reactor, which is an electrically heated cyclone. The TRBP thermally treats solids to a 5X decontamination level[i] (thorough heat soak for at least 15 minutes at 1,000°F [538°C]).

Post-Treatment

TW-SCWO represents the main post-treatment technology, processing the pH-adjusted hydrolysates from neutralization. SCWO uses water above its critical point (705°F [374°C] and 3,205 PSI [22,100 kPa]) to mineralize organics. TW-SCWO is a unique type of SCWO that uses a barrier of clean water on the inside wall of the reactor to minimize corrosion and solids buildup. The barrier forms by continuously pumping water through a perforated liner in the reactor. Liquid effluent from TW-SCWO is cooled for further processing.

Post-treatment of offgas from GPCR uses a caustic scrubber system with a combination of pH adjustment, hydrocyclones, and carbon filters to cleanse the brine. All other process offgas is carbon filtered and sent to a catalytic oxidation system before release to the atmosphere.

Effluent Management

Solids from the GPCR gas scrubber are collected in drums, the liquid is used to dilute caustic for plant use, and the offgas undergoes HT&R followed by burning as supplemental fuel in the process. Evaporation, crystallization, and filtration concentrates solid salts from the TW-SCWO brine effluent, which are then containerized for landfill. The remaining liquid is recycled to the process. Water used by the TW-SCWO is demineralized and deionized. 5X metals are recycled and 5X solids are landfilled.

C.4.2.1.2 Unit Operations Not Demonstrated in Demonstration II

As discussed previously in Section C.3.3, baseline reverse assembly, carbon filtration, and the BRA were not demonstrated. Other unit operations proposed by FW-ELI-K were also not selected for demonstration. The reasons that PMACWA elected not to demonstrate certain unit operations proposed by FW-ELI-K are as follows:

[i] Toxic Chemical Agent Safety Standards, Army Pamphlet 385-61, 31 March 1997. 5X (XXXXX) indicates that an item has been decontaminated completely of agent and may be released for general use or sold to the public.

- **Projectile Accessing**
  - **Punch Machine—**The PPM is a new addition to the proposed full-scale process, incorporated after Demonstration II was conducted.
  - **Projectile Burster Washout—**This operation is substantially similar to the burster washout technology previously validated by PMACWA in Demonstration I.[103]
- **Rocket Accessing**
  - **Modified Rocket Shear Machine—**The MRSM is a new addition to the proposed full-scale process, incorporated after Demonstration II was conducted. It is also based on the existing baseline RSM process.
  - **Propellant Grinding—**Several ACWA technologies will require size reduction of M28 propellant. PMACWA has therefore elected to conduct a single design study to address this requirement for these technologies.
- **COINS—**Originally, during the initial preparations for Demonstration I in 1998, the Lockheed-Martin team (see Section C.4.2) had proposed to demonstrate caustic hydrolysis of energetic materials contained in fuzes, bursters, and propellant from rockets and projectiles. However, after the reforming of the FW-ELI-K team in late 1999, PMACWA decided to discontinue the demonstration of caustic hydrolysis based on the success of Demonstration I. Data gathered during PMACWA's Demonstration I activities demonstrated the Energetic Rotary Hydrolyzer system,[104] and the batch energetics hydrolysis at Pantex and the Radford Army Ammunition Plant.[105] These technologies validated energetics hydrolysis, which is the underlying technology for COINS.

C.4.2.1.3 Unit Operations Demonstrated

This section explains the rationale for selecting the Neutralization/GPCR/TW-SCWO demonstration unit operations, the objectives of testing, and the significant deviations from the planned testing.

C.4.2.1.3.1 Agent Hydrolysis

The Army has previously demonstrated agent hydrolysis extensively during the ATAP. During Demonstration I and Demonstration II, PMACWA ran agent hydrolysis units to provide representative feed stock for TW-SCWO and to characterize the intermediate product stream for residual agent, for Schedule 2 compounds, and for other substances required to verify the mass balance.

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

- Use the hydrolysate recipes developed and tested by ECBC.
- Characterize solid and liquid process streams.
- Provide agent hydrolysate in support of demonstration testing.

During Demonstration I, approximately 9,750 lb of hydrolysates from 7.2% GB in 5% caustic and 4,300 lb of hydrolysates from 30.1% VX in 20% caustic were produced in the 100-gallon batch reactor at CAMDS. The design and manufacture of a hydrolysis system provided information on equipment and operational parameters for use in scale-up to a full-scale facility.[106] Approximately 584 lb of VX hydrolysate and 1,911 lb of GB hydrolysate remaining from Demonstration I were shipped to DPG for the TW-SCWO demonstration.

For Demonstration II, approximately 4,250 lb of 15% HD hydrolysate were produced in a campaign of 16 batch runs at ECBC at the Edgewood Area of APG, Maryland. The equipment used was not intended to model scale-up to a full-scale facility, but was an expedient design suitable for use in the contained environment of ECBC's Chemical Transfer Facility (CTF). Approximately 2,200 lb of the HD hydrolysate were shipped to DPG for the TW-SCWO demonstration.[107]

C.4.2.1.3.2 Energetics Hydrolysis

Other government agencies (including the Department of Energy) have previously demonstrated energetics hydrolysis; energetics hydrolysis was also demonstrated during Demonstration I for a variety of feedstocks.[108] Hydrolysis of M28 propellant, Comp B, and Tetrytol (using 6% or 12% caustic) was validated during Demonstration I.

During Demonstration II, feedstocks were similarly required for the TW-SCWO testing. 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

Approximately 4,300 lb of hydrolysate from 16.7% Tetrytol in 12% caustic and 4,065 lb of hydrolysate from 16.7% Cyclotol[i] in 12% caustic were produced at Pantex Plant, Amarillo, Texas. Approximately 29 lb of the Tetrytol hydrolysate and 646 lb of the Cyclotol hydrolysate were shipped to DPG for the TW-SCWO demonstration. Cyclotol was an alternate for Comp B since it contains roughly similar amounts of RDX and TNT.

Radford Army Ammunition Plant (RAAP), Radford, Virginia produced approximately 18,000 lb of hydrolysate from 16.7% M28 propellant in 12% caustic. 1,990 lb of M28 propellant hydrolysate were shipped to DPG for the TW-SCWO demonstration.

C.4.2.1.3.3 TW-SCWO Energetics/Agent Hydrolysate

The basic ability of SCWO to destroy agent and energetics hydrolysates separately had been demonstrated previously during Demonstration I.[109] TW-SCWO was demonstrated to validate the effectiveness of the unit for the treatment of a combined hydrolysate of agent and energetics. The TW-SCWO unit was demonstrated at Building 4165 at DPG, Utah.

[i] Cyclotol contains 70% RDX and 30% TNT, levels roughly similar to Comp B (60% RDX, 39% TNT, 1% wax).

The TW-SCWO reactor mixes feed materials, water, oxidant, and fuel under supercritical conditions. At supercritical conditions, these four materials are completely miscible and form a single phase with physical properties (high density, low viscosity) that are conducive to rapid oxidation. The transpiring-wall SCWO reactor is designed to protect the walls from plugging and corrosion. Clean, high-pressure water is pumped through passages in the wall and is metered through thousands of injection points in the perforated liner. The injected water forms a barrier between the liner and reaction products flowing through the reactor. Near the exit of the reactor, water at 60°F (15°C) is injected into the reactor to rapidly quench the effluent to 600°F (315°C). This causes most precipitated salts exiting the reactor to re-dissolve in the water. The quenched effluent is then depressurized, cooled, and enters a flash gas separator. Gaseous effluents are scrubbed in carbon filters and released to the atmosphere. Liquid effluents containing soluble and insoluble salts and metal oxides are collected and analyzed. The demonstrated TW-SCWO operated with a hydrolysate feed rate of 60 lb/hr with 46-87 lb/hr of auxiliary fuel added (depending on the feed) to increase the heating value of the feed.

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 long-term, continuous operability of TW-SCWO with respect to: salt plugging and corrosion in the reactor, effects of operation on the transpiring wall liner, and erosion of the pressure control valve.

- Determine if aluminum compounds from the energetic hydrolysis process can be processed by TW-SCWO without causing plugging.

- Demonstrate the ability of TW-SCWO to destroy Schedule 2 compounds present in the hydrolysate feed.

- Characterize the gas, liquid, and solid process streams from TW-SCWO.

Four different mixes of agent hydrolysate simulant or mixed agent/energetics hydrolysate were processed through TW-SCWO. Continuous, long-term (100 hr) runs were to be performed to meet the objectives. The length of these continuous runs required quantities of feed that exceeded the DPG treatability study permits; therefore, the agent hydrolysates were supplemented by hydrolysate simulants. The feeds included:

- **VX Hydrolysate Simulant—**13.2% dimethyl methylphosphonate, 15.3% sodium isethionate, 9.8% diethanolamine, 3.1% isopropanol (70% solution), 18.0% sodium hydroxide (50% solution), and 40.6% water. VX hydrolysate simulant was to be processed for 100 hours.

- **HD/Tetrytol/Aluminum Hydrolysate/Simulant—**This simulated combined agent (HD) and energetic (Tetrytol) hydrolysate obtained from an M60 105-mm projectile. Actual agent hydrolysate was to be used for the first 19 hours, at which time it was to be replaced by a mixture of 10.01% thiodiglycol and 9.58% sodium chloride in water, with sodium hydroxide added to bring the pH of the mixture to 11.

- **GB/Cyclotol/Aluminum Hydrolysate/Simulant—**This simulated combined agent (GB) and energetic (Cyclotol) hydrolysate obtained from an M426 8-in artillery shell. Actual agent hydrolysate was to be used for the first 28 hours, at which time it was to be replaced by a mixture of 6.37% dimethyl methylphosphonate, 2.15% sodium fluoride, 2.60% sodium hydroxide, 1.03% isopropanol, and 0.77% tri-*n*-butylamine in water.

- **VX/Cyclotol/M28 Propellant/Aluminum Hydrolysate/Simulant—**This simulated combined agent (VX) and energetic (Cyclotol and M28 propellant) hydrolysate obtained from an M55 rocket. Actual agent hydrolysate was to be used for the first 79 hours, at which time it was to be replaced by VX hydrolysate simulant.

Significant deviations from the planned 100-hour demonstration testing included the following:

- The HD/Tetrytol/aluminum hydrolysate test was stopped after 55 hours due to concern over the remaining life of the reactor upper liner. During an earlier workup run with this feed, a region at the top of the upper liner (unprotected by transpiring water due to a fabrication flaw) cracked, and had to be replaced with a spare lower liner segment modified for use as the upper liner. The new modified upper liner was not designed for use in the upper region but was installed due to unavailability of an appropriate spare upper liner. At the end of 55 hours of the validation test, the new upper liner exhibited significant deformation in the form of a bulge near the top of the liner.

- The GB/Cyclotol/aluminum hydrolysate was run continuously for only 50 hours; this was a planned change made at the end of the previous run.

- The VX/Cyclotol/M28 propellant/aluminum hydrolysate validation run was stopped just short of 26 hours primarily due to continued feed flow problems, high effluent temperatures from downstream low-pressure heat exchanger fouling, downstream low-pressure region plugging, and partial blockage of the reactor injector ports. No serious corrosion or salt plugging occurred within the reactor.

C.4.2.1.3.4 Gas Phase Chemical Reduction

The demonstration GPCR consists of the TRBP and the gas-fired reactor. GPCR was demonstrated to validate the effectiveness of the process for heating metal parts and dunnage to 5X conditions in the TRBP and for treating the gaseous effluent in the hot reducing environment of the reactor. The GPCR unit was demonstrated at Building E3726 at the Edgewood Area of APG, Maryland.

In the TRBP, contaminated materials and metal parts are heated to 1,110°F (600°C). Organic compounds are volatilized and swept into the reactor by the hydrogen purge gas that is fed to the TRBP. Metal parts are held at temperatures above 1,000°F (538°C) for at least 15 minutes to achieve 5X conditions. In the reactor, gas-phase reduction of organic compounds occurs, in the presence of hydrogen, at temperatures above 1,560°F (850°C). Organics in dunnage are reduced to methane, HCl (from chlorine-containing materials only), and small amounts of other hydrocarbons. Mustard agents (H, HD, and HT) and nerve agents (VX and GB) are chemically reduced to methane, HCl, hydrogen sulfide, phosphoric acid, steam, nitrogen, and HF. Although processing of energetics was not demonstrated, NOx produced from the decomposition of these substances should be converted into nitrogen and steam. Process gas leaving the top of the reactor is treated in two caustic scrubbers to remove acid gases, water, heat, and fine particulates. The acid gases are neutralized to form common salts. The setup for GPCR included three TRBPs (one 600 liter capacity and two 60 liter capacity) and one reactor with a common gas scrubber system.

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 GPCR to achieve a 5X condition for metal parts and dunnage.
- Demonstrate the effectiveness of GPCR for the treatment of the pyrolysis gases generated during the processing of metal parts and dunnage.
- Validate the ability of GPCR to achieve a DRE of 99.9999% for HD and GB.
- Demonstrate the ability to produce a gas effluent that meets either EPA Syngas or BIF requirements (see section C.4.2.2.3.2).
- Characterize gas, liquid, and solid process streams from GPCR for selected chemical constituents to determine the absence/presence of hazardous, toxic, agent, and Schedule 2 compounds.
- Determine the need for stabilization of residual dunnage solids based on TCLP results.

GPCR was to be tested with the following material:

- 150 lb carbon (in trays) (one tray for each of 3 runs)
- 66 lb wood spiked with 4,000 PPM PCP (22 lb for each of 3 runs)
- 54 lb double-bagged DPE with butyl rubber to simulate boots and gloves (16.5 lb DPE with 1.65 lb butyl rubber and 4 plastic bags for each of 3 runs)
- 12 lb fiberglass S&F container tubes (1/4 tube, or 4 lb for each of 3 runs)
- 32 lb GB (10.8 lb agent for each of 3 runs)
- Two mortars filled with a 30% HD heel (one mortar per run, consisting of 15.5 lb metal with 1.8 lb HD)

Significant deviations from the planned demonstration testing included the following:

- The first validation run with DPE was ended before 5X performance standards were met because a rise in system pressure was observed due to a blockage that formed in the gas line between the TRBP and the reactor.
- The third validation run with a mortar and HD heel was not conducted due to schedule constraints.

- The product gas stream and the stack gas stream could not be completely characterized during the processing of GB and HD. The results of agent analysis in the gas stream could not confirm the absence of agent. As a result, the gas samples could not be sent off-site to contract laboratories for analysis of non-agent related constituents and therefore were analyzed in on-site government laboratories using non-standard analytical methods that gave qualitative data. Most of the stack gas analyses (all except O_2, CO_2 and CO) and some of the product gas analyses (phosphine, HF, and hydrogen cyanide) were not conducted during the GB and HD validation runs.

C.4.2.2 Technical Evaluation

C.4.2.2.1 Process Efficacy/Process Performance

C.4.2.2.1.1 Effectiveness

The effectiveness of the aqueous neutralization of GB and VX chemical agents was validated by the Army during Demonstration I,[110] and was confirmed for HD during Demonstration II. HD was not detected in the hydrolysate product at levels as low as 0.02 µg/mL[111] indicating a destruction efficiency of >99.99998% for HD. During Demonstration I,[112] GB was not detected in the hydrolysate product, with a detection limit of 7.4 µg/L, indicating a destruction efficiency of greater than 99.999989% for GB and VX was not detected in the hydrolysate product with a detection limit of 16 µg/L or lower, indicating a destruction efficiency 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[113] there is a high degree of confidence that both these agents can be adequately destroyed by using this process. The provider proposes processing HD at up to an 18.4% concentration[114], rather than the 15% concentration demonstrated. This change is not expected to pose any operational problems or alter the effectiveness of the process.

Validation of GPCR for the destruction of HD and GB was not accomplished. No agent was detected in GPCR scrubber solution and scrubber filters, but product gas primary sampling methods (Depot Area Air Monitoring System, DAAMS) did not work as intended. As a result, the destruction efficiency could not be calculated for HD and for GB. GB was detected in the Product Gas Burner (PGB) stack by Miniature Automatic Continuous Agent Monitoring System (MINICAMS®) during one run, but was not confirmed by DAAMS.[115] However, based on the inherent characteristics of the process such as reaction chemistry and temperatures involved, it is believed likely that the agent is being destroyed and the MINICAMS was giving a false positive. This belief is supported in part by an estimated destruction efficiency value of >99.99999% for GB, which was based on a reduced sampling period for one run; however, this did not cover the entire period when agent was being fed to the unit.

The effectiveness of bulk caustic neutralization of energetic constituents was previously validated during Demonstration I for Comp B and Tetrytol. 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 efficiency 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 efficiency of greater than 99.9998% for TNT.[116] 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 efficiency 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.[117] This indicates a destruction efficiency of greater than 99.9997% for TNT.

The effectiveness of the overall process for the destruction of Cyclotol (which contains both TNT and RDX at levels roughly similar to Comp B) and M28 was further validated during Demonstration II. TNT was detected at levels of 39 to 460 µg/L and RDX was detected at levels of 59 µg/L to 27 mg/L in Cyclotol hydrolysate. For neutralization of M28, NC was detected in M28 hydrolysate at mg/L levels.[118] This indicates a destruction efficiency of less than 99.999% for NC hydrolysis; however, the total solution is able to adequately destroy NC. NG was not detected in hydrolysate at a detection limit of 0.1 mg/L, indicating a destruction efficiency of greater than 99.9994%.[119] The process for the destruction of fuze energetics was also validated previously by the Army during Demonstration I through hydrolysis of the aluminum booster cup and tetryl booster and initiation of the detonator in the muffle furnace, similar to what is proposed.[120] The levels of residual energetics in hydrolysate are acceptable for input to TW-SCWO. In those cases where residual energetics were detected, TNT, RDX and NG were not detected in TW-SCWO effluent at a detection limit of 0.50 µg/L and NC was not detected in TW-SCWO liquid effluent at a detection limit of 0.63 µg/L. Based on all available data the overall process (neutralization and TW-SCWO) is expected to be effective for the destruction of the energetics of concern.

HD-contaminated munitions and fiberglass S&F container tubes were successfully processed in the TRBP and the residual solids validated to be 5X.[121] Although no munition hardware contaminated with other agents or energetics was tested, 5X performance conditions were met. 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 GPCR to decontaminate or destroy all other contaminated wastes has been validated with successful testing of carbon trays, wood, and DPE.[122] One of the three DPE test runs was ended before a 5X condition was achieved due to blockage in the input line to the reactor.[123] Although no testing of agent-contaminated dunnage was planned, the 5X performance standard was achieved in this demonstration.

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.

In summary, the proposed processes for neutralization of agent and energetics have been validated as part of this demonstration and previous neutralization demonstrations. Processes used for decontamination of chemical weapons hardware and treatment of contaminated processing wastes were also validated. Validation of GPCR for the destruction of agents was not accomplished due to problems encountered with the process gas sampling and analysis.

C.4.2.2.1.2 Products

The overall characterization of Neutralization/GPCR/TW-SCWO is well defined based on data obtained during demonstration. In general, the major products from hydrolysis and SCWO of organic materials are CO_2, water, nitrogen, and mineral salts including sodium chloride, sodium fluoride, sodium sulfate, and sodium phosphate. The major products from GPCR of organic materials are methane, CO_2, CO, steam, nitrogen, and mineral acid gases. However, some areas of the proposed process were not addressed during demonstration, most notably incomplete characterization for agent and non-agent constituents in the GPCR offgas stream during agent runs.

During Demonstration I, agent reformation in neutralization followed by SCWO was previously validated not to occur for GB and HD.[124] VX reformation in caustic hydrolysate has also been shown not to occur at detectable levels.[125] Therefore, it was not planned to re-validate the lack of agent reformation as part of Demonstration II.

Neutralization/GPCR/TW-SCWO uses hydrolysis as the primary destruction mechanism for both energetics and agent. Data from demonstration testing confirm that Schedule 2 compounds are produced by agent hydrolysis as follows:

- EMPA, MPA, *O*-Ethyl methylphosphonothioic acid (EMPSH), and diisopropylamino-ethanethiol (VX-thiol) are generated during hydrolysis of VX
- IMPA, diisopropyl methylphosphonate (DIMP), and MPA are generated by the hydrolysis of GB
- Thiodiglycol (TDG) is generated by the hydrolysis of HD[126]

The effectiveness of TW-SCWO to destroy HD, GB, and VX chemical agent hydrolysates was validated. The Schedule 2 compounds TDG (from HD), IMPA and DIMP (from GB), and EMPA, EMPSH, and VX-thiol (from VX) were destroyed to below detection limits. MPA was present at µg/mL levels in the liquid TW-SCWO effluent from GB and VX hydrolysates; however TW-SCWO destroyed >99% of the Schedule 2 compounds in the hydrolysate feeds and the detected levels of MPA are judged to be insignificant. MPA was detected in insignificant (mg/L) quantities during 1 out of 3 GPCR runs with GB;[127] GPCR was validated not to produce significant quantities of Schedule 2 compounds.

No EA2192 was detected at the completion of the VX hydrolysis; however, other hazardous intermediates were produced. Data from Demonstration I testing shows HD hydrolysis produced sulfonium ions, 1,4-dithiane, and 1,2-dichloroethane. Energetic hydrolysis produced cyanide. SCWO adequately reduces the hazardous compound concentrations in the hydrolysate feeds; 1,4-dithiane and 1,2-dichloroethane were reduced to below detection limits, and cyanide was reduced to less than 36 µg/L, well below levels of concern. Hydrolysis of energetics can also produce large amounts of NOx, especially for Tetrytol, which can be treated with commercial equipment (e.g., NOx reformer) if necessary. Propellant hydrolysis resulted in volatilization of N-nitrosodiphenylamine (NDPA),[128] which will require vapor containment and collection in the COINS.

TW-SCWO effluents contained numerous organic compounds, including malonic and caproic acids at mg/m^3 levels and various aldehydes, 2-methylnaphthalene, naphthalene, benzene, and toluene at µg/m^3 levels in the outlet gases and ppb levels in the liquid effluent. Formaldehyde was found at up to PPM levels in the liquid effluent.[129]

Testing generally validated that use of GPCR product gas from dunnage runs as fuel adequately reduces the hazardous compound concentrations in the gas. GPCR product gases from carbon, PCP-spiked wood, DPE, and S&F container tubes (fiberglass), contained benzene at mg/m^3 levels and higher; levels in the stack gas were reduced to µg/m^3 levels.[130] GPCR product gases from PCP-spiked wood, DPE, S&F container tubes, contained polynuclear aromatic hydrocarbons (PAHs) at mg/m^3 levels; levels in the stack gas were below detectable quantities.[131] GPCR product gases from neat GB contained phosphine at 0.01-0.06%; reduction of phosphine levels would require modifications to the scrubber.[132] The scrubber removes HF.[133] Benzene was also detected at 0.02-0.07% in GPCR product gas from treatment of neat GB, possibly as a contaminant. However, levels in stack gases could not be determined because samples could not be sent to off-site laboratories, as discussed in Section C.4.2.1.3.4. GPCR product gases from HD-contaminated mortars contained hydrogen sulfide at 1.9% and benzene at 0.2%.[134] Levels in stack gases again could not be determined because samples could not be analyzed at off-site laboratories.

Several dioxin/furan congeners were found sporadically at pg/m^3 levels in gas and at pg/L levels in liquid effluent from TW-SCWO of HD/Tetrytol/Aluminum hydrolysate and from GPCR of DPE and PCP-spiked wood. Some blank contamination by dioxin/furans was also noted.

Wood spiked with PCP was treated in the GPCR with no detectable PCP (at levels as low as 1,300 µg/m^3) in the product gas. GPCR has been previously permitted under TSCA for PCB destruction, with tests showing >99.9999% DE.[135]

In summary, demonstration data provide good characterization of the products of the process with the exception of the process gas streams associated with GPCR. Non-reformation of agents was validated previously, as was the acceptable treatment of all Schedule 2 compounds produced in the process. Acceptable treatment of most hazardous intermediates (formed at relatively low levels) was validated for this process. However, problems with agent monitoring in GPCR product gas will need to be resolved in future studies.

C.4.2.2.1.3 Sampling and Analysis

Prior to the start of Neutralization/GPCR/TW-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: alcohols, and organic acids and anions in all matrices; cyanide in energetics hydrolysates[136]
- GB & VX low-level analyses for neutralization matrixes[137,138]
- HD low-level analyses for neutralization and SCWO matrixes[139]

- NG analysis by SEC/FTIR was validated for the M28 hydrolysate matrix[140]
- Low-level energetics analyses were validated for neutralization solutions[141]
- Hazardous substances: cyanide, alcohols, organic acids/anions, TOC, total Kjeldahl nitrogen, metals, volatile organics, mercury, semivolatile organics in GPCR scrubber solution, total inorganic carbon in scrubber solution, dioxins/furans, and sulfide[142]

Neutralization/GPCR/TW-SCWO testing uses the following standard sampling and analysis methodologies:

- Gas sampling methods for energetics followed the U.S. 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.

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:

- Headspace gas from GB hydrolysis failed to provide usable samples due to the high moisture content and high pH of the headspace.[143]
- Validation was unsuccessful for aldehydes and ketones in hydrolysate intermediates because of the poor reproducibility of spike recoveries.[144]
- Validation was unsuccessful for semivolatile organics in 15% HD hydrolysate and VX/Comp B/M28 hydrolysate intermediates because of interference from the sample matrix.[145]
- Validation was unsuccessful for total inorganic carbon in hydrolysate intermediates because of the inconsistent spike recoveries.[146]
- VX hydrolysate contains volatile compounds that give false positives for air monitoring of agent with MINICAMS. No attempt was made to sample the headspace of the VX hydrolysate reaction vessel.
- The high organic loading and large mass of the scrubber filters will require optimization of the sample preparation approach for effective analysis in any future testing.

During the Neutralization/GPCR/TW-SCWO demonstration, most of the data generated have been deemed usable for evaluation of the technology and characterization of the process effluents. All methods used for determining the mass balance,[147] determining low-level agent in neutralization matrices,[148] determining residual energetics,[149] and determining residual compounds of concern[150] were verified to perform adequately during demonstration by providing an acceptable amount of usable data.

Currently, there is no reliable sampling and analysis approach for the effective measurement of chemical agents in the GPCR gas streams. DAAMS tube and impinger sampling methods for agents GB and HD in GPCR process gases did not provide usable data. MINICAMS were not demonstrated for the product gas. Data indicate that some method development will be required, but this appears to present a manageable technical risk.[151]

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 acceptably verified and validated. The level of verification for each type of analysis is given in Table C.4-4. However, method development for the detection of agent in GPCR product gas is required.

Table C.4-4. Level of Verification for Neutralization/GPCR/TW-SCWO Analyses

Type of Analysis	Amount of Usable Data
Feed and Product Composition	Acceptable
Low Level Agent	Acceptable for hydrolysis and TW-SCWO samples Unacceptable for agent in GPCR product gas samples
Low Level Energetics	Acceptable
Hazardous Substances	Acceptable

C.4.2.2.1.4 Process Maturity

In general, the unit operations that comprise Neutralization/GPCR/TW-SCWO have an acceptable level of maturity for implementation, completing most of the demonstration objectives.

Neutralization/GPCR/TW-SCWO incorporates a combination of four major operations—modified reverse assembly; neutralization; GPCR (thermal treatment with hydrogen); and TW-SCWO. Most of these operations have been demonstrated at the bench scale or greater, they are based on common industrial processes, or they are being developed by the PMACWA. This constitutes a major benefit of the proposed process. However, extensive modifications to reverse assembly, the proposed caustic dissolution process, and problems observed during demonstration of GPCR and TW-SCWO still pose some technical risks.

Pre-Treatment

The baseline reverse assembly operations (PMD and RSM) used in this process have been extensively used for ACW. However, it must be noted that the proposed modifications to reverse assembly have never been built or tested, such as shearing bursters into 1-inch sections.

The technology provider has proposed some changes to the RSM that are not beneficial and have never been built or tested. These differences pose only small technical risks, but there are other, better options being developed by the PMACWA. The operations of concern are: unscrewing the fin assembly, pulling the propellant grain from rocket motor, and grinding the grain whole. Unscrewing the fin assembly is akin to demating, which is an operation that was discouraged by PMACWA early in the program and is not considered a practical approach. The proposed method of pulling the M28 propellant grain from the rocket motor differs somewhat from that shown during Demonstration I. The technology provider proposes to leave the anti-resonance rod in place, which is likely to interfere with the pulling mechanism. Although propellant grinding has been commercially developed, shearing the grain into smaller pieces prior to grinding would be preferable.

Projectile punching techniques are well-developed,[152] but the overall process has never been built or tested with ACW and is expected to pose a much higher technical risk than techniques currently available under baseline reverse assembly and ACWA EDS. Use of the baseline MDM/PDS and the Projectile Washer being developed under EDS[153] would provide better access (i.e., less residual agent) than the proposed PPM while reducing the uncertainty and technical risk. The complex manipulations required for the proposed process inevitably present greater problems than those observed with the MDM, contrary to the technology provider's claims.[154]

COINS is based on commercial/industrial parts washers,[155] but has never been used for ACW. Concerns exist with the effectiveness of the system to clean the hardware before thermal treatment and potential problems resulting from the unknown physical and chemical condition of the resulting sludge bottoms. The proposed shearing of the bursters into 1-inch lengths, if possible, would expedite separation of energetics from the hardware, but only partial hydrolysis is expected.

Treatment

The proposed 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 ATAP system) is well developed and demonstrated. Agent hydrolysis has been demonstrated for HD (40-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, Tetrytol, and M28 propellant were hydrolyzed in 12% aqueous caustic. 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 difficult.

The thermal treatment systems have commercial, industrial bases[156]—the TRBP is an oven and the GPCR reactor has a basic cyclone design. Feeding large, primarily organic ACW feeds to the TRBP (batch processing) and the use of a hydrogen/steam atmosphere makes GPCR somewhat less mature. Creation of carbonaceous material in the TRBP and removal by GPCR during treatment of DPE[157] remains unaddressed for full-scale and could pose problems. Studies are required for materials of construction for the GPCR system.

Post-Treatment

The proposed TW-SCWO is constructed from commercially available and specialty components.[158] Solid wall SCWOs have a growing technical basis as discussed in the 1999 *PMACWA Supplemental Report to Congress*. In general, the greatest concerns with the maturity of SCWO units are corrosion minimization and solids management. Although problems were observed during TW-SCWO testing (some demonstration specific),[159] promising durability and solids management in the reactor were shown. However, the ability of the control system to maximize organic destruction was not demonstrated. Strategies to eliminate aluminum compound plugging in the feed injector and downstream low-pressure components have also not been demonstrated.

In addition, the most significant adverse effects of operation observed on the reactor liner were three occurrences of cracking or bulging before or during testing.[160] Although there was a different cause in each instance, the mechanism of cracking or bulging was always connected to thermal cycling stresses. These stresses must be minimized in order to allow long-term operation of the liner.

For full scale and potential EDS, the technology provider anticipates increasing the transpiring water temperature and flow rates in the upper and lower segments in order to maintain desirable thermal gradients. Thermal analysis performed by the technology provider indicates that higher transpiring water coolant temperature will increase liner wall protection and decrease the thermal gradient and the resulting stresses across the liner and reactor housing.[161] However, the technology provider has not provided any information to indicate an empirical, formulaic approach to establish the scalability of TW-SCWO.

Finally, pressure control valve erosion occurred with an effluent containing high levels of aluminum compounds, but replacement of the valve by one with a more erosion-resistant coating minimized the erosion[162] to the point that none was visually detected at the conclusion of the demonstration tests.

The scrubbing systems for GPCR offgas are of a common, commercial design.[163] However, the materials of construction for the GPCR offgas scrubber system need to be addressed.

Effluent Management

The effluent management techniques and equipment are of common design and are commercially available.[164] Solids removal units have not been tested with TW-SCWO process streams.

Summary

Overall, the total solution is moderately mature. A number of the unit operations of Neutralization/GPCR/TW-SCWO are sufficiently mature to go to full-scale. Most of the equipment has a good history of operations, is readily available, and scalable. Baseline reverse assembly and neutralization were developed and are used for chemical weapons demilitarization.

The maturity of Neutralization/GPCR/TW-SCWO is enhanced by ACWA Demonstrations I and II. GPCR has historical, full-scale commercial experience. There are still technical risks associated with scale-up of batch processing with ACW feed streams and generation of carbonaceous material in GPCR. TW-SCWO is showing promising durability and solids management, but is still an emerging technology. This causes some reservation regarding the maturity of TW-SCWO, which still requires additional development.

The PPM is a derivation of an existing design and the basis of COINS is on standard industrial equipment. Significant technical risks are associated with the proposed modifications to the RSM and the use of the PPM, while there is moderate technical risk associated with the COINS. These technologies have not been tested in the proposed configuration or with the proposed materials and in some cases may be inappropriately employed.

C.4.2.2.1.5 Process Operability

Most unit processes are expected to be inherently stable, robust, and tolerant of moderate changes in operating conditions. Stability of a majority of unit operations (reverse assembly [the portions used], neutralization, GPCR, and TW-SCWO) has been demonstrated at least at the bench scale with process materials of interest (agent, agent hydrolysate, dunnage, and metal parts). With the exception of GPCR, these unit operations are expected to behave similarly at full-scale as regards process stability. The use of HT&R for caustic neutralization of agent and energetics, liquid effluents from TW-SCWO, and gaseous effluents from GPCR supports the stability of the total solution. Caustic hydrolysis, GPCR, and TW-SCWO are all run as batch or semi-batch processes.

There are several process operability concerns for COINS, GPCR, and TW-SCWO. Further studies of energetics hydrolysis are required to assure stability of processing all energetics and transportability of the resulting hydrolysates due to the viscosity of some partially hydrolyzed energetics. The combination of energetics hydrolysate and energetics “sludge” in the COINS will produce a slurry with an unpredictable consistency, and the provider’s conceptual plan is to transport sludge with an unknown energetics concentration. Energetics sludge could accumulate in confined areas of the caustic neutralization system and create pressure excursions because of gas evolution from chemical reactions. The operating characteristics of this system will be clarified only after substantial development is conducted. As discussed in Section C.4.2.2.1.4, COINS is a complicated approach for accessing and partial caustic neutralization of energetics and the system will need refinement and possibly redesign.

The maturity of the industrial GPCR provides a certain degree of confidence that the system can be operated as a stable treatment unit.[165] However, some controllable instabilities observed during demonstration of GPCR are of concern for larger scales. Specifically, gas evolution resulting from ramping up the temperature too quickly is of concern.[166] Due to the batch nature of GPCR, the system could become unstable if heat ramp-up to the TRBP is sudden and gas evolves at a faster rate than can be controlled downstream. While the system has a control system for automatic shutdown, the large mass of material with a high heat capacity present in the TRBP could continue to create an upset that can only be controlled with a proper high-pressure abatement strategy. Individual feeds require individual control strategies for heat input to the TRBP, and additional data for each feed is required to develop these strategies. In addition, the passage of excess energetics (e.g., undissolved burster material) to the TRBP is still of some risk because the operational safety margins for expected feeds are not known. For example, an excess of bursters could be overfed to a COINS hydrolysis basket and not undergo complete dissolution/hydrolysis. Results of ERH testing (from Demonstration I and EDS) will require examination to determine equivalent hydrolysis rates. Lastly, the TRBP and loading bins must be designed and built to withstand the repeated impacts of metal shrapnel expected when processing fuzes in large quantities.

The TW-SCWO demonstrated an ability to minimize plugging and corrosion within the TW-SCWO reactor. The greatest obstacles remaining in the operability of TW-SCWO are the management of aluminum compounds and maintaining liner integrity.[167] As shown in demonstration, any feed port obstructions may decrease the ability of TW-SCWO to treat organic feeds. Scaling/lining of the downstream TW-SCWO equipment and piping with aluminum compounds was also shown to be problematic in demonstration, and must be resolved for feeds with high concentrations of aluminum compounds. It is unlikely that the TW-SCWO effluent will behave as an aluminum compound slurry as anticipated by the technology provider. Although the proposed approach to aluminum-containing solids management may present difficulty, the problem could be avoided through removal of aluminum compounds from the SCWO feed streams, which is currently being developed under EDS. There is uncertainty about the ability of the liner to resist deformation after extended periods of testing. This may be mitigated by the proposed higher temperature for the transpiring water.

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.[168] Nevertheless, the full-scale system is expected to have poor to average RAM characteristics. Baseline reverse assembly has known (poor to average) RAM characteristics while agent and energetics hydrolysis are expected to have good RAM characteristics. The punch-and-drain and COINS accessing systems are expected to have poor RAM characteristics based on present design. TW-SCWO and GPCR are expected to have average RAM characteristics. The long-term ability for TW-SCWO to resist deformation and the buildup of solids has yet to be demonstrated, but reliability is expected to improve prior to full-scale implementation. Corrosion and erosion of GPCR materials of construction could be quite problematic without sufficient testing of materials of construction. Extrapolating from demonstration results, the RAM characteristics of GPCR for treatment of DPE are unacceptable unless changes to the operating conditions significantly reduce coating of the reactor and downstream units with carbonaceous product material.

The large number of unit operations makes the overall total solution complex. Major unit operations include 2 PMDs, punch-and-drain of projectiles, 3 MSRMs, 2 BSRMs, 3 COINS, CSTRs for agents and energetics, 3 SCWOs, 3 to 8 TRBPs, 2 GPCR reactors with follow-on pollution abatement equipment, and demineralization/deionization and evaporator/crystallizer units. Overall, SCWO is a complex system and efficient control depends on achieving the right blending of the five feeds: waste, transpiring water, kerosene, oxygen, and quench water. The additions to the reverse assembly process and the COINS are considered quite complex. These systems have numerous interfaces and potential locations for system malfunctions, including: unscrewing the rocket fin assembly, rocket propellant extraction and size reduction, and multiple munition manipulations by the projectile punch and drain process. However, certain, individual interfaces for the full-scale system are mostly straightforward and well defined. The most complex interfaces are feeding of dunnage and metal parts to the TRBP.

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 moderate skill levels is required for the full-scale process. Unknown and potentially lengthy preventative and routine maintenance requirements are predicted for the punch-and-drain, rocket propellant accessing, and COINS, and standard preventative and routine maintenance requirements are expected for TW-SCWO, additional hydrolysis units, and reverse assembly. There are known or standard preventative and routine maintenance requirements for the commercial GPCR, but there is less certainty for processing the ACW materials of interest (e.g., DPE, wet metal parts partially filled with agents).[169] Requirements for cleaning carbonaceous residues and other solids out of TRBPs, GPCR reactors, and downstream gas polishing units could be extensive.

In summary, Neutralization/GPCR/TW-SCWO is a complex process with manageable operability characteristics. The modifications to reverse assembly and energetics accessing (COINS) are not optimal approaches in regards to operability but can be improved with design simplifications. The TW-SCWO reactor experienced minimal corrosion and plugging problems during demonstration. The solids management with feeds containing high aluminum-containing solids content is untested, but is expected to pose a manageable technical risk. There are also operability concerns for the treatment of DPE with GPCR.

C.4.2.2.1.6 Process Monitoring and Control

The total solution relies on a high degree of modularity and redundancy to minimize the effects of process upsets on system safety and performance. Most unit operations can be effectively monitored and controlled by using commercially available controls and instrumentation, including on-line monitoring and liquid HT&R procedures.[170] Agent and energetic CSTRs, and TW-SCWO can be controlled effectively and easily to prevent upsets.

There were no major problems experienced with system control or automatic shutdown for TW-SCWO during the demonstration test program. The control system was able to provide stable operation, and all automatic shutdowns occurred smoothly and without incident. However, during the TW-SCWO demonstration, there were insufficient diagnostics to allow assessment of reactor conditions, and none of the parameters monitored on the control screen correlated with the frequency and magnitude of change in the visible appearance of the liquid effluent. The technology provider has not addressed the ability to control TW-SCWO for maximum destruction of organic compounds. There were also several failures of monitoring equipment (i.e., oxygen analyzer, pH probe, and TOC analyzer) during the TW-SCWO demonstration, but some may be random failures, unrelated to TW-SCWO operating conditions.

The effectiveness of the monitoring and control approach was also validated in demonstration testing for GPCR. The GPCR process control software is identical to that already used in an existing large-scale Eco Logic commercial unit and is proposed for use at full-scale. The technology provider states that a full-scale system would not be significantly more complex than the demonstration unit.[171] During an automatic shutdown of GPCR, the shutdown procedures for GPCR were implemented properly, indicating that the control system had performed adequately. The computer control system and its programmed alarms and interlocks were adequate to allow for safe and controlled shutdowns each time they occurred as intended. However, control of the heat input to the TRBP (the primary control of GPCR) is manual, putting a large amount of responsibility on the operator. There is a potential in GPCR for the slow, controlled rate of heating to exceed the level at which gas evolution is effectively controlled.[172] Pressure spikes in the TRBP occurred during several validation runs, but they were handled by the control system. Nonetheless, the amount of gas evolution may be of concern at full-scale. In demonstration and at full-scale, high gas evolution is controlled by operating two compressors at all times with a third used as a backup. At a minimum, the nature of GPCR requires “trial and error” treatment methods with multiple runs of every type of feed proposed for full-scale. This is required in order to gain experience with how fast the heat transfer to the TRBP can be ramped up. There is also no proven monitoring approach for the prevention of an excess quantity of energetics from entering the TRBP. While well-investigated operational criteria should minimize excess energetics from passing from the COINS to the TRBP, an over-reliance on an impractical and ill-defined organic solvent wash system (see Section C.4.2.2.1.5)[173] could lead to process upsets.

There are some additional concerns with the proposed monitoring and control strategies. There are no validated methods for monitoring for agent in the GPCR product gas stream, and VX hydrolysate contains volatile compounds that give false positives for air monitoring of agent with MINICAMS. Sampling and analysis methods must be improved for agents in the GPCR effluent, and Army investigations have been ongoing for several years to improve VX air monitoring in a hydrolysate environment. The monitoring and control for quantities of energetics in the COINS needs investigation in order to minimize the accumulation of energetics, which if not properly managed, could increase risks for explosion propagating conditions.

In regards to complexity of monitoring and control, the proposed modifications to reverse assembly are immature and involve complicated monitoring and control schemes to insure reliable operations. These include unscrewing the rocket fin assembly, rocket propellant extraction and grinding, and multiple munition manipulations required for the projectile punch and drain process.

In summary, effective control is expected of critical unit operations for normal operations and to minimize or control process upsets. However, the ability of the TW-SCWO monitoring and control system to maximize organic destruction has not been demonstrated. Two concerns exist relating to the GPCR system, agent monitoring in the GPCR product gas stream and control of energetic levels in the feed, which can be resolved through improvements to design and additional development.

C.4.2.2.1.7 Applicability

Neutralization/GPCR/TW-SCWO is capable of demilitarizing all ACWs at all sites.

C.4.2.2.2 Safety/Worker Health and Safety

C.4.2.2.2.1 Design or Normal Facility Occupational Impacts

The primary destruction process for chemical agent (neutralization) operates at low temperature and ambient pressure. Neutralization/GPCR/TW-SCWO utilizes four major hazardous process chemicals: sodium hydroxide, liquid oxygen, hydrogen (an explosive/flammable gas), and kerosene (a flammable liquid). Some of these materials are used in large quantities, and all pose some routine exposure risk to workers during feed preparation and maintenance of process equipment. However, all process materials for Neutralization/GPCR/TW-SCWO have moderate to low toxicity and persistency, are commonly used in industry, and can be handled in accordance with well-established industrial safety practices. The ultimate choice, volume, concentration, and use of volatile solvents proposed for the COINS basket energetics detection and quantification process was not adequately defined and needs further clarification.[174] TW-SCWO forms some corrosive intermediate products, but no final products are corrosive. Neutralization/GPCR/TW-SCWO units are remote operations, which generally protect workers from chemical and physical hazards. Worker exposure to process materials and equipment is primarily associated with maintenance activities. The Neutralization/GPCR/TW-SCWO processes are not likely to cascade out of control during upset conditions.

TW-SCWO and TRBP/GPCR hot surfaces are effectively mitigated by prudent use of insulation and interlock to ensure safe operations.[175], TW-SCWO uses a combustible material (kerosene) as a process chemical.[176] Liquid oxygen produces a combustion-promoting gas used in the TW-SCWO. GPCR utilizes hydrogen (a potentially explosive or flammable gas) in the process. TW-SCWO can be cooled down rapidly in the event of an emergency, but the TRBP does not permit a rapid cool down in that event.

Baskets used for the removal of energetic materials in COINS are to be routinely washed with solvent to detect and quantify possible energetic residues remaining on the hardware. Although the technical provider identified six possible candidates for the energetic solvent material, final selection has not been made.[177] The COINS containment capability and level of required worker interaction was not defined. Because of the lack of process design details and final selection of solvent, the risk associated with normal processing could not be effectively evaluated and is a major area of concern.

In summary, the primary destruction process for chemical agent operates at low temperature and ambient pressure. Neutralization/GPCR/TW-SCWO utilizes process materials that are commonly used in industry, and can be handled in accordance with well-established industrial safety practices. Neutralization, GPCR, and TW-SCWO are remote operations, which generally protect workers from chemical and physical hazards. However, there are still inherent risks associated with the COINS, a high volume of hazardous chemicals used in the process, and the use of high temperature hydrogen in the GPCR process.

C.4.2.2.2.2 Facility Accidents with Worker Impact

The primary destruction process for chemical agent (neutralization) operates at low temperature and ambient pressure. Neutralization/GPCR/TW-SCWO utilizes four major hazardous process chemicals: sodium hydroxide (a significant dermal hazard), liquid oxygen (a severe dermal hazard), hydrogen (an explosive/flammable gas), and kerosene (a flammable liquid). Some of these materials are used in large quantities; however, all process materials for SCWO/GPCR are commonly used in industry, and can be handled in accordance with well-established industrial safety practices. Neutralization/GPCR/TW-SCWO units are remote operations, which generally protect workers from chemical and physical hazards.[178] HT&R points after neutralization and GPCR operations prevent the accidental release of hazardous materials to the environment. Neutralization/GPCR/TW-SCWO systems are energy-dependent, and are not likely to cascade out of control during upset conditions. There is a limited amount of agent and energetics accumulation associated with the processes, and destruction occurs within 12 hours. Worker exposure to process materials and equipment is primarily associated with maintenance activities.

There are small, but manageable, interferences with agent monitoring associated with false agent alarms on ACAMS from VX hydrolysate. The use of DAAMS tubes is still effective to confirm if agent is actually present. Industrial chemicals proposed for this process have been tested by PMCD and they have demonstrated no ACAMS interferences. Analytical validation of agent concentration in GPCR product gas did not work as intended during demonstration due to interference or product gas incompatibility with the sampling media. An effective means of analyzing GPCR product gas for agent still needs to be developed.

SCWO operates at very high pressure (3,400 PSI), very high temperature (750-1,500°F [400-815°C]),[179] and uses a combustible material (kerosene) as a process chemical. Liquid oxygen produces a combustion-promoting gas used in the TW-SCWO. Accident scenarios associated with SCWO include the potential for plugging of the reactor and/or high reactor temperature from the loss of transpiration water (although automatic system shutdowns are in place). GPCR operates at very high temperature as well (above 1,500°F [815°C]), and utilizes hydrogen (a potentially explosive or flammable gas) in the process.[180] TW-SCWO can be cooled down rapidly in the event of an emergency, but the TRBP does not permit a rapid cool down in that event.

Baskets used for the removal of energetic materials in COINS are to be routinely washed in a solvent bath to detect and quantify possible energetic residues remaining on the hardware. Although the technical provider identified six possible candidates for the energetic wash solvent, final selection has not been made and the quantity remains unknown. The COINS containment capability and level of required worker interaction were not defined. The solvent wash may generate an aerosol and increase the potential for fugitive emissions. In addition, the process has the potential for the aerosol to exceed the lower explosive limit (LEL) for the solvent, which requires a mitigation strategy. The effectiveness of the proposed safety monitoring technique to detect/remove energetics prior to transfer to the GPCR has not been established. The TRBP is currently designed to contain deflagration of minimal quantities (0.55 kg) of energetic materials, and a method is needed to ensure that the design limit is not exceeded during plant operations.

Disposal of the M28 propellant removed from M55 rockets will require that the propellant be size-reduced through a grinding operation before being incorporated into the energetics sludge that is fed into the SCWO reactor. While grinding operations have been successfully demonstrated in the past for some types of propellant, the ability to safely grind M28 propellant while in caustic solution has not yet been successfully demonstrated. Burster energetic materials are removed from munitions in COINS. Pumps are used to transfer the energetics sludge/caustic slurry from COINS. A characterization of the composition and consistency of the slurry that would ensure safe pumping (an energy imparting operation) of the energetic materials has not been provided.

In summary, Neutralization/GPCR/TW-SCWO incorporates commonly used process materials, has only a limited accumulation of agent and energetic materials, and is not likely to cascade out of control during upset conditions. However, there are still inherent risks associated with the COINS, the use of high temperature hydrogen in the GPCR process, the high temperature and pressure conditions within TW-SCWO and the remaining uncertainties in the handling and processing of energetics within the system, including the energetic solvent wash detection and quantification system.

C.4.2.2.2.3 Facility Accidents with Public Impact

The primary destruction process for chemical agent (neutralization) operates at low temperature and ambient pressure. Although Neutralization/GPCR/TW-SCWO uses large quantities of hazardous chemicals, most of these materials are not highly volatile, and only have moderate to low toxicity and persistency. All of the process materials are commonly used in industry and can be handled in accordance with well-established industrial safety practices. The proposed use of volatile solvents for the COINS energetics detection and quantification process still needs further clarification and development. HT&R points after neutralization and GPCR reduce the potential for release of agents or other hazardous materials to the public. Commercial monitoring equipment for agents and other hazardous materials can be used for most of Neutralization/GPCR/TW-SCWO. Analysis of agent in GPCR product gas did not work as intended during demonstration due to interference or product gas incompatibility with the sampling media. Effective analysis of GPCR product gas for agent still needs to be developed. The primary destruction processes are not likely to cascade out of control during upset conditions. Total containment in the event of an accident or explosion is provided at the equipment and facility level. In addition, there is only limited agent and energetics accumulation associated with the processes.

There are small, but manageable, interferences with agent monitoring associated with false agent alarms on ACAMS from VX hydrolysate. The use of DAAMS is effective in confirming agent presence.[181] Industrial chemicals proposed for this process have been tested by PMCD and they have demonstrated no ACAMS interferences. GPCR operates at very high temperatures (above 1,500°F [815°C]), and utilizes hydrogen (a potentially explosive or flammable gas) in the process. However, the safeguards, monitoring, and controls that minimize worker impact in the event of a facility accident are similarly beneficial with respect to public impact. These provisions mitigate the risk of an accidental release of agent or process chemicals that could otherwise disperse to the public. Even if an accident occurred during operations, public impact is minimized or eliminated since several layers of system and facility secondary containment should sufficiently contain the effects and prevent public exposure.

C.4.2.2.2.4 Off-Site Transportation Accidents

Neutralization/GPCR/TW-SCWO uses several hazardous materials, including sodium hydroxide (classified by DOT as corrosive),[182] kerosene (a flammable liquid),[183] liquid oxygen (an oxidizer that forms a non-flammable gas),[184] and liquid nitrogen (a non-flammable gas).[185] Of these chemicals, none are carcinogenic. The chemicals pose relatively low hazard to the public in the event of a transportation accident. However, the total volume of both process and waste-stream materials is expected to be high. The proposed choices for volatile solvents for the COINS basket energetics detection and quantification process are not expected to have a significant impact from a transportation perspective.

Munitions-related metal parts, rocket S&F containers, spent carbon, munitions processing dunnage, and DPE are treated in the TRBP to 5X conditions (indicates that an item has been decontaminated completely of the indicated agent and may be released for general use or sold to the general public) prior to shipment offsite for disposal or recycling.

Standard HAZMAT and fire department PPE, containment equipment, and techniques should be sufficient to contain any potential spills. Evacuation zones of 30-50 yards would be required for spills involving liquid oxygen, sodium hydroxide, kerosene, or liquid nitrogen.[186] No special training beyond OSHA HAZMAT and DOT requirements is needed. In summary, this technology poses very little risk of a transportation accident affecting the public.

C.4.2.2.3 Human Health and Environment

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

All waste streams generated during demonstration were characterized with the exception of GPCR gas effluents during agent operations. Proposed full-scale disposal options were specified for all waste streams. There are no external liquid effluents. The only solid products from the total solution include salts from TW-SCWO and solid residue from GPCR. Solid residue from GPCR collected during the demonstration passed TCLP requirements with the exception of DPE runs. The gaseous emissions from GPCR will undergo HT&R prior to use as a fuel (see below).

All primary destruction processes and their associated intermediate waste streams are held tested and reworked (if necessary) before release. GPCR product gas (containing hydrogen, methane, CO_2, CO and acid gases) is scrubbed with caustic and then held for agent testing. Once cleared, the product gas is burned in a boiler or other energy recovery device and the combustion products are then passed through a catalytic converter. The gas product from GPCR is a RCRA hazardous waste, but may be burned in the process if it meets certain requirements defined in RCRA (the boiler or industrial furnace [BIF] exemption).[187] Based on demonstration results, it appears likely that the GPCR product gas exceeds the minimum required heating value of 5,000 BTU/lb, which is used as a key test to determine the applicability of the BIF exemption. TW-SCWO gaseous effluents are scrubbed before release to the plant ventilation system. Projected emissions of hazardous air pollutants are expected to be minimal. Priority pollutant emissions are also expected to be below permitting thresholds.[188]

All liquid streams within the system are recycled to neutralization or TW-SCWO for destruction.[189] Scrubber brine will be directly recycled for use as makeup water for the preparation of the caustic solution. This reduces the quantity of liquids processed through TW-SCWO and reduces the volume of potential effluent. TW-SCWO effluents had low concentrations of organics, except during the GB hydrolysate run, when the TW-SCWO reactor feed injector was damaged. The effluent from this run contained higher than expected organics.

Inorganic solid (metal, glass, equipment, etc.) is thermally decontaminated to a 5X level on-site. Projectile bodies will be sent to a commercial metal recycler. The salt cake from the TW-SCWO evaporator/crystallizer and GPCR residues resulting from DPE processing contain metals and may fail TCLP. Stabilization may be required prior to off-site disposal. This was not demonstrated, but it is expected to be technically feasible.

Sampling and analysis methodologies for determining energetic breakdown products and regulated toxic substances were generally validated and verified. The substances included cyanide, alcohols, organic acids/anions, TOC, total Kjeldahl nitrogen, metals, volatile organics, mercury, semivolatile organics, total inorganic carbon, dioxins/furans, and sulfide.[190]

A method for sampling and analysis for agent in GPCR product gases was not verified.[191] MINICAMS was not used with this stream during demonstration due to safety concerns of the test facility (a change in facility policy). Use of MINICAMS or other equivalent instruments needs to be resolved.

In summary, there are no liquid effluents, and the gaseous and solid effluents from demonstration appear to present a low hazard. GPCR gaseous effluents are held, tested, and reworked (if necessary) prior to release. However, the overall impact on human health and the environment could not be fully ascertained due to the lack of validation for the method for detection of agent in GPCR gas effluents.

C.4.2.2.3.2 Completeness of Effluent Characterization

Sufficient characterization of the effluent process streams was achieved with the exception of the effluent gas stream associated with GPCR agent operations. Currently, there is no reliable sampling and analysis approach for the effective measurement of chemical agents in the GPCR process effluent gas stream. In addition, most of the gas samples from the product gas burner and some of the product gas samples were not collected during the GB and HD runs due to a change in test facility policy. This led to an incomplete characterization and the inability to validate the gas stream mass balance for GPCR with HD and GB.

TW-SCWO effluents had good characterization with a validated mass balance for all demonstrated effluents.

C.4.2.2.3.3 Effluent Management Strategy

The technology provider has had some experience in managing similar waste streams but has no experience in managing agent derived RCRA waste. However, the proposed waste management strategy is basically sound. GPCR has a history of successful permitting. TW-SCWO is expected to meet regulatory acceptance. GPCR includes a HT&R concept in which all gases are contained until confirmed to be acceptable for release. If the gas is not confirmed acceptable, it can be recirculated to the GPCR reactor for reprocessing. Solid residue from GPCR collected during the demonstration passed TCLP requirements (with the exception of DPE). Most waste streams are HT&R. The evaporator/crystallizer, which is expected to recycle water and produce dried SCWO salts, may not process the salts as proposed, affecting the TW-SCWO effluent management strategy.

The permitting strategy includes discussion of options for effluents to air, including using GPCR gases as supplemental fuels (the BIF exemption; see section C.4.2.2.3.2), and sending other air effluents through plant HVAC with no expected permitting issues. There is no expected water discharge (except minor quantities of hydration in salt cakes) and solid wastes treated are to 5X conditions. TW-SCWO salts and GPCR residue may require stabilization to pass TCLP prior to off-site disposal.

The GPCR gas passes through a caustic scrubber and it is then held for agent testing. Once cleared, the gas is used as a fuel in the process, and the combustion products are then passed through a catalytic converter. TW-SCWO gaseous effluents are scrubbed before release to the plant ventilation system.

All solid wastes are thermally treated to a 5X condition; the metal parts are sent to a recycler, and other solid wastes (some SCWO salts and GPCR residues may require stabilization) are sent to RCRA landfills. Most residues from the demonstration test passed TCLP and the full-scale residues should qualify for disposal as non-hazardous waste if they meet local and state requirements.

In summary, the proposed waste management strategy is basically sound.

C.4.2.2.3.4 Resource Requirements

The design included order of magnitude estimates for resource consumption. The proposed total solution uses the same footprint as the baseline plant. No other special land use requirements are proposed. Specific water and energy requirements could not be quantitatively verified from the technology provider's report; however, a qualitative assessment has determined that no unusual requirements are anticipated.

C.4.2.2.3.5 Environmental Compliance and Permitting

There are no apparent issues associated with permitting this technology and there is a well-developed strategy to assure compliance with all environmental laws and regulations. This process or similar processes have been permitted by RCRA, TSCA, CAA, and CWA. Meeting the BIF exemption requirements for process offgas may facilitate permitting. GPCR met the BIF requirements for the dunnage runs.[192]

Reaction chemistry is well defined. RCRA, CAA, and CWA waste analysis plans have been identified for some treatment streams. GPCR has a history of successful permitting for PCB destruction in the U.S. TW-SCWO is expected to meet regulatory acceptance and a similar process has received a permit for pilot operations at Newport, IN. The permitting strategy includes discussion of options for effluents to air (GPCR gases to boiler, and other air effluents through plant HVAC with no expected permitting issues), no discharges to water are proposed, and all solid wastes are treated to 5X. TW-SCWO salts and GPCR residues may need stabilization to pass TCLP.

C.4.2.2.4 Potential for Implementation

In order to evaluate the cost and schedule portions of the Potential for Implementation criteria, the total capital cost and schedule for Blue Grass were developed using the approach discussed in Attachment C-D. Using this same approach and information obtained from PMCD, the total capital cost and schedule were estimated for baseline incineration at Blue Grass. A preliminary comparison between this alternative technology and baseline incineration with respect to total capital cost and schedule was made. In addition, a qualitative assessment of operating and maintenance cost was conducted and was compared to those of baseline incineration. Cost and schedule were not evaluated for Pueblo due to Public Law 106-398, which precludes consideration of technologies at Pueblo that were demonstrated after 1 May 2000.

The final 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). Integrated Process Teams have been established within the Department of Defense as part of the Defense Acquisition Executive 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*
>
> *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

The potential for Public Acceptance was evaluated by the ACWA Dialogue and the results presented to PMACWA at the Dialogue in Lexington, KY on 25-26 January 2001.

C.4.2.2.4.1 Cost

The estimated total capital cost for Neutralization/GPCR/TW-SCWO as proposed by the technology provider for Blue Grass is comparable to that for baseline incineration:

- Blue Grass: Neutralization/GPCR/TW-SCWO total capital cost may be approximately less than or equal to that of baseline incineration.

It is also interesting to note that 55% of the total capital cost for Neutralization/GPCR/TW-SCWO is attributed to equipment and buildings common to baseline incineration and the other alternative technology demonstration tested.

Sufficient information currently does not exist to make a reasonable estimate of Neutralization/GPCR/TW-SCWO O&M cost. However, based upon a review of Neutralization/GPCR/TW-SCWO, it was independently estimated that the O&M labor requirements for this alternative technology would be comparable to those for baseline incineration. Furthermore, since O&M labor requirements account for 65 to 70% of the total O&M cost for baseline, it is likely that the total O&M cost for Neutralization/GPCR/TW-SCWO will be comparable to baseline. This is because no extraordinary chemical usage or utility requirements are anticipated for Neutralization/GPCR/TW-SCWO and its operating schedule is similar to baseline.

Table C.4-5. Total Capital Cost Estimate for Neutralization/GPCR/TW-SCWO—Blue Grass

Neutralization/GPCR/TW-SCWO	Blue Grass Total Capital Cost ($Millions)
Installed Core Process Equipment	117
Installed Baseline Equipment Additions	72
Total Installed Equipment Cost	**189**
Buildings and Support Facilities	234
Total Capital Cost	**423**

C.4.2.2.4.2 Schedule

The basic schedule assumptions, key milestone activities, and key activity duration periods are summarized below:

- The Kentucky Statute was revised in July 2000. This allows for alternative technologies demonstrated under the PMACWA program to be considered at Blue Grass.
- The Demonstration II technologies must be validated by PMACWA in order to enter the EDS Phase. The objectives of the EDS are to:
  - Support the certification decision of the Under Secretary of Defense for Acquisition, Technologies & Logistics as directed in PL 105-261 with respect to a Full-Scale Facility Total Life Cycle Cost, Schedule, and Safety
  - Support NEPA documentation and RCRA permit application
  - Support contract RFP for a full-scale pilot plant facility
- PMACWA and PMCD are preparing separate Environmental Impact Statements (EIS) and each will have a Record of Decision (ROD). The PMACWA Programmatic EIS will be comparing the PMACWA-validated alternative technologies. The PMCD Site Specific EIS for Blue Grass will be evaluating the incineration technologies along with the PMACWA-validated alternative technologies. The Department of Defense (DOD) will review both RODs and approve a Technology Decision for Blue Grass.

- The draft acquisition strategy for alternative technologies at Blue Grass utilizes a "Dual Contract Approach"[i]:
  - Contractor A, from an initial solicitation, will be responsible for completing the facility design, constructing, operating and closing the facility and providing support to Contractor B during training, systemization and pilot testing.
  - Contractor B, from a follow-on solicitation, will be responsible for completing the core process technology design, procuring/fabricating core process technology specific equipment, training, systemization, pilot testing and providing support to Contractor A during facility operations and closure.
- Contracting:
  - Contract A RFP Release occurs prior to DOD Technology Decision.
  - Contract A Award occurs immediately following DOD Technology Decision.
  - Contract B RFP Release occurs as soon as possible after DOD Technology Decision (allowing 6 months for proposal preparation and evaluation).
- Permitting:
  - The RCRA Part B Application can be submitted within four months of DOD Technology Decision (based on current experience that EDS Engineering Packages are sufficient for preparing RCRA Part B Application).
  - The RCRA Part B Permit will be issued 15 months after submittal of the application.
- Construction/Operations:

  (1) MDB construction (the single most important critical path item) begins upon RCRA Part B approval.

  (2) 16-month Initial Systemization

  (3) 5-month Pilot Testing

  (4) 5-month Design/Equipment Modifications

  (5) 6-month Final Systemization

Based on the above, Table C.4-6 summarizes the key milestones and corresponding dates for Blue Grass.

[i] Subsequent to this analysis, the Dual Contract Approach was eliminated; this change in contracting approach is not expected to substantially alter the estimated completion date.

Table C.4-6. Implementation Schedule for Neutralization/GPCR/TW-SCWO—Blue Grass

Key Milestones	Dates
Publication of Notice of Intent – PMACWA	April 2000
Publication of Notice of Intent – PMCD	December 2000
Start of EDS Testing	April 2001
DOD Technology Certification	March 2002
PMACWA Programmatic EIS Submittal	July 2001
PMACWA Programmatic ROD Submittal	August 2001
PMCD Site-Specific EIS Submittal	March 2002
PMCD Site-specific ROD Submittal	April 2002
DOD Technology Decision	April 2002
Contract A (Site Infrastructure and Non-Technology Specific Buildings) RFP Release[i]	September 2001
Contract Award for Contract A[i]	June 2002
Contract B (Core Process Technology) RFP Release[i]	April 2002
Contract Award for Contractor B[i]	October 2002
RCRA Part B and Clean Air Act Permits Submittal	August 2002
RCRA Part B and Clean Air Act Permits Approval	November 2003
MDB Construction Start	November 2003
MDB Construction Completion	September 2006
Systemization/Pilot Test Start	September 2006
Systemization/Pilot Test Completion	June 2008
Design and Equipment Modification/Final Systemization Start	June 2008
Design and Equipment Modification/Final Systemization Completion	May 2009
Operations Start	May 2009
Operations Completion	November 2010

[i] Subsequent to this analysis, the Dual Contract Approach was eliminated; this change in contracting approach is not expected to substantially alter the estimated completion date.

As indicated in the table, the schedule developed for the demilitarization of assembled chemical weapons utilizing Neutralization/GPCR/TW-SCWO estimates the following date for completion of operations:

- Blue Grass: November 2010

The implementation schedule for Neutralization/GPCR/TW-SCWO indicates demilitarization operations are not completed until after the CWC date of 29 April 2007; however, demilitarization operations for Neutralization/GPCR/TW-SCWO are estimated to likely be completed within the possible 5-year CWC extension.

C.4.2.2.4.3 Public Acceptance

As discussed in the report to which this evaluation is appended, based on the full consensus of the Dialogue, the Neutralization/GPCR/TW-SCWO process was deemed likely to obtain public acceptability.

C.4.3 Teledyne-Commodore Solvated Electron System

This section of the technical evaluation report covers the description and evaluation of the Solvated Electron System (SES) proposed to PMACWA by Teledyne-Commodore.

C.4.3.1 Description of the Proposed Technology

The process uses fluid-abrasive cutting and fluid mining to access agent and energetics, which are then destroyed by solvated electron technology (SET™); the SET reaction products are subsequently oxidized. Metal parts and dunnage are decontaminated by SET reagent.

C.4.3.1.1 ACWA Total Solution

As shown in Figure C.4-3, the SES is composed of two major subsystems, each with several components. The Extraction Subsystem provides access to the portions of the munition containing chemical agent and energetics. The Destruction Subsystem destroys agent and energetics, decontaminates dunnage and metal parts, and prepares the products for disposal.

<u>Pre-Treatment</u>

The Extraction Subsystem uses a pressurized fluid to access agent and energetics within munitions and separates them from the associated metal parts. Ammonia and abrasive grit cuts projectiles and neat ammonia washes agent and mines energetics from projectiles. Isopar-L™ (an iso-paraffinic liquid) rather than ammonia is used for accessing (cutting, mining, and washout) of all munitions at sites with M55 rockets. The Extraction Subsystem is a single device with six, separate stations on a common transfer mechanism (e.g., rotary turntable) similar to the baseline reverse assembly PMD and MDM. The Extraction Subsystem stations are:

- Station 1: Agent Removal perforates and spray washes/drains agent from rockets
- Station 2: Fuze Removal cuts fuzes off
- Station 3: Explosive Removal sections munitions and fluid mines burster charges (energetics)
- Station 4: Reservoir Cleaning sections and spray washes agent reservoirs

- Station 5: Propellant Removal cuts the rocket to fluid mine the propellant from the motor case

- Station 6: Motor Rinse sections the remaining rocket while spray washing

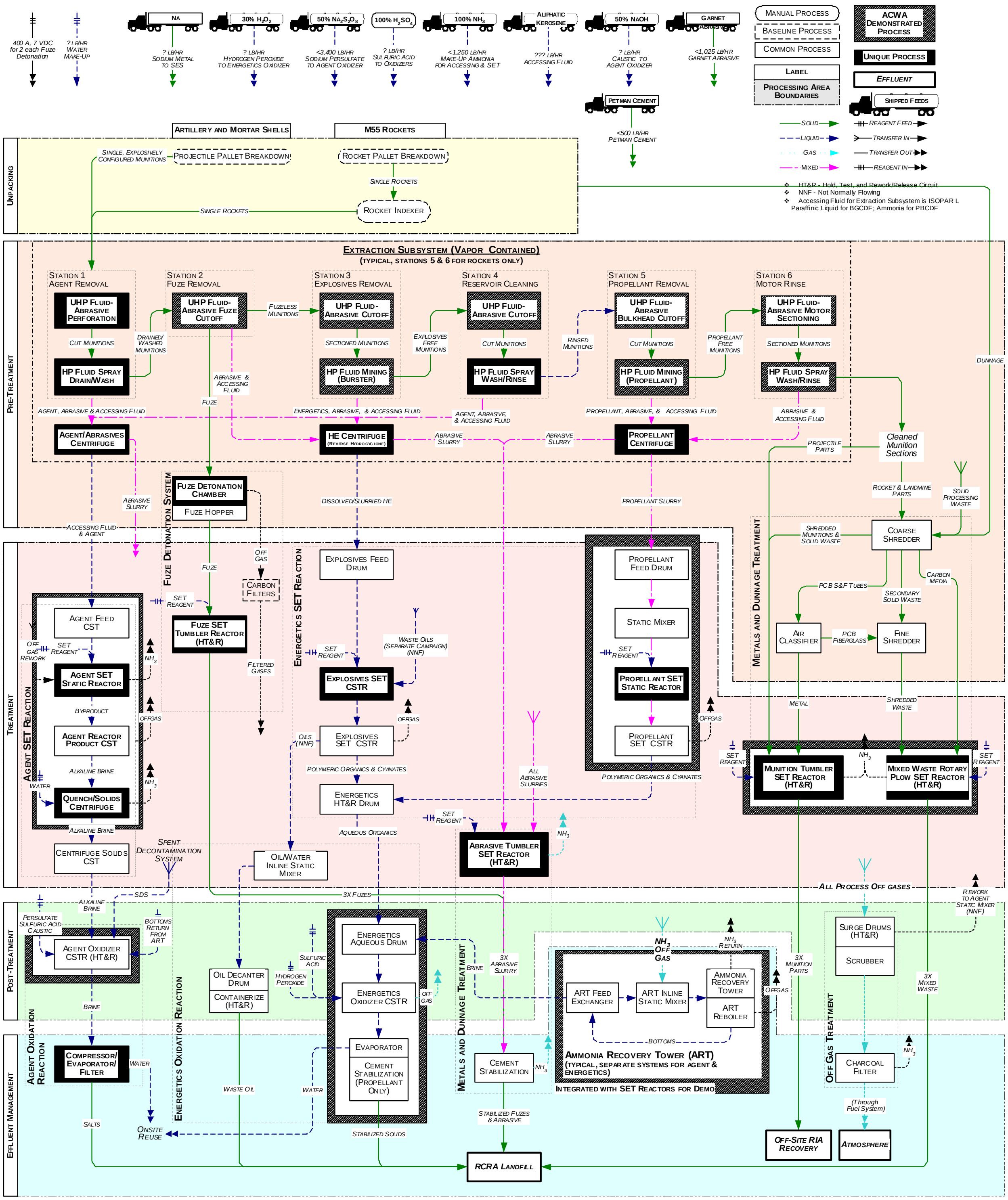

Figure C.4-3. Teledyne-Commodore Solvated Electron System Process Flow Diagram

As part of the Extraction Subsystem, centrifuges separate liquids from grit (spent abrasive and swarf): the Agent Centrifuge for Stations 1 and 4; the High Explosives Centrifuge for Stations 2 and 3; and the Propellant Centrifuge for Stations 5 and 6.

The Coarse Shredder size-reduces dunnage and solid processing waste as well as rockets from the Extraction Subsystem. Air classification separates metal from coarse-shredded mixed waste. Coarse-shredded, non-metallic, mixed-waste (except carbon) is further size reduced in the Rotary Knife Granulator fine shredder.

The Fuze Detonation System detonates fuzes and treats the hardware with SET. This system uses a Fuze Detonation Chamber (FDC), which uses an electric arc to destroy fuzes in an explosion-hardened vessel.

Treatment

The SES uses Solvated Electron Technology (SET) for treatment of agent and energetics. The SET reagent is sodium metal dissolved in anhydrous ammonia, which generates solvated electrons that destroy organic material by chemical reduction. SES has separate processing lines:

- **Agent SET Reaction—**Static mixer/reactors and CSTRs for centrifuged liquid from agent draining and washout at Extraction Subsystem Station 1 and 4
- **Energetics SET Reaction—**CSTR for centrifuged liquid from energetics fluid mining and washout at Extraction Subsystem Station 2
- **Fuze SET Treatment—**Tumbler/reactor for shrapnel from the FDC
- **Metals SET Treatment—**Tumbler/reactor for size-reduced metals and artillery shells
- **Dunnage SET Treatment—**Rotary plow reactor[i] for size-reduced mixed wastes, waste oils, and spent hydraulic fluid

The SET reaction effluents are quenched with water to destroy remaining sodium. Agent and energetics are combined into one SET reaction train for sites with projectiles only (Pueblo). Separate agent and energetics SET reaction trains are used at sites with M55 rockets in the inventory.

Post-Treatment

Residual organics in alkaline brines from SET, after quenching, are oxidized with aqueous chemical reagents. Sodium persulfate is used to oxidize effluent from the Agent SET Reaction. Hydrogen peroxide is used to oxidize effluent from the Energetics SET Reaction. Effluent from the Agent SET reaction is combined with the bottoms from the ART and with spent decontamination solution (SDS) for persulfate oxidization.

SET produces flammable synthesis gas, which is used a supplemental boiler fuel. Spent ammonia is evaporated from the process and recovered in respective Agent or Energetics

[i] A horizontal cylinder with a rotating "plow" along the side of the cylinder for material movement

Ammonia Recovery Towers (ARTs). Each processing line has HT&R. FDC offgas is carbon filtered and, along with all other process offgas, sent to Offgas Treatment for HT&R (rework to agent static mixer), scrubbing, and carbon filtration.

Effluent Management

Brine from sodium persulfate oxidation (agent line) is evaporated with the salts being sent to a RCRA landfill. If only high explosives are processed (projectiles only), the brine is evaporated and the salts are sent to a RCRA landfill. If propellant is processed, the brine is stabilized in cement and sent to a RCRA landfill. Treated grit and fuze shrapnel are each stabilized with cement and sent to a RCRA landfill. 3X metals[i] are sent to Rock Island Arsenal for thermal decontamination to 5X [ii] and eventual commercial recycle. Treated mixed solid wastes are sent to a RCRA landfill.

Deviations from the original design include the following:

- The fluid-accessing carrier is changed from anhydrous ammonia to Isopar-L for accessing ACW at sites with rockets.
- Only one SET reaction train (for treatment of agents and energetics together) is used for sites with projectiles (due to the low energetics content of the munitions present at such sites).
- The waste oils, spent hydraulic fluid, and dunnage material are treated in the Dunnage SET Reactor.

C.4.3.1.2 Unit Operations Not Selected for Demonstration in Demonstration II

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

- **Shredder (Size-Reduction)—**This is common commercial equipment used for marginal size reduction of material for feed to the Metal and Dunnage SET Reactor. Although size reduction was not demonstrated, material was shredded off-site to validate the ability of the shredder to adequately prepare the dunnage and metal parts for downstream processing in the Metal and Dunnage SET Reactor.
- **Air Classifier—**This is a well-established industrial process used on a variety of materials.

[i] Toxic Chemical Agent Safety Standards, Army Pamphlet 385-61, 31 March 1997. 3X (XXX) indicates that the item has been surface decontaminated, then contained and the headspace air verified to contain agent concentrations below the airborne exposure limits for unmasked workers. Access to 3X material is generally restricted to government personnel and contractors.
[ii] Ibid. 5X (XXXXX) indicates that an item has been decontaminated completely of the indicated agent and may be released for general use or sold to the public.

- **Fuze Detonation Chamber—**This well-developed process has been demonstrated at Iowa Army Ammunition Plant.
- **Offgas Treatment—**This is a well-developed scrubber and filtration system demonstrated commercially and in baseline CDFs.
- **Ammonia Recovery Tower—**Distillation of ammonia for recycling is a well-established industrial process.

C.4.3.1.3 Unit Operations Selected for Demonstration

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

C.4.3.1.3.1 Demonstration Test Issues

The technology provider experienced significant problems in getting their Agent SET Reaction System (see Section C.4.3.1.3.4) operational at CAMDS, resulting in significant delay of the installation and systemization phases. The three primary causes of the delay were:

- Incomplete systems were shipped to the test facility, which added considerably more time for installation (such as electrical connection and instrumentation placement).
- Incomplete and inaccurate electrical and mechanical design drawings (the field installation teams frequently needed clarification on how to install the system).
- The technology provider underestimated the time required to conduct the necessary installation and systemization activities.

In addition to these causes for delay, on July 6, 2000, several workers were exposed to a small sulfuric acid spill that occurred during systemization activities. This incident required an investigation by both the technology provider and test facility personnel. Some minor corrective actions were identified and incorporated to reduce the risk of similar events from happening in the future. The process of determining and implementing the necessary corrective measures delayed the program further.

On August 24, 2000, it was determined that agent testing could not be completed prior to the PMACWA deadline of September 25, 2000, and as a result, PMACWA terminated all SES demonstration testing at CAMDS. Consequently, there were no agent tests conducted for SES. The schedule delays resulted in a test end date that went far beyond the timelines established to deliver this report to Congress in March 2001. In addition, substantial cost growths occurred. Procurement sent a letter to the technology provider on August 24, 2000 ordering them to cease work under their contract with ACWA. The PMACWA authorized the technology provider to complete energetics testing at DPG (portions of the Extraction Subsystem and Energetics SET\Oxidation) at the technology provider's own expense providing that testing was complete by September 27, 2000 and a final report was delivered.[193] The PMACWA's decision to terminate the agent testing was because the technology provider could not maintain the Demonstration II test schedule even if the entire SES cost overrun was funded. Any delays in the Congressional Report would also delay the execution of the FY01 funds programmed for

ACWA. There were also concerns that the cost growths associated with the SES demonstration could jeopardize completion of other technology demonstrations.[194]

As discussed in Section C.4.3.1.3.2, an energetic incident occurred on 19 September 2000.

C.4.3.1.3.2 Extraction Subsystem

Only the fluid accessing portions of the Extraction Subsystem, as a non-integrated system, were to be demonstrated. Fluid-abrasive cutting and fluid mining technologies, the primary accessing technologies of the Extraction Subsystem, are reasonably well-established industrial operations. The ability to cut through the materials in an M55 rocket was not the major reason for demonstrating these technologies. Rather, the demonstration rationale was to verify the application of fluid accessing to energetics in the ACW components. This is because the use of ammonia as the fluid medium is not as well established; fluid mining and spray washing (to remove energetics from ACW) have not been validated with ammonia. In addition, it was important to characterize the quantity and type of grit required, fluids produced, and energetics remaining in the rocket as well as to determine the suitability of energetic particles from rocket access and washout for subsequent Energetics SET/Oxidation. The physical and chemical attributes of the streams from the Extraction Subsystem are critical to materials handling and downstream operations. The Extraction Subsystem was demonstrated at the Suppressive Shield Facility at DPG, Utah.

Fluid accessing also provides feeds required for testing Energetics SET/Oxidation. The test objectives of the fluid accessing demonstration included the following:

- Demonstrate the ability of the fluid-abrasive cutting and fluid mining to prepare a suitable feed to the SET reactions and subsequent oxidation reactions
- Demonstrate the ability of fluid-abrasive cutting and fluid mining to separate the burster charges and propellant from rockets
- Demonstrate the accuracy and precision with which fluid-abrasive cutting can position and cut the rockets by using manual placement of the rockets
- Determine the impact of fluid-abrasive cutting and fluid mining operations on containment vessel components (e.g., integrity of the chamber seals)

The design of the fluid accessing demonstration unit used ammonia fluid-abrasive cutting to remove the fuzes and section the rockets and used fluid mining to erode out the energetics (burster charges and the propellant). The demonstration planned to process 18 115-mm rockets—15 M60 (inert) and 3 M61 (energetics only). M60 rockets have no agent or explosive fills and M61 rockets are fully explosively configured (contain the same M417 fuze, Comp B burster, and M28 propellant as the M55 rocket) but have an ethylene glycol fill instead of agent.

Although 15 inert M60 rockets were processed, an energetic incident occurred on 19 September 2000 during the second of three workup runs held prior to the start of validation testing for this unit. A fire occurred due to ignition of the rocket during fluid mining of a burster charge in a M61 rocket. Because of this incident, the test schedule was severely compromised and no further testing of the technology provider's energetics processing system was conducted.[195]

An ACWA/DPG investigation team was assembled to review the findings of an incident investigation conducted by the technology provider. The most likely cause of the incident was determined to be propellant ignition. Although suspected, it cannot be proven that the ignition was due to an exothermic reaction between the M55 rocket materials and ammonia vapors. Because of this incident, the technology provider elected to change the fluid-accessing carrier from ammonia to Isopar-L for all M55 rockets and other munitions at sites with M55 rockets in their inventory.

C.4.3.1.3.3 Energetics SET/Oxidation

The Energetics SET/Oxidation demonstration was intended to validate destruction of the energetics contained in ACW, but it could not be completed due to failure to complete the fluid accessing demonstration (discussed above). The Energetics SET/Oxidation system was installed at the Suppressive Shield Facility at DPG, Utah. The demonstration system was an integrated unit consisting of the following:

- **Energetics SET Reaction System—**This system included a solids addition canister for dissolution of sodium and solid feeds in ammonia; the SET reactor; the quench reactor where the SET reactor effluent was quenched with water; and the ammonia recovery and offgas treatment systems.

- **Oxidation Reaction System—**The standalone oxidation system oxidized the effluent from the quench reactor with hydrogen peroxide. Caustic and sulfuric acid were used for pH control of the oxidation reaction.

The fluid accessing demonstration system was located adjacent to and was intended to provide certain feeds for Energetics SET/Oxidation. Laboratory scale testing of both the SET and the oxidation reactions was previously performed with typical ACW energetic feeds. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives of Energetics SET/Oxidation included the following:

- Validate the ability of the SET and the oxidation reactors to achieve a DRE of 99.999% for Comp B (RDX and TNT), Tetrytol (tetryl and TNT), and M28 propellant (NC and NG)

- Demonstrate the operation and performance of the Energetics SET Reaction, Ammonia Recovery (contaminant buildup), and the Oxidation Reaction to support future scale-up

- Demonstrate the ability to produce a gas effluent meeting requirements of either EPA syngas or BIF requirements

- Demonstrate the effectiveness of the solidification and stabilization process for treatment of the solids from Energetics SET/Oxidation (M28 propellant runs only)

- Characterize gas, liquid, and solid process streams from Energetics SET/Oxidation for selected chemical constituents and physical parameters, and for the presence/absence of hazardous and toxic compounds

The technology provider completed two workup runs—one for treatment of Comp B and one for treatment of M28 propellant. However, due to the energetic incident (discussed in Section C.4.3.1.3.2) that occurred prior to the start of validation testing, no validation data were obtained for Energetics SET/Oxidation.

C.4.3.1.3.4 Agent SET/Oxidation

Agent SET/Oxidation demonstration was intended to validate destruction of chemical agents, but could not be completed due to problems encountered during demonstration (discussed previously). The Agent SET/Oxidation system was installed at the Chemical Test Facility at CAMDS at Deseret Chemical Depot, Utah. The demonstration system was an integrated unit consisting of the following:

- **Agent SET Reaction System—**This system included a solids addition canister for dissolution of sodium and solid feeds in ammonia; the agent SET reactor itself; the quench reactor where the agent SET reactor effluent was quenched with water; and the ammonia recovery and offgas treatment systems.

- **Oxidation Reaction System—**This standalone system oxidized the effluent from the quench reactor with sodium persulfate. Caustic and sulfuric acid were used for pH control of the oxidation reaction.

The oxidation reaction was to demonstrate the destruction of Schedule 2 and other organic compounds from Agent SET Reaction quench products. Destruction of Schedule 2 compounds is a CWC requirement and thus demonstration of the oxidation system was essential. Laboratory scale testing of the SET and oxidation reactions had previously been performed with HD, GB, and VX. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives of this demonstration unit included the following:

- Validate the ability of the SET/Oxidation Reactors to achieve a DRE of 99.9999% for VX, GB, and HD

- Demonstrate the operation and performance of the Agent SET Reactor, Ammonia Recovery, and the Oxidation Reactor to support future scale-up.

- Demonstrate the effectiveness and accuracy of the ambient monitoring equipment for agent in the presence of ammonia

- Validate the ability of the Oxidation Reaction to eliminate Schedule 2 compounds present in the effluent from the Agent SET Reactor

- Demonstrate the ability to produce a gas effluent meeting requirements of either EPA syngas or BIF requirements

- Characterize gas, liquid, and solid process streams from each reactor for selected chemical constituents and physical parameters, and for the presence/absence of hazardous and toxic compounds including residual agent and Schedule 2 compounds

Due to the schedule delays and substantial cost growths discussed in Section C.4.3.1.3.1, no testing was conducted with the Agent SET/Oxidation demonstration equipment.

C.4.3.1.3.5 Metal and Dunnage SET Reactor

The Metal and Dunnage SET Reactor was demonstrated to validate destruction of chemical agent simulants. The demonstration system included a multi-purpose Metal and Dunnage SET Reactor where sodium was gravity fed and mixed with ammonia followed by quenching with water at the conclusion of the run, and the ammonia recovery system. The Metal and Dunnage SET Reactor was demonstrated at the Suppressive Shield Facility at DPG, Utah.

This demonstration was to validate 3X decontamination (surface decontamination) of solid and liquid secondary wastes. Characterization of gaseous, liquid, and solid effluents was required, as was verification of operating parameters. The test objectives of this demonstration unit included the following:

- Demonstrate the ability to handle and feed the shredded dunnage and metal into the Metal and Dunnage SET Reactor
- Validate the ability of the Metal and Dunnage SET Reactor to achieve a 3X condition or equivalent using agent simulant on shredded metal parts and dunnage
- Demonstrate the operation and performance of the Metal and Dunnage SET Reactor and Ammonia Recovery to support future scale-up
- Characterize the Metal and Dunnage SET Reactor offgas to determine if the gas effluent meets either the EPA syngas or BIF requirements
- Characterize gas, liquid, and solid process streams from the SET process for selected chemical constituents and physical parameters and for the presence or absence of hazardous and toxic compounds including residual agent simulants

The Metal and Dunnage SET Reactor was tested with the following materials:

- 15 lb shredded metal parts spiked with 1,000 PPM 1,4-dichlorobutane (DCB, a simulant for mustard agents), (3 runs of 5 lb each)
- 15 lb shredded double-bagged DPE with butyl rubber spiked with 1,000 PPM DCB (3 runs of 5 lb each)
- 15 lb shredded wood pallet material spiked with 1,000 PPM DCB and 4,000 PPM PCP (3 runs of 5 lb each)
- 15 lb carbon spiked with 1,000 PPM DCB (3 runs of 5 lb each)
- 15 lb shredded S&F container fiberglass spiked with 1,000 PPM Malathion (a simulant for nerve agents) (3 runs of 5 lb each)

C.4.3.2 Technical Evaluation

C.4.3.2.1 Process Efficacy/Process Performance

C.4.3.2.1.1 Effectiveness

The lack of any validation data for agent or energetics from the ACWA demonstration prohibits the validation of the SET technology. Extensive laboratory and bench scale testing of the SET with agents HD, HT, GB, and VX indicates that destruction efficiencies greater than 99.9999% can be achieved routinely.[196] Laboratory testing of SET with energetics (TNT, RDX, tetryl, M28 propellant, and Comp B)[197] as well as limited chemical analyses from the SET-Energetics workup runs indicate that destruction efficiencies greater than 99.999% can be achieved routinely for all energetics except NG; the highest DRE for NG was 99.996%.

SET was not validated to provide effective 3X decontamination of simulants DCB and Malathion. The reported detection limits associated with the technology provider's approach to analysis of the headspace samples are significantly greater than the levels required to document the 3X condition. Neither simulant was detected[198] with a detection limit of 0.1-0.2 mg/m^3 in the headspace over the dunnage residue after treatment of shredded metal parts, double-bagged DPE with butyl rubber, wood pallet material, carbon, and fiberglass S&F containers. Coupon tests of HD-, GB-, and VX-contaminated carbon steel, stainless steel, aluminum, copper, brass, and titanium conducted prior to the ACWA demonstration[199] indicate that a 3X condition could be achieved. Mustard heel, agent-contaminated solid wastes, and energetics contaminated with agent have been destroyed in laboratory experiments with SET.[200]

Insufficient data were obtained during demonstration to validate the effectiveness of the process with known impurities and additives, including mixtures of agent and energetics and agent or energetics degradation products. However, SET destroys PCBs to below federal standards.[201]

In summary, no information regarding the effectiveness of SET was collected during the ACWA Demonstration Test Program. Although prior small-scale laboratory testing by the technology provider indicates the likely effectiveness with agent and energetics, agents and energetics destruction have not been independently verified and validated in demonstration testing. There is information available that indicates that SET effectively decontaminates metal parts to 3X, but demonstration data for 3X decontamination of metal parts and dunnage were inconclusive.

C.4.3.2.1.2 Products

No information regarding the products of the Agent SET and Energetic Systems was collected during the ACWA Demonstration Test Program. Therefore, validation of products from treatment of agent and energetics with SET and the subsequent oxidation was not possible. The lack of demonstration testing also prevents validation of the absence of agent reformation. The technology provider showed in laboratory testing that the SET reactions of mustard species generate no Schedule 1 or 2 compounds. However, Schedule 2 compounds are formed by the reaction of GB and VX with SET.[202] The absence of Schedule 1 or 2 compounds from the product of the oxidation step was not validated because of the absence of demonstration data.

The technology provider has provided mass balances for agent and energetics feeds based on test data from prior laboratory studies.[203] Based on the chemistry of the process,[204] and laboratory tests, it appears that SET cannot reform agent. Laboratory experiments conducted by the technology provider showed that the oxidation step removes Schedule 2 compounds from the effluents. Reaction products of RDX and Comp B with SET, gaseous effluents from energetic testing, and residues of TNT-SET reaction were also characterized by the technology provider.[205] Identification of TNT-SET, M28-SET, or tetryl-SET, reaction products using standard techniques is incomplete because the residue is an uncharacterized polymer.[206] The SET energetics oxidation products are also not well characterized. Laboratory-scale studies indicate that SET reduces organic compounds; based on the chemistry of the process, it appears that SET does not form chlorinated VOCs, dioxins, and furans. However, the chemistry of the process indicates a potential for SET reactions with tetryl or TNT to form carcinogens.[207] A more complete characterization of products from treatment of agent and energetics with SET and the subsequent oxidation was not possible.

The products of the SET Metal Parts and Dunnage processing with agent simulants were characterized during the ACWA Demonstration Test Program. The Metal Parts & Dunnage SET system processes PCB-containing rocket S&F containers; SET destroys PCBs to below federal standards and it has been permitted for PCB destruction.[208]

In summary, the lack of demonstration data from agent or energetic treatment from both SET and the subsequent oxidation step prohibits validation of the products of this process.

C.4.3.2.1.3 Sampling and Analysis

Modified method evaluation studies were successfully completed for the EPA analytical methods and for measuring chemical agents and energetic constituents in a simulated SET liquid matrix.[209] Limitations of the method evaluation studies include the need for significant sample dilution prior to analysis to reduce matrix interference and the use of simulated matrices that may not be entirely representative of actual samples. However, acceptable method detection limits (MDLs) were attained for the following sampling and analysis methodologies:

- Agent in SET quench solutions[210]
- TOC in VX-SET and in SET oxidation solution
- Ammonia in SET quench solution and in SET oxidation solution
- Metals in VX-SET quench solution
- Mercury in VX-SET quench solution
- Cyanide in Energetics-SET oxidation solution and in Energetics-SET quench solution
- Anions in SET quench solutions
- Volatile organic compounds in SET quench solutions and in SET scrubber brine solution
- SVOCs in SET scrubber brine solution
- Dioxins/furans in SET oxidation solution

- Aldehydes/ketones in Energetics-SET oxidation solution (with some easily resolved difficulties)

- NG in SET quench solution

In addition, analysis of SVOCs in SET oxidation solution was successfully validated, with the exception of aniline derivatives. This is a significant exception, because aniline derivatives are likely products of the SET-Energetics process.

No validation data were generated for the Agent SET or Energetics SET operations. Therefore, it is not possible to assess whether the sampling and analysis methodologies produce data usable for evaluation of the technology and characterization of the process effluents. Sampling and analysis methodologies for several hazardous compounds of concern did provide acceptable quality control results in laboratory testing prior to the ACWA demonstration. Validation of PCB analysis has been performed as part of the process of obtaining approval to dispose of PCBs using SET. Laboratory testing by PMACWA indicated that an ammonia environment did not limit agent monitoring with standard Army agent monitoring methods such as ACAMS or DAAMS.

In summary, nearly all sampling and analysis methodologies proposed for use during demonstration were validated in the laboratory. However, no agent or energetics validation testing was conducted during demonstration, so it cannot be determined whether the methods would have produced acceptable amounts of usable data with the actual SET matrices.

Table C.4-7. Level of Verification for SET Analyses

Type of Analysis	Amount of Usable Data
Feed and Product Composition	Not verified
Low Level Agent	Not verified
Low Level Energetics	Not verified
Hazardous Substances	Not verified

C.4.3.2.1.4 Process Maturity

In general, the unit operations that comprise SES do not have a level of maturity adequate for timely implementation and constitute a high technical risk. The fluid accessing system did not complete the required ACWA demonstration validation tests. Explosives accessing of rockets was not completed due to an inadvertent ignition of an M61 rocket motor during operations. Systemization of Agent SET/Oxidation was never completed so no testing was conducted. The Metal and Dunnage SET Reactor was demonstrated with agent simulants.

Pre-Treatment

Although, fluid accessing systems have historical commercial industrial basis, the SES Extraction Subsystem fluid accessing techniques have not been validated in the proposed configuration or with ACW. Although there is some limited full-scale testing, there is insufficient information to extrapolate the functionality of the proposed system to full-scale.

Since demonstration was not completed, there has been no validation of data and process parameters.

The Extraction Subsystem uses high-pressure fluid to cut, mine, and wash the munitions, an indiscriminant, robust process that uses common fluid systems and equipment. Fluid accessing equipment and principles where validated during Demonstration I by using water as the fluid medium. However, there is insufficient information to extrapolate its applicability to the SES. The proposed SES has not shown itself capable of effective accessing, removal, and size reduction of propellant for SET treatment. In addition, SET requires significant size reduction of rockets and dunnage with extensive material segregation for treatment in the SET reactors. Centrifuges, which are a critical part of this segregation, are widely used commercially, but they have not been demonstrated for SES.

Rocket accessing has not operated with the proposed materials, representing a high technical risk. As indicated by the rocket ignition incident observed during demonstration, there is still much that is unknown about the physical and chemical interactions of ammonia with the ACWs. There appears to be an inherent incompatibility between ammonia and the M55 rocket materials, the likely candidate being the M28 propellant. Insufficient data were provided regarding the technology provider's proposed use an alternative fluid, Isopar-L, at sites with rockets. Based on the lack of data on the use of Isopar-L in SES,[211,212] the unknown compatibility of rockets and ammonia,[213] and the absence of any validation data, the revised SET process is considered immature.

The Extraction Subsystem consists of many munition handling and manipulation steps and an integrated unit has not been built or demonstrated. The ACWA demonstration system had only limited automation (manually setup for automated movement). Extensive design and development are required for full-scale implementation, which increases the technical risk associated with this portion of the proposed process.

Treatment

The SET reagent is used to treat agent and energetics in neat form and on metal parts and dunnage. The different, segregated feeds are treated in a variety of reactors (CSTR, tumbler, and rotary plow). Although numerous tests have been previously conducted by the technology provider,[214] the ACWA demonstration of Agent SET or Energetics SET was not demonstrated or validated by PMACWA. SET treatment for dunnage and metal parts was demonstrated; however, decontamination of agent simulants was not validated.

Most components in SES, including all those supporting the SET reaction and oxidation treatment, are off-the-shelf or made-to-order; a comprehensive list of equipment and suppliers was provided.[215] The SES Extraction Subsystem components are specialty items. Stainless and carbon steel are the only materials of construction required.

Post-Treatment

The SES process uses oxidation for post-treatment; however, this was not demonstrated for PMACWA. Considerable laboratory data were previously provided to support post-treatment oxidation of residues from SET agent and energetic treatment.[216] While the specified equipment is in common industrial use, this particular application is unique. There are still questions regarding the configuration of the oxidation step for the SET energetics residue and the control of vigorous chemical reactions with the potential for foaming and the generation of heat and gases, as indicated by laboratory testing. Cement stabilization has not been demonstrated for the SES waste streams. The lack of any industrial experience in processing agent or energetics residues from SET treatment at a demonstration scale is a major process maturity concern at this stage of the ACWA program.

Summary

Demonstration was required to provide information on transport and segregation of materials, control of the overall extraction and treatment systems, ability to demonstrate scale-up, and accumulated experience with working with agents and energetics at larger than laboratory quantities. Three of the four proposed major unit operations were not demonstrated, and information required on the performance of this technology was not available. PMACWA considers the level of maturity of SES inadequate for timely implementation.

C.4.3.2.1.5 Process Operability

The operability characteristics of the SES process for ACWs remain undemonstrated, and the stability of the various SES reactions cannot be extrapolated with the necessary degree of confidence beyond laboratory scale. There are several major concerns about the SES related to process stability including the unknown stability of post treatment oxidation, and the unknown operating characteristics of the process with Isopar-L.

The operability of the SET reaction within safe operating ranges is complicated by the fact that SET reactions are vigorous, exothermic, and sensitive to both sodium concentration and feed ratios.[217] Laboratory experience indicates that post-treatment oxidation could be inherently unstable, with heat, foam, and gas generated when reagents such as persulfate and hydrogen peroxide are added to SET energetics residues. The implications of this laboratory experience for full-scale operation are not clear, and the lack of any demonstration data precludes alleviation of these concerns.

The technology provider found an incompatibility between ammonia and most likely the propellant of the M55 rocket, as evidenced by the rocket ignition during the second M61 rocket accessing workup run.[218] The use of Isopar-L has not been demonstrated and insufficient data on the operability of the process were provided. In the absence of such data, the operability and stability of the revised process is unknown.

SET is a relatively indiscriminate reaction, which has been shown in the laboratory to tolerate modest changes in feed rate and purity without reducing destruction efficiency. The demonstration testing that was performed with dunnage showed that greater than expected amounts of gas were produced in the SET fiberglass, carbon, and wood validation runs. Although the reactors can be designed for higher temperatures and pressures, the dunnage runs indicate the potential for rapid changes in conditions if not properly controlled.

The entire system is complex with a large number of unit operations and numerous mass transfer challenges. The complexity arises from the 6-station fluid accessing Extraction Subsystem that replaces reverse assembly; extensive segregation of feed materials involving centrifuges, shredders, and classifiers; interfaces involving multi-phase streams (gas, liquid, vapor, slurry, and solid). Pretreatment involves the use of the SES Extraction Subsystem with six stations and multiple articulations inside a pressurized vessel. Segregation of feed is required throughout the process, involving multiple centrifuges, shredders, and classifiers. The five SET reactors require complex controls for addition of feed and chemicals, control and testing of reaction, elimination of excess sodium, and evaporation of ammonia. The interfaces involve transport of slurries between vessels maintained at high pressure to keep ammonia as a liquid. Transport of agent, energetics, and SET residues will involve non-homogenous mixtures, including emulsions, suspensions, and slurries. The lack of bench scale experience with the multitude of expected process fluids further complicates the prediction of mass transfer methods required for a full-scale design.

The lack of demonstration data results in an inability to extrapolate reliability, availability, and maintainability (RAM) characteristics for full-scale. Based on current information, the RAM characteristics for the Extraction Subsystems are expected to be poor. Without the benefit of demonstration testing, the number and skill levels of operators and the requirements for preventative and routine maintenance cannot be estimated. Based on the batch nature of the SET and oxidation reactions, there are manageable demands for startup/shutdown, idle, and upset recovery.[219]

In summary, the SES process for ACWs is complex with undemonstrated operability characteristics. There are numerous concerns about the reliability and stability of the Isopar-L rocket accessing and follow on SET treatment.

C.4.3.2.1.6 Process Monitoring and Control

The lack of operating data at demonstration scale with neat agents and energetics poses a high technical risk at this stage of the ACWA process. The ability to monitor and control the SES could not be verified.

Concerns raised during the technical evaluation prior to demonstration remain unresolved. For instance, there are considerable demands on the monitoring and control system for reliability and responsiveness since the SET reactions are very rapid. Another demanding area for monitoring and control is cooling the SET reactors. This is accomplished through ammonia evaporation, which increases the concentration of sodium relative to ammonia, thus increasing reactivity and temperature. Results from the dunnage treatment studies indicate the immaturity of the proposed conductivity monitoring scheme to control SET reactions with dunnage, and a potential to improperly gauge the remaining amounts of sodium in the reactor before or after water quenching.

The proposed monitoring and control technologies are commonly used and commercially available and they were described in detail as they relate to SES, with particular emphasis on SET reactions, and subsequent oxidation.[220] Most of the critical process units are batch mode, and the monitoring and control strategy incorporates ten HT&R points throughout the process to increase stability. Commodore’s industrial SET unit for PCB destruction, very similar in many aspects to the proposed system,[221] includes a monitoring and control system that measures conductivity and controls temperature and pressure through ammonia evaporation. The controls are fully automated, with safety interlocks to prevent upsets.

Monitoring and control of the SES Extraction Subsystem are defined in less detail. The instrumentation for this system has not been tested, and there are some questions about interference when optical sensors are used in the presence of debris. In addition, control of cross-contamination among stations in the SES Extraction Subsystem has not been addressed. A potential remains for propellant energetics to agglomerate in the cutting vessel or reactor and spontaneously react with ammonia. Minimal data were provided on monitoring and control for the use of Isopar-L in SES, and there are reservations about an unvalidated monitoring and control strategy for the revised process.

In summary, there are insufficient data to show that SES can be monitored and controlled. A major concern relates to the ability to effectively monitor and control the rocket accessing process and subsequent treatment.

C.4.3.2.1.7 Applicability

Based on previous testing conducted by the technology provider, SES could be feasible for treatment of all agents and energetics. However, the SES process was not validated by demonstration for treatment of agents and energetics. Treatment of agent simulant contaminated metal parts and dunnage was demonstrated with inconclusive results. The use of Isopar-L for fluid accessing at site with rockets remains undemonstrated, which represents a significant uncertainty in the applicability of SES.

C.4.3.2.2 Safety/Worker Health and Safety

C.4.3.2.2.1 Design or Normal Facility Occupational Impacts

The SET design incorporates many positive features with regard to worker safety during normal operations,[222] but some additional items must also be taken into account. Agent and energetics destruction systems operate at ambient temperature, eliminating hazards associated with high temperature operations. The potential for worker exposure is minimized by immediate destruction of agent and energetics. All process materials are commonly used in industry and can be handled in accordance with well-established industrial safety practices. Since the remote nature of the SET process protects workers from chemical and physical hazards associated with normal operating conditions, worker exposure to process materials and equipment is generally limited to maintenance operations. Maintenance will only be performed after the system is shut down, emptied of material, purged, and locked out, further protecting workers. Additional worker protection is provided by the fact that the SET reactors should be self-decontaminating to 3X, reducing the potential for worker exposure to agent. HT&R is used to monitor for agents at ten points throughout the process, reducing the potential for worker exposure. Agents and other hazardous materials can be detected with commercial monitoring equipment.

This technology is a complex array of process chemistry operations at near-ambient temperature but moderately high pressure. The SET solution has strong reducing power, which can cause gaskets, packing, and hoses to leak. There is likely to be a significant amount of maintenance and inspection in PPE.

There are eight major hazardous process chemicals used in large quantities:[223] sodium, anhydrous ammonia, sodium persulfate, hydrogen peroxide, copper chloride, sodium hydroxide, sulfuric acid, and iso-paraffinic hydrocarbon (Isopar-L). SET also generates hazardous intermediates, including SET hydrolysates, flammable gases, and cyanide salts. The technology provider's test report proposes the use of Isopar-L, a new process chemical.[224,225] The effect of this new chemical on intermediate and final products has not been established, adding uncertainty to the process evaluation. All of these chemicals (and particularly anhydrous ammonia and sodium) pose some routine exposure risk to workers during feed preparation and maintenance of process equipment. The risks of handling hazardous materials are mitigated with appropriate engineering design, remote operations, and process monitoring and control.

In summary, SES utilizes process materials that are commonly used in industry, and which can be handled in accordance with established industrial safety standards. The remote operations protect workers from chemical and physical hazards. However, there remain inherent risks associated with the large volume of hazardous chemicals used in the process (particularly anhydrous ammonia and sodium) and the uncertainty associated with the late introduction of new process chemicals.

C.4.3.2.2.2 Facility Accidents with Worker Impact

While there are many features incorporated into the SES design to provide for worker safety, there remain additional concerns that have not been adequately addressed. Agent and energetics destruction systems operate at near-ambient temperature, eliminating hazards associated with high temperature operations. The potential for worker exposure to agent is minimized by immediate destruction of agent and energetics and containment at the equipment level. All process materials are commonly used in industry and can be handled in accordance with well-established industrial safety practices. Since the remote nature of SES protects workers from chemical and physical hazards associated with accidents during operation, worker exposure to process materials and equipment is generally limited to maintenance. Maintenance will only be performed after the system is shut down, emptied of material, purged, and locked out, further protecting workers. Additional worker protection is provided by the fact that the SET reactors should be self-decontaminating to 3X, reducing the potential for worker exposure to agent.

HT&R is used to monitor for agents at ten points throughout the process, reducing the potential for contamination of process equipment and maintenance worker exposure. Agents and other hazardous materials can all be detected with commercial monitoring equipment.

There are eight major hazardous process chemicals used in SET in very large quantities: sodium, anhydrous ammonia, sodium persulfate, hydrogen peroxide, copper chloride, sodium hydroxide, sulfuric acid, and Isopar-L. SES also generates hazardous intermediates, including SET hydrolysates, flammable gases, and cyanide salts. The technology provider's test report proposes the use of a new process chemical, iso-paraffinic hydrocarbon (Isopar-L). The effect of this new chemical on intermediate and final products has not been established, adding uncertainty to the process evaluation. All of these chemicals pose some accidental exposure risk to workers upon failure of reactors, pumps, or pipes. The fluid-jet accessing system operates at very high pressure and the SET system operates at moderately high pressure, each creating a worker hazard during maintenance.

Accident initiators are associated with various process conditions that could result in worker injury from the accident itself or from exposure to agent or hazardous chemicals as part of the subsequent repair or maintenance activities. There is a potential for fires or explosions if sodium and water come into contact in an uncontrolled manner. This should be prevented through appropriate process controls. The flammable gases generated during the SET process also pose a risk of accidental fire or explosion. Design features to prevent accumulation of gases, monitor for gas buildup, and contain explosions at the equipment level can mitigate this risk.

A rupture in any of the high-pressure ammonia lines (ultra-high pressure fluid jet system or the pressurized lines to the SET reactors) would cause a jet of expanding and cooling ammonia gas. This would pose an inhalation or cold burn risk to workers, and could generate an explosive environment under certain conditions. Overpressurization of the fluid cutting line is prevented through the use of double wall piping with special fittings to prevent pressure buildup and detection of ammonia from bleed holes, with automatic system shutdown if leakage is detected.

There is a possibility that energetics or SET residues from the energetics reaction could ignite. Since some SET residues are sensitive to electrostatic discharge and show sustained flammability, there is some risk to workers during maintenance of SET systems. There is a possibility of temperature or pressure excursions if the concentration ratios of ammonia, sodium, energetics, and agent drop below critical values. Controlling the ratios to levels below their critical levels and providing for automatic shutdown if the ratios are reached prevents this event.

In summary, SES utilizes process materials that are commonly used in industry, and which can be handled in accordance with established industrial safety standards. The remote operations protect workers from chemical and physical hazards. However, the inability of the technology provider to demonstrate that the process can be carried out safely and effectively coupled with the ignition of the rocket during demonstration testing severely impacts the safety evaluation and reduces the confidence in the inherent safety of this technology. Because insufficient data supporting the assumption that the use of Isopar-L would prevent propellant ignition were provided, there is still an undefined element of risk associated with the process.

C.4.3.2.2.3 Facility Accidents with Public Impact

The potential for public exposure to agent is minimized by immediate destruction of agent and energetics. Agent and energetics are introduced to the SET reactors immediately upon separation from the munitions, where they are destroyed very rapidly. This aspect of the SET process minimizes the risk to the public by minimizing the amount of time and quantity of material at risk of accidental release. Agent and energetics destruction systems operate at near-ambient temperature, eliminating hazards associated with high temperature operations. Total containment of vapor in the event of an accident or explosion is provided, mostly at the equipment level.

HT&R is used to monitor for agents at various points throughout the process, reducing the potential for release of agents or other hazardous materials to the public. Commercial monitoring equipment for agents and other hazardous materials can be used in the SET process. In general, the safeguards, monitoring, and controls that minimize worker impact in the event of a facility accident are similarly beneficial with respect to public impact. Although SET uses or generates large quantities of hazardous materials, all process materials are commonly used in industry and can be handled in accordance with well-established industrial safety practices. These provisions mitigate the risk of accidental release of process chemicals that are stored in large quantities and could be dispersed to the public. However, if an accident were to occur involving significant amounts of ammonia, which will volatilize at ambient temperature and pressure, there could be an impact to nearby populations with a protective action zone of up to 0.7 miles downwind being established.[226]

There are several additional accident scenarios that have the potential for facility damage, including: the initiation of energetics from the reaction of M28 propellant; fires or explosions from sodium and water interactions or the flammable gases generated during the SET process; and temperature or pressure excursions if the ratio of ammonia to sodium drops below a critical value. These accidents are prevented through design features, automatic monitoring and control, and administrative controls. The consequences of these and other accidents are mitigated through the application of containment at the equipment and facility level and with extensive monitoring. Even if an accident occurs during operations, public impact is minimized or eliminated since several layers of system and facility secondary containment should efficiently mitigate and contain the effects and prevent public exposure.

In summary, this technology minimizes the risk of a serious accident affecting the public because exposure to agent is reduced by the immediate destruction of agent and energetics, and containment is provided at the equipment and facility level. The only accident scenario likely to have a public impact would be one involving the rapid release of significant amounts of ammonia.

C.4.3.2.2.4 Off-Site Transportation Accidents

Process chemicals transported onto the site for use with SET are materials commonly used in industry, and which can be handled in accordance with well-established industrial safety practices. Seven major hazardous process chemicals (sodium, anhydrous ammonia, sodium persulfate, hydrogen peroxide, sodium hydroxide, sulfuric acid, and Isopar-L) are utilized. Of these chemicals, none are carcinogenic. However, the total volume of both process and waste-stream materials is expected to be high.

The DOT has classified the process chemicals as corrosive (sulfuric acid),[227] oxidizer (sodium persulfate),[228] corrosive oxidizer (hydrogen peroxide),[229] dangerous when wet (sodium),[230] flammable liquid (Isopar-L),[231] and non-flammable gas (ammonia).[232] Most of these chemicals pose relatively low hazard to nearby populations or workers in the event of a transportation accident. However, anhydrous ammonia is the most hazardous process material. As a gas, it can spread quickly in an accident, and can readily damage body tissue on contact. Ammonia can give an explosive mixture in air. Additionally, sodium reacts violently in contacting water.

The overall process produces no liquid effluent.[233] Waste materials that would have to be transported offsite consist of containerized salts, waste oil, solid mixed waste, and treated energetics residues that are cement stabilized.[234] Solid mixed wastes are likely to be at the 3X level of decontamination. Detailed characterization of the waste oil treatment product and the treated energetics residues has not yet been provided. The effectiveness of cement in stabilizing the toxic energetics residues has also not been demonstrated. Very high volumes of waste products are to be generated.

Standard HAZMAT and fire department PPE, containment equipment, and techniques should be sufficient to contain any potential spills. However, standard fire department PPE is not adequate for sulfuric acid or ammonia spills.[235] Evacuation zones would be less than 100 yards for most of the process chemicals, although transportation accidents involving truckload quantities of anhydrous ammonia could result in an evacuation zone of up to 200 yards, with a larger protective action zone being established as well.[236] No special training beyond OSHA HAZMAT and DOT requirements is needed.

In summary, this technology poses minimal risk of a serious accident affecting the public. Standard HAZMAT responses are adequate. The chemicals, however, are transported and used in large volumes and ammonia accidents may require the establishment of a significant protective action zone if a serious accident were to occur.

C.4.3.2.3 Human Health and Environment

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

The Demonstration Test Programs for both the Agent SET and Energetics SET Systems were terminated by PMACWA before any validation testing was conducted. Because these two test programs were not conducted, the data that are available on the effluent characterization are based on limited testing by the technology provider conducted prior to the ACWA Demonstration Test Program. The effluents from the Metal and Dunnage SET Reactor were characterized; however, the system tested for PMACWA is not entirely representative of the proposed full-scale system and modifications to the unit may change the characterization of the effluents. Demonstration did not answer critical issues associated with effluent characterization and impact on human health and environment.

Many effluent sampling and analysis methods are well developed and applicable to proposed stream monitoring, but they were not demonstrated due to the early termination of the SET demonstration. HT&R following several stages of treatment is utilized for gaseous effluents. There are no external liquid effluents proposed in the technology provider's final report.[237]

There are several positive aspects with regard to effluent characterization. SET recycles or reuses many of the product streams from various unit operations. Synthesis gas produced is proposed for use as supplemental fuel for heating, reducing the need for boiler fuel and exhausting CO_2, a low toxicity compound. However, the quality of the synthesis gas could not be confirmed for the agent and energetic processes due to early termination of the demonstration. The SET process has had EPA approval for PCB disposal. Due to the nature of the process, concerns about the production of dioxins, furans, and other chlorinated hydrocarbons that might be hazardous are minimal.

There are several negative aspects in effluent characterization. The process will generate a large volume of RCRA waste that will require off-site disposal, some of which may require stabilization, which has not yet been demonstrated. No alternative air management strategy was identified for process synthesis gas if it is unsuitable for use as boiler fuel. Offgas characterization from the secondary oxidation units was not completed due to the cancellation of the demonstrations, creating a critical data gap in demonstration results. The final disposition of aqueous decontamination fluids is unclear. Several of the expected product streams will require either stabilization or disposal as hazardous waste. The proposed use of cement stabilization of these wastes has not yet been demonstrated and may be complicated by the presence of organics. None of these negative aspects could be resolved due to the early termination of the demonstration.

C.4.3.2.3.2 Completeness of Effluent Characterization

The Demonstration Test Programs for both the Agent SET Reaction and Energetics SET Reaction Systems were terminated by PMACWA before any validation testing was conducted. Because these two test programs were not conducted, the data that are available on the effluent characterization is based on limited testing by the technology provider conducted prior to the ACWA Demonstration. The effluents from the Metal and Dunnage SET Reactor operations were characterized; however, the system tested for PMACWA is not entirely representative of the proposed full-scale system and modifications to the unit may change the characterization of the effluents.

Some non-ACWA SET process effluents are characterized from previous PCB operations and non-ACWA testing, however final effluent characterization on specific ACWA waste streams was not completed due to the early termination of this demonstration. Some of the intermediate and effluent products have been analyzed quantitatively in non-ACWA testing; others remain relatively poorly characterized. Full characterization of the constituents (including rates) for expected plant air and solid effluents was not completed due to the early termination of this demonstration. Lack of demonstration data did not allow for the following technical concerns to be resolved: small amounts of energetics residues that bypass oxidation before solidification, the potential for non-metallic components to be sent to Rock Island Arsenal, and the lack of data on the effectiveness of cement stabilization of process wastes.

Demonstration did not answer any critical issues associated with effluent characterization.

C.4.3.2.3.3 Effluent Management Strategy

Elements of waste management plan in the technology provider's final report included a general plan outline with stated goals and commercial applications.[238] Most waste streams are qualitatively assessed as treatable, although some questions remain due to the lack of testing during demonstration. Therefore, validation of waste streams was not possible. In addition, no confirmation of planned off site disposal was provided.

PCB permitting and treatment and some prior non-ACWA agent testing give the technology provider some prior history in managing some but not all types of munitions and associated waste streams.

HT&R of effluent streams is proposed for all waste streams. Some of the solid waste stream may also be a hazardous waste due to the presence of metals. Although commercial applications exist for stabilization of lead, satisfactory demonstration of cement stabilization of this particular stream is necessary.

In summary, the technology provider's Demonstration Test Technical Report included a general plan outline with stated goals and commercial applications. Because the Agent SET and Energetics SET system tests were terminated before any validation testing was conducted, a definitive effluent management strategy cannot be completed. The lack of demonstration test data precludes full determination of the treatability of all wastes generated by the SES.

C.4.3.2.3.4 Resource Requirements

The design included order of magnitude estimates for resource consumption.[239] SES uses the same footprint as the baseline plant.[240] Specific water and energy requirements could not be quantitatively verified from the information in the technology provider's final report; however, a qualitative assessment has indicated that no unusual requirements are anticipated. Water recovery and recycle may further reduce water consumption.

C.4.3.2.3.5 Environmental Compliance and Permitting

A qualitative assessment has indicated that no unusual requirements are anticipated. The technology provider's final report includes three permitting options,[241] however at least one of these options is not viable (treatability study). Because both the agent and energetic tests were terminated by PMACWA before validation, an evaluation of the environmental compliance and permitting approach cannot be completed.

C.4.3.2.4 Potential for Implementation

As agreed to at the 1-3 November 2000 ACWA Dialogue Meeting held in Pueblo, Colorado, the three Potential for Implementation criteria (Life Cycle Cost, Schedule, and Public Acceptance) were not evaluated because of Teledyne-Commodore's severely curtailed SES demonstration. These criteria were included in the Implementation Evaluation Criteria in anticipation of the availability of demonstration data. However, there was insufficient information generated at demonstration to allow a detailed assessment of the life cycle cost and schedule for this process. The lack of demonstration data related to the technical criteria precludes judging public acceptance of this technology.

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C.5 Conclusions and Recommendations

C.5.1 Conclusions

C.5.1.1 AEAT/CH2MHill SILVER II

The AEAT/CH2MHill SILVER II process to demilitarize chemical weapons was validated during demonstration. In addition, the Dialogue agreed by full consensus that SILVER II is likely to be publicly acceptable. Therefore, this process is considered a viable total solution for demilitarization of all ACWs. The basis for this conclusion is summarized below.

C.5.1.1.1 Process Efficacy/Process Performance

The AEAT/CH2MHill process uses SILVER II electrochemical oxidation as the primary destruction method for the agent and energetics extracted from chemical weapons. The destruction of agents was validated to 99.9999% destruction efficiency and the destruction of propellant was validated to 99.999% destruction efficiency in government testing. The Tetrytol demonstration was curtailed, with destruction validated to 97.5% destruction efficiency. The curtailed Tetrytol demonstration and lack of any demonstration data for Comp B prohibit the complete validation of the process. However, destruction of the constituents of Comp B and Tetrytol in laboratory experiments indicates the likely effectiveness with these energetic compounds. The thermal treatment of metal parts and other solid wastes has been validated to effectively treat the components of ACW. SILVER II was validated not to produce Schedule 1 or significant quantities of Schedule 2 compounds regulated under the CWC. Characterization of products from agent and propellant destruction was completed to an acceptable degree. Acceptable treatment of most hazardous intermediates (formed at relatively low levels) was validated for this process; other treatment steps that should effectively destroy the remaining hazardous intermediates were proposed but not demonstrated. Although it poses a manageable technical risk, the incomplete demonstration of energetics destruction in turn leads to incomplete validation of product acceptability. The majority of sampling and analysis methodologies and techniques required were acceptably verified and validated. Optimization of some analytical methods is required, but this is not anticipated to be a problem for full-scale operation.

Although some concerns remain for the integrated process, unit operations demonstrated an acceptable level of maturity for proceeding towards implementation. Two SILVER II units were successfully demonstrated for agents and propellant. Newly proposed changes to the SILVER II process (after demonstration) to address solids management (Tetrytol and Comp B are of particular concern) and the impurities removal systems with continuous operation appear appropriate but they have not been built or tested. Other technical risks are associated with extensive untested modifications to the reverse assembly, the proposed propellant size reduction, and the projectile punch/drain/steam washing systems. These technologies have not been tested in the proposed configuration. To minimize these risks, the conceptual processes can be replaced with existing systems from baseline reverse assembly and from those already being developed by the PMACWA.

The overall AEAT/CH2MHill SILVER II process is complex and has a large number of unit operations. Effective operation of independent semi-batch SILVER II units was demonstrated for agents and propellant. However, the proposed continuous operability of SILVER II units with impurities removal systems has not been demonstrated and there are concerns about the ability to maintain stability of the complex full-scale system. Operability of SILVER II for treatment of burster energetics (Tetrytol and Comp B) with proposed changes is undemonstrated; solids management is of particular concern. Most of the proposed unit operations are inherently stable and can be effectively monitored and controlled using commercially available controls and instrumentation. However, the inherent monitoring and control advantages of SILVER II are offset by the complexity of continuous operation with many interdependent unit operations.

The proposed process is applicable to all ACWs at all sites.

C.5.1.1.2 Safety

The process poses manageable risks for worker safety during normal operations. The SILVER II agent and energetics destruction systems operate at ambient pressure and at relatively low temperature; they are energy dependent and cannot cascade out of control. The process requires relatively large quantities of process chemicals, some corrosive, but they are commonly used in industry and can be handled in accordance with well-established industrial safety practices. The process uses fully automated controls as well as highly automated and remote[i] primary destruction operations. Minimal quantities of explosive or flammable gases are produced. However, several accident initiators are associated with various process conditions that could result in worker injury from the accident itself or from the subsequent exposure to agent or hazardous chemicals. The potential to encounter explosive materials represents the most significant, potentially hazardous situation for the worker during maintenance on SILVER II. This is due to the accumulation of possibly explosive materials within the system and the potential for explosive crystal formation from leaks or in isolated system segments. Size reduction of M28 propellant has not been demonstrated, and the potential for ignition during the process is uncertain. Nevertheless, these risks should be minimized with appropriate engineering design and personal protective equipment and by procedures that ensure the review and approval of maintenance practices.

The process involves relatively large quantities of process chemicals and solid waste, but all have moderate to low toxicity, persistency, and volatility; none are carcinogens. SILVER II operates at ambient pressure. All gaseous effluents are processed through catalytic oxidation followed by hold, test, and rework/release. Public impact from potential accidents should be minimized or eliminated through several layers of system and facility secondary containment, which are expected to efficiently mitigate and contain the effects and prevent public exposure. There are no unusual transportation accident response requirements, and risk to the public is minimal.

C.5.1.1.3 Human Health and Environment

All SILVER II gaseous effluents undergo HT&R prior to discharge, although only a conceptual HT&R plan was provided. Gaseous emissions will be treated to well below regulatory limits.

[i] Unattended by personnel during operations

SILVER II includes the discharge of liquid effluent, consisting primarily of the dilute nitric acid waste stream. The Agent Impurities Removal System produces an evaporator bottoms solid waste stream with high concentrations of acids, metals, and organics that is containerized and sent to a RCRA TSD. Offsite recycling/recovery is proposed for three effluent streams: 5X metals, concentrated nitric acid for use in the production of energetics, and silver chloride for silver recovery. Characterization of effluents from demonstration, except those from processing Comp B, is sufficient to support the proposed effluent management strategy. Effluents have minimal impact on human health and the environment.

SILVER II's effluent management strategy is well developed for this stage of the process, although some disposal issues still require resolution. The plan is dependent on the availability of a POTW capable of accepting the dilute nitric acid waste stream under a pretreatment exemption. This availability was not confirmed, however other disposal options for this waste stream were determined to be available. The plan also assumes off-site acceptance of the evaporator bottoms by a RCRA TSD, however this was not confirmed. Despite these uncertainties, analysis indicates that effluents appear treatable and disposable. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Although there are no unusual issues associated with this technology, the permitting strategy has not yet been fully defined.

C.5.1.1.4 Potential for Implementation

The final 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). Integrated Process Teams have been established within the Department of Defense as part of the Defense Acquisition Executive 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*
>
> *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Therefore, in order to evaluate the cost and schedule portions of the potential for implementation criteria, a preliminary comparison between this alternative technology and baseline incineration with respect to total capital cost and schedule was made.

Life Cycle Cost—The SILVER II estimated total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M cost for the SILVER II process may be slightly greater than baseline due the expected longer operating period.

Schedule—The schedule estimates developed for the demilitarization of ACWs utilizing SILVER II indicates completion of Blue Grass operations in February 2012.

Public Acceptance—Based on input from the ACWA Dialogue, SILVER II is likely to obtain public acceptance.

C.5.1.2 Foster Wheeler/Eco Logic/Kvaerner Neutralization/GPCR/TW-SCWO

Neutralization/GPCR/TW-SCWO was validated during demonstration. In addition, the Dialogue agreed by full consensus that Neutralization/GPCR/TW-SCWO is likely to 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.

C.5.1.2.1 Process Efficacy/Process Performance

Neutralization/GPCR/TW-SCWO uses modified baseline reverse assembly to access agent and energetics that are neutralized by sodium hydroxide (caustic) or water hydrolysis followed by TW-SCWO. Metal parts, dunnage, and other solids (including secondary wastes), and gases are thermally treated using GPCR. The proposed neutralization processes have been validated effective to 99.9999% destruction efficiency for all agents and to 99.999% destruction efficiency for all energetics as part of this demonstration and previous neutralization demonstrations. Processes used for decontamination of chemical weapons hardware and treatment of contaminated processing wastes were also validated. Validation of GPCR for the destruction of agents was not accomplished due to problems encountered with the process gas sampling and analysis. Agent hydrolysis produces Schedule 2 compounds, but the TW-SCWO effectively destroyed all Schedule 2 compounds to acceptable levels. 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 optimization of the remaining methods appears straightforward. However, agent monitoring in GPCR product gas will require method development for complete product characterization.

Although some concerns remain for the integrated process, unit operations demonstrated an acceptable level of maturity for proceeding towards implementation. Agent neutralization and relevant portions of reverse assembly are well developed. Fluid accessing was successfully demonstrated in Demonstration I, and GPCR and TW-SCWO have been successfully demonstrated in Demonstration II. Fluid systems (mining and dissolution/washing in the COINS) and GPCR have commercial industrial history. However, extensive modifications to reverse assembly (projectile punch/drain/steam washing, propellant size reduction, and COINS) are untested in the proposed configuration and represent a significant technical risk compared to existing systems. There are still technical risks associated with scale-up of batch processing of ACW feeds and generation of carbonaceous material in the GPCR. The TW-SCWO reactor demonstrated promising corrosion resistance and solids management, but the process as a whole is still an emerging technology.

Neutralization/GPCR/TW-SCWO is a complex process and has a large number of unit operations, but appears to have manageable operability characteristics, although some concerns remain. Most unit processes are expected to be inherently stable, robust, and tolerant of moderate changes in operating conditions. The TW-SCWO reactor experienced minimal corrosion and plugging problems during extended, continuous periods of operation during demonstration, but the solids management with feeds containing high aluminum-containing solids content and long-term liner integrity is untested. Modifications to reverse assembly and energetics accessing (COINS) are complicated and unproven. There are also operability concerns for the coating of the GPCR system with carbonaceous residue during DPE processing.

Most operations can be effectively monitored and controlled using commercially available controls and instrumentation to prevent or minimize process upsets. Segregation steps required for rockets and projectiles will require complex monitoring and control strategies that have not yet been tested. Concerns exist relating to the GPCR system, including agent-monitoring methods for the product gas stream, control of energetic levels in the TRBP feed, and manual thermal control for TRBP. These issues are expected to be resolved through improvements to design and further development.

The proposed process is applicable to all ACWs at all sites.

C.5.1.2.2 Safety

The process poses manageable risks for worker safety. Neutralization/GPCR/TW-SCWO incorporates commonly used and well-characterized process materials. Primary destruction operations are remote and operate at low temperature and ambient pressure. Feed or energy shut-off stops all processes, limiting the potential for cascading out of control. Intermediate streams after neutralization and GPCR undergo HT&R. However, there are still inherent risks associated with the process. SCWO and GPCR operate at very high temperature; additionally, SCWO operates at high pressure. The COINS solvent energetics detection and quantification system and GPCR generate highly flammable, potentially explosive atmospheres. There are also some areas of uncertainty in the handling and processing of energetics in the system. Agent monitoring of VX hydrolysate and of GPCR process gases needs development. Additional mitigation of these risks needs to be developed, but is expected to be feasible.

The process involves relatively large quantities of process chemicals and solid waste, but most are not highly volatile or flammable or do not present an acute inhalation hazard. However, GPCR uses hydrogen, a highly flammable and potential explosive hazard. The use of potentially large quantities of highly flammable, volatile solvents requires further detail. Nonetheless, even if an accident were to occur during operations, public impact would be minimized or eliminated since several layers of system and facility secondary containment should efficiently mitigate and contain the effects and prevent public exposure. The process also accumulates minimal quantities of agent and energetics. There are no unusual transportation accident response requirements, and risk to the public is minimal.

C.5.1.2.3 Human Health and Environment

Most waste streams, with the exception of GPCR gas effluents from the processing of agents, have been well characterized and the proposed disposal methods minimize impact on human health and the environment. All primary destruction processes and their associated intermediate waste streams undergo HT&R. GPCR product gas is scrubbed with caustic, undergoes HT&R, and is burned in an energy recovery device with the combustion products passed through a catalytic converter. There are no external liquid effluents. The solid products from the total solution include salts from TW-SCWO and solid residue from GPCR. The overall impact on human health and the environment could not be fully ascertained due to the lack of validation for the method for detection of agent in GPCR gas effluents, however the overall impact of effluents is expected to minimal.

The effluent management strategy for Neutralization/GPCR/TW-SCWO appears sound. All major operations have a history of successful permitting. The evaporator/crystallizer may not process brine salts as proposed, affecting the TW-SCWO effluent management strategy. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. There is a well-developed strategy to ensure compliance with all environmental laws and regulations, including permit conditions. The Army has obtained permits for piloting neutralization/SCWO at Newport, Indiana. GPCR has a history of successful TSCA permitting, although the GPCR agent monitoring issue needs resolution before the effluent management and permitting strategies can be finalized.

C.5.1.2.4 Potential for Implementation

The final 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). Integrated Process Teams have been established within the Department of Defense as part of the Defense Acquisition Executive 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*
>
> *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."*

In addition to the certification requirements above, the Under Secretary of Defense must also determine that an alternative is able to satisfy the Federal and State environmental and safety laws that are applicable to the use of the technology and to the design, construction, and operation of a pilot facility for use of the technology.

Therefore, in order to evaluate the cost and schedule portions of the potential for implementation criteria, a preliminary comparison between this alternative technology and baseline incineration with respect to total capital cost and schedule was made.

Life Cycle Cost—Neutralization/GPCR/TW-SCWO estimated total capital cost may be approximately equal to that of baseline incineration. It is likely that the total O&M cost for the process are comparable to those of baseline.

Schedule—The schedule estimates developed for demilitarization of ACWs utilizing Neutralization/GPCR/TW-SCWO indicates completion of Blue Grass operations in November 2010.

Public Acceptance—Based on input from the ACWA Dialogue, Neutralization/GPCR/TW-SCWO is likely to obtain public acceptance.

C.5.1.3 Teledyne-Commodore Solvated Electron System

The Teledyne-Commodore SES to demilitarize chemical weapons was not validated for agent or energetics destruction during the ACWA Demonstration Test Program. Therefore, this process cannot be considered a viable total solution. The basis for this conclusion is summarized below.

C.5.1.3.1 Process Efficacy/Process Performance

The Solvated Electron System (SES) uses fluid-abrasive cutting and fluid mining to access agent and energetics, which are then destroyed by SET using sodium metal and ammonia; the SET reaction products are subsequently oxidized with a chemical reagent. Metal parts and dunnage are 3X decontaminated with SET reagent. Although prior small-scale laboratory testing by the technology provider indicates the likely effectiveness with agent and energetics, agents and energetics destruction has not been independently verified and validated in ACWA demonstration testing. Demonstration of both the Agent SET/Oxidation and Energetics SET/Oxidation systems was terminated by PMACWA before any validation testing was conducted. Due to the failure to complete required demonstration tests, products from processing agent and energetics were not validated. There is information available indicating that SET effectively decontaminates metal parts to 3X, but demonstration data for 3X decontamination of metal parts and dunnage were inconclusive. Sampling and analysis methodologies were validated, but their performance was not verified for agent and energetics processing.

SES has an unacceptable level of maturity for proceeding towards implementation. Demonstration was required to provide information on the transport and segregation of materials, the control of the overall extraction and treatment systems, and the ability to demonstrate scale-up and to accumulate experience with working with agents and energetics at larger than laboratory quantities. Three of the four proposed major unit operations were not demonstrated, and information required on the performance of this technology was not available. Although fluid accessing systems have historical commercial industrial basis, the PET considers the level of maturity of SES inadequate for timely implementation. Although previous testing conducted by the technology provider generally supports the stability of SET reactions, the SES process for ACWs is complex with undemonstrated operability characteristics. There are numerous concerns about the reliability and stability of using Isopar-L (a hydrocarbon solvent) for fluid accessing and its effect on downstream SET and oxidation processes.

Proposed monitoring and control technologies are commercially available. Most of the critical process units are operated in batch mode and there are many HT&R points. However, no process monitoring or control data were obtained during demonstration for the Energetics SET/Oxidation and Agent SET/Oxidation operations. Minimal process monitoring and control data were obtained during demonstration for Dunnage SET operations. Thus, there are insufficient data to prove that SES can be monitored and controlled.

Based on previous testing conducted by the technology provider, SES could be applicable to all agents and energetics. However, SES was not validated by demonstration for treatment of agents and energetics. Treatment of metal parts and dunnage contaminated with agent simulant was demonstrated, but removal of the simulant was inconclusive. The use of Isopar-L for fluid accessing at sites with rockets remains undemonstrated, which represents a significant uncertainty in the applicability of SES.

C.5.1.3.2 Safety

There appears to be a sound risk mitigation strategy. SES utilizes process materials that are commonly used in industry and which can be handled in accordance with established industrial safety standards. The remote primary destruction operations protect workers from chemical and physical hazards. SET destruction of agent and energetics is essentially immediate at ambient temperature and low pressure. There are HT&R points throughout the process. However, concerns remain relative to energetics, reducing confidence in the inherent safety of SES. The technology provider states that ammonia, a major process chemical, is incompatible with M28 propellant. The effectiveness of the proposed mitigation strategy—use of Isopar-L rather than ammonia—has not been demonstrated. Because insufficient data supporting the assumption that the use of Isopar-L would prevent propellant ignition were provided, there is still an undefined element of risk associated with the process. Energetics residue is potentially present during maintenance. There are several hazardous materials used in large quantities and the process generates hazardous intermediates (including cyanide salts and flammable gases). Use of sodium presents unique risks because of its reactivity with water.

This technology minimizes the risk of a serious accident affecting the public because exposure to agent is reduced by the immediate destruction of agent and energetics and containment is provided at the equipment and facility level. However, accidents involving ammonia storage could require establishing large protective action zones, a significant public impact even though the safety risk is minimal. Overall, the technology poses minimal risk to the public.

C.5.1.3.3 Human Health and Environment

Critical issues associated with impact on human health and environment, effluent characterization, the effluent management strategy, and the environmental compliance and permitting approach could not be assessed. Demonstration of both the Agent SET/Oxidation and Energetics SET/Oxidation systems was terminated by PMACWA before any validation testing was conducted. Because these two test programs were not conducted, the data that are available on the effluent characterization are based on limited testing by the technology provider conducted prior to the ACWA demonstration. The effluents from the Metal and Dunnage SET Reactor were characterized; however, the demonstration system is not entirely representative of the proposed full-scale system and modifications to the unit may change the characterization of the effluents.

SES utilizes HT&R for gaseous streams at several stages of treatment. Synthesis gas produced is proposed for use as supplemental fuel for heating, reducing the need for boiler fuel. There are no external liquid effluents proposed in the technology provider's final report. The process will generate a large volume of RCRA waste that will require off-site disposal, some of which may require stabilization, which has not yet been demonstrated. A general effluent management plan with stated goals and commercial applications was provided. A qualitative assessment of resource requirements indicates no expected exceptional energy or water demands. Similarly, a qualitative assessment of the permitting strategy indicates that no unusual issues are anticipated. However, treatment and disposal options for all wastes could not be verified.

C.5.1.3.4 Potential for Implementation

By agreement with the ACWA Dialogue, life cycle cost, schedule, and public acceptance were not evaluated because the SES demonstration was severely curtailed. These criteria were included in the Implementation Evaluation Criteria in anticipation of the availability of demonstration data. However, there was insufficient information generated at demonstration to allow a detailed assessment of the life cycle cost and schedule for this process. The lack of demonstration data related to the technical criteria precludes judging public acceptance of this technology.

C.5.2 Recommendations

C.5.2.1 AEAT/CH2MHill SILVER II

Based on the findings summarized in Section C.5.1.1, the AEAT/CH2MHill SILVER II 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 to address the technical issues identified in this report (Agent and Energetics Impurities Removal Systems and changes proposed for the processing of Comp B and Tetrytol), the PET recommends that prior to pilot implementation, EDS focus on the following:

- Modifications to energetics feed and ancillary systems of the 12-kW SILVER II plant currently located at ATC, Aberdeen Area of APG, Maryland, to better reflect the system as currently proposed
- Longer-term testing of agent simulant, Comp B, and M28 Propellant in the 12-kW SILVER II plant, including characterization of the process chemistry of Comp B destruction
- Lab scale testing to address the following design issues:
  - Cell membrane performance
  - Fluoride containing feeds
  - Hydrocyclones

  - High shear mixing
  - Organic transfer

- Review literature data and prepare reports to address the following design issues:
  - Projectile Burster Washing
  - Energetics Slurry Concentration

Additionally, to minimize the technical risks associated with this process, the conceptual operations could be replaced with existing systems from baseline reverse assembly and from those already being developed by the PMACWA. Specifically, the PET recommends that the conceptual Punch/Drain/Washout Machine and Rocket Demilitarization Machine operations proposed by the technology provider be considered for replacement by the baseline Multipurpose Demilitarization Machine Pull & Drain Station and spray washing operations being developed under the current ACWA EDS and by propellant grain accessing, respectively.

C.5.2.2 Foster Wheeler/Eco Logic/Kvaerner Neutralization/GPCR/TW-SCWO

Based on the findings summarized in Section C.5.1.2, the Foster Wheeler/Eco Logic/Kvaerner Neutralization/GPCR/TW-SCWO process is considered a viable total solution for the demilitarization of all ACWs. 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 EDS focus on the following issues:

- Optimization of systems related to the GPCR unit operation, focusing on the following:
  - Development of methods for detecting agent in GPCR process gases and GPCR process monitoring
  - Longer-term testing of materials of construction for the GPCR
  - Testing of the explosive limits of the TRBP/GPCR systems
  - Development of strategies to manage solids buildup in GPCR
- Longer-term testing of agent and energetics hydrolysates or simulants with a new TW-SCWO reactor, focusing on the following:
  - Develop operating characteristics of the Evaporator/Crystallizer
  - SCWO Methods and Process Monitoring Development
  - Optimization of TW-SCWO process to maximize organic destruction, effluent quality and throughput, upstream and downstream solids handling, and liner integrity
- Testing of methods for M28 propellant size reduction

Additionally, to minimize the technical risks associated with this process, the conceptual operations could be replaced with existing systems from baseline reverse assembly and from those already being developed by the PMACWA. Specifically, the PET recommends that the proposed Projectile Punch Machine and the Continuously Indexing Neutralization System be considered for replacement with the baseline Multipurpose Demilitarization Machine Pull & Drain Station and operations being developed under the current ACWA EDS, respectively. Similarly, the modified Rocket Shear Machine could also incorporate existing techniques and equipment being developed by the PMACWA. The PET also recommends that any final neutralization/SCWO design for potential implementation use the best match of components from all three neutralization-based technologies. For example, removal of aluminum compounds from SCWO feed streams, which is currently being developed under EDS, could be considered for application to the TW-SCWO.

C.5.2.3 Teledyne-Commodore Solvated Electron System

Based on the findings summarized in Section C.5.1.3, the Teledyne-Commodore SES for demilitarization of ACWs is not considered a viable total solution at this time. Therefore, the PET recommends that PMACWA not consider this process for future EDS or pilot testing.

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Attachment C-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
	Greg Mason	ECBC
	Gerald Starnes	PMACWA
	Scott Susman	PMACWA
TET Adjunct Advisory Team	George Bizzigotti	Mitretek Systems
	Clifford Bunton	University of California at Santa Barbara
	Tom Cain	Mitretek Systems
	David Cleaves	Mitretek Systems
	Jon Horin	Mitretek Systems
	Rick Rhoads	Mitretek Systems
	Michael Berger	Mitretek Systems
Demonstration Working Group (DWG)	Darren Dalton—Chair	PMACWA
	Armand Balasco—Coordinator	Arthur D. Little
	Ric Bowen	Arthur D. Little
	Colette Lamontagne	Arthur D. Little
	Jesse Margolin	Arthur D. Little
	Phil Marrone	Arthur D. Little
	Rob O'Neil	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	Bob Poor	SBCCOM
Facilitator	Diane Affleck	ECBC

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Attachment C-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
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.
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.
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.

	Question	Information Requirements
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
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 compatibility/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 compatibility/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.
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.

	Question	Information Requirements
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.

	Question	Information Requirements
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.
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

	Question	Information Requirements
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.

	Question	Information 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 C-C Evaluation of Sampling and Analysis

C-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.[i] 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.

C-C.2 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

[i] 40 CFR 136 Appendix B

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.

- 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.

C-C.3 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.

C-C.4 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 C-D Analytical Approach for Estimating Cost 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 cost and schedules for the final technical evaluation is discussed below.

C-D.1 Cost Estimating Approach

The methodology used in developing the independent total capital cost estimates was a bottom-up approach which consisted of the following steps:

- Utilized Technology Providers' "delivered core process equipment" cost as the foundation to develop a total capital cost
- Made "baseline" equipment cost additions (as required)
- Made "baseline" buildings/support facilities cost additions (as required)
- Developed cost "workup" factors for cost buildup
  - Direct cost
  - Indirect cost
  - Process contingency
  - Project contingency
- Used technical evaluation of technologies as the basis for discriminating between the two technologies in developing the cost "workup" factors

It is important to note that the "delivered core process equipment" cost was the only cost data that was used from the Technology Providers' Draft Final Demonstration Test Technical Reports. We felt that the Technology Providers were the most knowledgeable about the actual purchase cost of the major (core) process equipment items comprising their alternative technology. In addition, both of the alternative technologies require some aspects of the baseline reverse assembly process (RSM, PMD and MDM equipment) along with BRA and PUB process equipment and baseline infrastructure (process/support) buildings. Therefore, the capital cost associated with this baseline equipment and infrastructure were added to the Technology Providers' purchased equipment cost in developing the technology's total capital cost.

Once all the cost "workup" factors had been developed, the total capital cost was estimated by applying the direct, process contingency, indirect and project contingency cost factors to the delivered core process equipment cost and making the necessary baseline equipment and baseline buildings/support facilities cost additions.

As stated earlier, since a standard, consistent, workup factored cost estimating methodology was employed in developing these independent total capital cost estimates, the cost associated with both alternatives technologies and baseline incineration can be compared. The total capital cost are in constant (year 2000) dollars; there is no inclusion for 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.

C-D.2 Schedule Development Approach

The methodology used in developing independent full-scale implementation schedules was a bottom-up approach that consisted of the following steps:

- Developed an overall bottom-up schedule philosophy and defined all basic assumptions
- Identified all key activities and made a determination as to their reasonableness to proceed in series or parallel
- Estimated the likely "duration" of all key activities
- Estimated likely, reasonable start dates for all key activities
- Determined key activity interrelationship/dependence
- Integrated the schedule assumptions with key activities, key activity durations and key activity start dates to develop implementation schedules for both alternative technologies demonstrated

It is important to note that the actual "estimated duration" for operations (including both agent and munition changeovers) was the only schedule data that was used from the Technology Providers' Draft Final Demonstration Test Technical Reports. We felt that the Technology Providers were the most knowledgeable about the actual operation and processing throughput for the major (core) process equipment items comprising their alternative technology. We did, however, review their processing throughputs and found them to be reasonable and generally compatible with the baseline reverse assembly processing throughputs. Agent/munition changeover durations provided by the Technology Providers were modified, however.

In order to compare the independently developed schedules for both alternative technologies to baseline incineration, a schedule for baseline was required. This was accomplished by using the same basic assumptions used for developing the schedules for the alternative technologies, the same key milestone activity start dates and information provided by the Program Manager for Chemical Demilitarization (PMCD) for baseline incineration.

As stated earlier, since a standard, consistent, bottom-up methodology was employed in developing these independent implementation schedules, the schedules associated with both alternative technologies and baseline incineration can be compared. The confidence level (likelihood of success) for these estimated schedules is 75%.

Definitions of Selected Terms and Acronyms

Symbols

°C ....degrees Celsius
°F..........................degrees Fahrenheit
µg ....micrograms
3X (XXX) ....indicates that the item has been surface decontaminated, then contained and the headspace air verified to contain agent concentrations below the airborne exposure limits for unmasked workers. Access to 3X material is generally restricted to government personnel and contractors.
5X (XXXXX).......indicates that an item has been decontaminated completely of agent and may be released for general use or sold to the public

A

ACAMS ....Automatic Continuous Air Monitoring System
ACW ....Assembled Chemical Weapon
ACWA ....Assembled Chemical Weapons Assessment
AgCl ....Silver Chloride
AIRS ....Agent Impurities Removal System (AEAT/CH2MHill)
APG......................Aberdeen Proving Ground
ART......................Ammonia Recovery Tower (Teledyne-Commodore)
ATAP ....US Army Alternative Technology and Approaches Project (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)
BRT......................Batch Rotary Treater (AEAT/CH2MHill)
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
CATOX................Catalytic Oxidation unit (Parsons/Honeywell)
CATT ....Citizens Advisory Technical Team
CDF......................Chemical Demilitarization Facility
CEES....................Chloroethyl Ethyl Sulfide
CFR ....Code of Federal Regulations
CH_4 ....Methane
CHPPM................Center for Health Promotion and Preventive Medicine
CLIN ....Contract Line Item Number
CO ....Carbon Monoxide
CO_2.......................Carbon Dioxide
COINS™.............Continuously Indexing Neutralization System (FW-ELI-K)
Comp B ....Composition B, a high explosive composition of 60% RDX, 39% TNT, and 1% wax

CSDP....................Chemical Stockpile Disposal Program
CSTR....................Continuous Stirred Tank Reactor
CTF ....Chemical Transfer Facility at ECBC
CWA ....Clean Water Act
CWC ....Chemical Weapons Convention

D

DAAMS ....Depot Area Air Monitoring System
DACWA ....Dialogue on Assembled Chemical Weapons Assessment
DCB 1,4-Dichlorobutane
DCD ....Deseret Chemical Depot (Tooele, UT)
DDT ....Deflagration-to-Detonation (an explosive transition)
DE ....Destruction Efficiency
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)
DNT ....Dinitrotoluene
DOD.....................US Department of Defense
DOT ....US Department of Transportation
DPE ....Demilitarization Protective Ensemble (highest level of chemical agent PPE)
DPG......................Dugway Proving Ground (Dugway, UT)
DRE......................Destruction Removal Efficiency
DWG....................Demonstration Working Group (part of the ACWA PET)

E

ECBC ....Edgewood Chemical and Biological Center
EDS ....Engineering Design Studies
EIRS.....................Energetics Impurities Removal System (AEAT/CH2MHill)
EIS........................Environmental Impact Statement
ELI ....Eco Logic International
EMPA ....Ethyl Methylphosphonic acid
EMPSH ....*O*-Ethyl Methylphosphonothioic acid
EPA ....US Environmental Protection Agency
ET.........................Environmental Team (part of the ACWA PET)

F

FDC......................Fuze Detonation Chamber (Teledyne-Commodore)
furans....................A group of chlorinated hydrocarbons consisting of multiple isomers of tetrachloro- through octachloro-p-dibenzofuran
FW........................Foster Wheeler

G

gal.........................gallon
GC ....Gas Chromatography

gm ....gram
GPCR™ ....Gas-Phase Chemical Reduction (FW-ELI-K)

H
HAPS ....Hazardous Air Pollutants
HAZMAT ....Hazardous Material
HCl ....Hydrogen chloride, hydrochloric acid
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)
HF ....Hydrogen fluoride, hydrofluoric acid
H_2O_2 ....Hydrogen Peroxide
hr ....hour(s)
H_2SO_4...................Sulfuric Acid
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)

I
IMPA....................Isopropyl methylphosphonic acid
IRIS ....Integrated Risk Information System

J
JACADS ....Johnston Atoll Chemical Agent Disposal System

K
K...........................Kvaerner
kW........................kilowatt

L
L ....liter
lb ....pound
LEL ....Lower Explosive Limit

M
M2 ....4.2-inch mortar shell (HD or HT)
m^3 ....cubic meter
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
MDB ....Munitions Demilitarization Building
MDLs ....Method Detection Limits
MDM....................Multipurpose Demilitarization Machine (baseline reverse assembly equipment)

mg ....milligram
MIL-STD ....Military Standard
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 (AEAT/CH2MHill)
MRSM.................modified Rocket Shear Machine

N

N or N_2 ....Nitrogen
NaOCl ....Sodium Hypochlorite (supertropical bleach, household bleach)
NaOH ....Sodium Hydroxide
NCRS ....Nose Closure Removal Station (part of the PMD)
NDPA...................*N*-Nitrosodiphenylamine
NESHAPS............National Emissions Standards for Hazardous Air Pollutants
ng..........................nanogram
NH_3 ....Ammonia
NNF......................Not Normally Flowing
NOx......................Nitrogen Oxides

O

O or O_2 ....Oxygen
O&M....................Operating And Maintenance
OPCW..................Organisation for the Prohibition of Chemical Weapons
OSHA...................Occupational Safety and Health Administration

P

PAHs....................Polynuclear Aromatic Hydrocarbons
PAS ....Pollution Abatement System (common emission control system consisting of quench cooling, chemical scrubbing, filtration, etc.)
PCBs ....Polychlorinated biphenyls
PCP ....Pentachlorophenol
PDS ....Pull & Drain Station (baseline reverse assembly equipment on the MDM) or Punch & Drain Station (baseline reverse assembly equipment on the MIN)
PDWM ....Punch/Drain/Washout Machine (AEAT/CH2MHill)
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
POTW ....Publicly Owned Treatment Works

PPE.......................Personal Protective Equipment
PPL.......................Pick & Place Loader (baseline reverse assembly equipment)
PPM......................Projectile Punch Machine (FW-ELI-K) or Parts Per Million
PSI........................Pounds per Square Inch

Q
QA........................Quality Assurance
QAPP ....Quality Assurance Program Plan
QC........................Quality Control

R
RAAP...................Radford Army Ammunition Plant
RAM ....Reliability, Availability, Maintainability
RCRA...................Resource Conservation and Recovery Act
RDM ....Rocket Demilitarization Machine (AEAT/CH2MHill)
RDS......................Rocket Drain Station (baseline reverse assembly equipment on RSM)
RFP ....Request for Proposal
ROD ....Record of Decision
RSM ....Rocket Shear Machine (baseline reverse assembly equipment)
RSS ....Rocket Shear Station (baseline reverse assembly equipment on RSM)

S
S&F......................Shipping And Firing
Sarin ....nerve agent
SBCCOM.............US Army Soldier and Biological Chemical Command
Schedule 2............chemical agent precursors listed in Schedule 2 of the CWC
SCWO..................Supercritical Water Oxidation
SDS ....Spent Decontamination System (baseline) or Spent Decontamination Solution (secondary waste from surface decontamination operations)
SES.......................Solvated Electron System (Teledyne-Commodore)
SET™...................Solvated Electron Technology (Teledyne-Commodore)
sodium isethionate sodium hydroxyethylsulfonate
SSEB....................Source Selection Evaluation Board
SVOC...................Semivolatile Organic Compound

T
T ....designation for bis-chloroethyl thioethylether
TCLP....................Toxicity Characteristic Leaching Procedure
TDG ....Thiodiglycol
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
TNB......................1,3,5-trinitrobenzene
TNT......................2,4,6-trinitrotoluene (a high explosive)
TOC......................Total Organic Carbon
TOCDF ....Tooele Chemical Agent Destruction Facility
TOX ....Toxic Cubicle (baseline bulk agent buffer tank)
TRBP....................Thermal Reduction Batch Processor (FW-ELI-K)
TSCA ....Toxic Substance Control Act

TSD......................Treatment, Storage, and Disposal
TW-SCWO ....Transpiring wall supercritical water oxidation (FW-ELI-K)

U
UT ....Utah

V
VOC.....................Volatile Organic Compound
VX........................designation for nerve agent methylphosphonothioic acid
VX-thiol...............Diisopropylaminoethanethiol

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Appendix D

Acronyms/Abbreviations

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ACRONYMS/ABBREVIATIONS

ACWA	Assembled Chemical Weapons Assessment
AFJC&W	Ammonia Fluid Jet Cutting and Washout System
APG	Aberdeen Proving Ground (Maryland)
BAA	Broad Agency Announcement
BGAD	Blue Grass Army Depot
BGCDF	Blue Grass Chemical Agent Disposal Facility
BIF	Boiler and Industrial Furnace
CAMDS	Chemical Agent Munitions Disposal System (Utah)
CatOx	Catalytic Oxidation
CAC	Citizens’ Advisory Commission
CATT	Citizens’ Advisory Technical Team
CDPHE	Colorado Department of Public Health and Environment
CEES	Chloroethyl Ethyl Sulfide
CO_2	Carbon Dioxide
COINS™	Continuously Indexing Neutralization System
CST	Continuous Steam Treater
CWC	Chemical Weapons Convention
DAE	Defense Acquisition Executive
DCD	Deseret Chemical Depot (Utah)
DMMP	Dimethyl Methylphosphonate
DOD	Department of Defense
DPE	Demilitarization Protective Ensemble
DPG	Dugway Proving Ground (Utah)
DRE	Destruction and Removal Efficiency
DSHS	Dunnage Shredding and Hydrolysis System
DWG	Demonstration Working Group
ECBC	Edgewood Chemical and Biological Center (Maryland)
EDS	Engineering Design Studies
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERH	Energetics Rotary Hydrolyzer
FY	Fiscal Year
GPCR	Gas Phase Chemical Reduction
H_2O	Water
HT&R	Hold, Test and Release
ICB™	Immobilized Cell Bioreactor
IIPT	Integrating Integrated Process Team
IITRI	Illinois Institute of Technology Research Institute
kW	Kilowatt
NEPA	National Environmental Policy Act
NOI	Notice of Intent
NRC	National Research Council
PCBs	Polychlorinated Biphenyls
PCD	Pueblo Chemical Depot

PCP	Pentachlorophenol
PET	Program Evaluation Team
PMACWA	Program Manager Assembled Chemical Weapons Assessment
PMCD	Program Manager Chemical Demilitarization
POTW	Publicly Owned Treatment Works
PUCDF	Pueblo Chemical Agent Disposal Facility
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RFP	Request for Proposal
ROD	Record of Decision
SCWO	Supercritical Water Oxidation
SES	Solvated Electron System
SET™	Solvated Electron Technology
SOP	Standard Operating Procedure
TNT	Trinitrotoluene
TRBP	Thermal Reduction Batch Processor
TSD	Treatment, Storage and Disposal
TW	Transpiring Wall
U.S.	United States
WIPT	Working Integrated Process Team

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