Design, Safety, Schedule, and Cost Assessment of General Atomics GATS Total Solution

Final Technical Report

Prepared for:
Program Manager for Assembled Chemical Weapons Assessment (PMACWA)
APG, Maryland

8 June 2001

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Reference 71375-16

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2.0 Introduction

The Assembled Chemical Weapons Assessment (ACWA) Program originated from laws enacted by Congress in 1996. Public Law 104-201 established the requirement for an assessment of alternative technologies for demilitarization of assembled chemical munitions. Public Law 104-208 provided funding to identify and demonstrate not less than two alternatives to the Baseline incineration process for the demilitarization of assembled chemical munitions. Assembled chemical munitions for this purpose represent the chemical weapons stockpile configured with fuzes, explosives, propellant, chemical agents, shipping and firing tubes, and packaging materials.

2.1 General Background

The ACWA Program involved a three-phased approach – evaluation criteria development, technology assessment, and demonstration of the technologies.

Evaluation Criteria Development
The evaluation criteria development phase took place during the months of May, June and July 1997. During this phase, the Program Manager for Assembled Chemical Weapons Assessment (PMACWA), in concert with the Dialogue on ACWA, developed the program evaluation criteria. These evaluation criteria were grouped into four major categories: Process Efficacy/Process Performance; Safety; Human Health and Environment; and Potential for Implementation.

Technology Assessment
The technology assessment phase took place during the September 1997 – June 1998 timeframe. In July 1998, based on the evaluation of the Demonstration Work Plans and a determination of best value to the government, three Technology Providers were awarded task order contracts to conduct demonstration testing. They were Burns and Roe (Plasma Arc), General Atomics (Neutralization/Supercritical Water Oxidation), and Parsons/Honeywell (Neutralization/Biotreatment).

Demonstration I Testing
The actual demonstrations (Demonstration I) of alternative technologies took place between January and May 1999. The purpose of the demonstrations was to validate the chosen technologies' ability to safely destroy chemical munitions and their associated materials. The evaluation of the demonstrations took place between June and August 1999. The evaluations were performed collectively by the Technology Providers, Dialogue participants, PMACWA contractor personnel and PMACWA personnel. The PMACWA Program Evaluation Team (PET) and representatives from the Dialogue conducted the assessment of the technology demonstrations. Using the previously approved evaluation criteria, the PET and representatives from the Dialogue assessed each of the technologies demonstrated. The information used for these assessments included the Technology Providers' demonstration reports, the PMACWA's milestone reports, the validated demonstration data, and all previous documentation submitted by the Technology Providers. As reported in the September 1999 Supplemental Report to Congress, the technology assessment concluded that the General Atomics (General Atomics Total Solution

– GATS) and Parsons/Honeywell (Water Hydrolysis of Energetics and Agent Technology – WHEAT) technologies were viable to go to pilot testing.

2.2 Certification Decision Process

The PMACWA is currently completing Engineering Design Study (EDS) I testing for the General Atomics (GATS) and Parsons/Honeywell (WHEAT) technologies to develop the information necessary to satisfy the requirements in the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 (Public Law 105-261).

The EDS I testing (to date) has supported the preparation of an Engineering Package that will be the basis for the cost, schedule and safety Certification Decision process. The Engineering Package includes drawings and documentation sufficient to generate capital and operational and maintenance costs to within ±20 percent. The Engineering Package also includes a cost estimate that was reviewed/adjusted and used to develop a program life cycle cost estimate (LCCE). A program schedule is included in the package along with a Preliminary Hazards Analysis (PHA) that will be used as a tool in the safety certification process. Parsons/Honeywell developed an Engineering Package for the Pueblo Chemical Agent Disposal Facility (PUCDF) only, while General Atomics developed an Engineering Package for the PUCDF and is currently developing a package for the Blue Grass Chemical Agent Disposal Facility (BGCDF). This is due to the fact that the PUCDF would process only mustard munitions while BGCDF would process both mustard and nerve agent munitions; WHEAT was concluded to be viable for treating only mustard munitions while GATS was deemed viable for treating both mustard and nerve agent munitions. These packages will be used for the Certification Decision process, the request for proposals (RFPs) for the two demilitarization sites, and for Environmental Impact Statement (EIS) development and Resource Conservation and Recovery Act (RCRA) permit applications.

Preliminary Engineering Packages by Parsons/Honeywell (for WHEAT) and General Atomics (for GATS) were submitted to the Government on 27 October 2000. Design reviews were conducted by PMACWA and Arthur D. Little at the end of November 2000 and changes were made to these packages as a result. The Final Engineering Packages for both WHEAT and GATS were submitted to the Government on 5 January 2001.

As part of Public Law 105-261, and the certification process, the Under Secretary of Defense for Acquisition, Technology and Logistics (ATL) must certify in writing to Congress that any alternative proceeding to pilot testing is—

(i) as safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions; and

(ii) 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; . . .

This report provides Arthur D. Little's independent assessment of General Atomics' Total Solution (GATS) Engineering Package, and compares the results to Baseline incineration (as represented by the PUCDF). This report constitutes the most comprehensive information available for the ACWA Program Manager to formulate his recommendation to the Under Secretary of Defense for ATL regarding "certification" of an agent and energetic hydrolysis (neutralization)/supercritical water oxidation technology (illustrated by GATS) required under Public Law 105-261.

3.0 Overall Objective of Independent Assessment

The overall objective of Arthur D. Little's independent assessment of the General Atomics' Total Solution (GATS) Engineering Package (dated January 2001) was to provide support for the Certification Decision of the Undersecretary of Defense for Acquisition, Technology and Logistics (ATL) as directed in Public Law (PL) 105-261. Public Law 105-261 requires that for an alternative technology (to incineration) for the destruction of lethal chemical munitions to be considered, the Under Secretary of Defense for ATL must certify in writing to Congress that it 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 order to provide the Program Manager for Assembled Chemical Weapons Assessment (PMACWA) the most comprehensive information to formulate their recommendation to the Under Secretary of Defense for ATL regarding the Certification Decision, Arthur D. Little conducted the following assessment of the General Atomics' GATS Engineering Package:

- Design Assessment
- Preliminary Hazards Analysis Review
- Schedule Assessment
- Cost Assessment

3.1 Design Assessment

The Design Assessment had four overall objectives with regard to review of the GATS design itself and the supporting Engineering Package:

1. Consistency with the requirements of the disposal facility design as set forth in the GATS Design Basis and the results of their Engineering Design Study (EDS) I testing;
2. Completeness in addressing all necessary aspects of the facility and, in particular, in terms of providing a "total solution;"
3. Core process viability in terms of operational efficacy and capability to consistently achieve both required levels of agent and energetics destruction as well as environmental performance; and
4. Adequacy to support the ±20 percent cost estimate and to justify the proposed schedule (with modifications as required).

3.2 Preliminary Hazard Analysis (PHA) Review

Preliminary Hazards Analyses (PHAs) for the PMACWA EDS I alternative technologies (WHEAT and GATS) are performed to ensure the safety of the workers, the general public, and the environment during the disposal of assembled chemical weapons. The application of various hazard analyses reviews to the Department of Defense facilities are guided by MIL-STD-882D and other government codes and regulations applicable to this type of facility. The overall safety analysis goal is to assure the safety of the facility design, construction, equipment installation, systemization, operation, and closure/decommissioning.

The purpose of the PHA is to ensure that safety is addressed during the Engineering Design Study (preliminary engineering stage). The PHA applies the Failure Mode and Effects Analysis (FMEA) technique to identify and evaluate the potential hazards resulting from system component failures and to make recommendations for corrective design changes. The PHA focuses on hazardous materials, equipment, instrumentation, utilities, human actions (routine and nonroutine), and external factors that might impact the process during the preliminary design stages of the EDS I activities.

There are three specific objectives in conducting a PHA:

- Identify potential hazards, which reflect inherent risks of the unit operations involved;
- Analyze the design at an early stage and provide recommendations to guide the designers in mitigating potential hazards; and
- Identify residual hazards of significance that must be addressed in later design phases.

The PHA Review focussed on three objectives:

1. Review of the General Atomics GATS PHA for completeness, consistency, and accuracy;
2. Assessment of the risk of the GATS design; and
3. Comparison of the safety of the GATS design to Baseline Incineration.

3.3 Schedule Assessment

The Schedule Assessment focused on two objectives:

1. Independent assessment of the General Atomics GATS schedule for completeness, consistency, accuracy, and realism; and
2. Independent comparison of the General Atomics GATS schedule to the Baseline Incineration schedule.

The following guidelines (for both GATS and Baseline) were established for fulfillment of these objectives:

- The schedule would encompass all aspects of the design phase, construction, systemization, pilot testing, operations, and closure;

- The Defense Acquisition Executive (DAE) Review would culminate in a "Technology Decision" for Pueblo in December 2001;
- The Record of Decision (ROD) for Pueblo would be signed in December 2001;
- The Resource Conservation and Recovery Act (RCRA) Part B submittal would be made in January 2002;
- The RCRA Part B approval would be granted in September 2003; and
- The schedule estimates would be achievable within a confidence level of 75%. This means that relative to historical schedules for projects of similar type and scope, the estimated overall (end of operations) completion date would be expected to be achieved 75% of the time.

3.4 Cost Assessment

There were two principal objectives in the Cost Assessment:

1. Prepare a total life cycle cost estimate (LCCE) for the General Atomics GATS technology adequate for certification of the technology.

   The following guidelines were established for fulfillment of this objective:

   - The cost estimate would encompass all aspects of technology development and implementation beginning with the inception of demonstration testing through the completion of all munitions operations. Facility closure would be explicitly excluded.
   - Costs would be for the complete demilitarization facility.
   - The GATS technology would offer a "total solution" for onsite treatment of all chemical munitions, agent and dunnage.
   - The cost estimate would be to a "relative" accuracy of +20%/-20% at a 90% confidence level. This means the GATS estimate is accurate within +20%/-20% to the same extent that Baseline is also accurate to within +20%/-20%.
   - The cost estimate would be to an "absolute" accuracy of +20%/-20% within a confidence level of 75%. This means that relative to historical costs for projects of similar type and scope, the estimate would be expected to be within 20% of final costs incurred 75% of the time.
   - Conform the GATS technology cost estimate bases, assumptions, cost factors and costing methodology as closely as possible with those used in the Baseline LCCE in order to provide the greatest degree of direct comparability and to ensure that the GATS LCCE would be within the same degree of accuracy as that for the Baseline.

2. Characterize and quantify, to the extent possible, the risk for cost growth.

   The intent in meeting this objective has been to identify and characterize the principal technical and economic issues relevant to the implementation of the GATS technology that would pose significant potential for cost growth beyond the 20% limit established. This specifically excludes issues deriving from:

- Redirection (management and/or technical) of the overall Chemical Stockpile Disposal Project (CSDP);
- Changes in scope, Design Basis, or performance requirements relative to those established for the technology testing and design; and
- Availability of new information regarding the costs for Baseline equipment and facilities not made available to Arthur D. Little during the development and evaluation of the design and costs.

4.0 GATS Technology Description and Testing

The General Atomics Total Solution (GATS) proposed for assembled chemical weapons demilitarization at Pueblo is presented in Table 4-1 and illustrated in Figure 4-1. Table 4-1 also shows the corresponding Baseline processes. The unit operations presented in this section are based on the Engineering Design Package that General Atomics prepared and submitted to PMACWA on 5 January 2001. When this package was submitted, the Engineering Design Studies (EDS) had not been completed. The portion of EDS relevant to the Pueblo design was completed on 14 April 2001. This report is based on data from EDS testing received up to 16 March 2001. The largest area of uncertainty in the design is with the operation of the agent and energetics/dunnage supercritical water oxidation (SCWO) units.

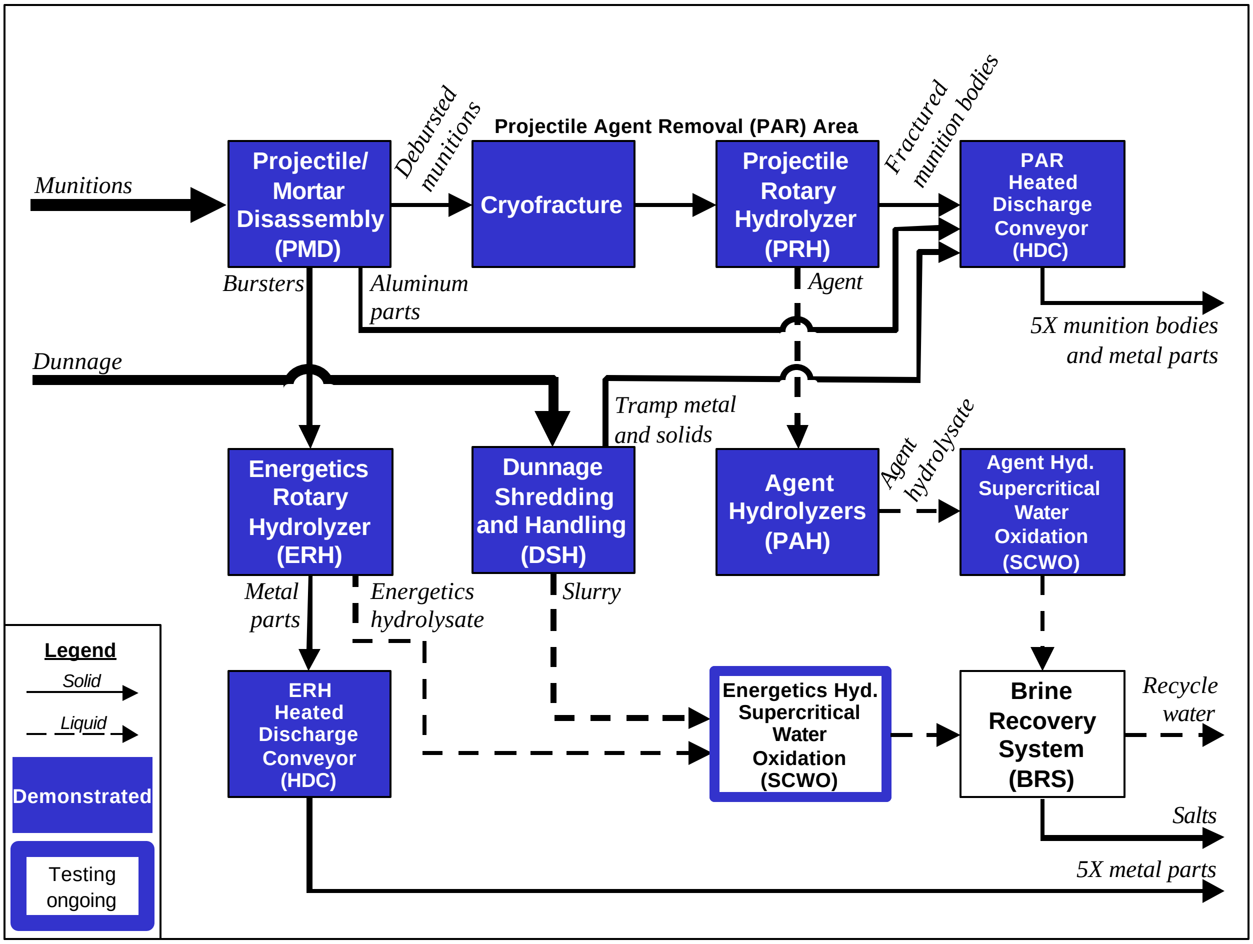
The Design, Preliminary Hazards Analysis (PHA), and Cost Assessments for GATS are based on the design proposed in the January Engineering Package. Some subsequent EDS test results have been incorporated into the assessments. At the conclusion of the EDS Program, Arthur D. Little will review the results of this report to ensure that they are still correct given the outcome of the ongoing testing.

The January 2001 Engineering Package is based on the use of projectile/mortar disassembly machines (PMD) to remove the energetics from the munition body. Instead of using the Multipurpose Demilitarization Machine (MDM) to drain and/or wash the agent out of the munition body, the munition body is cryogenically cooled and fractured to access the agent for hydrolysis. The energetics and agent are hydrolyzed separately in similar rotary hydrolyzers. The hydrolysates are oxidized to carbon dioxide, water and inorganic salts in the SCWO units.

Table 4-1: General Atomics Proposed Total Solution for PUCDF

Material to be Processed	Baseline	General Atomics EDS Design Package
Explosives	• PMD • Burster Shear	• PMD • ERH • Hydropulper • SCWO
Agent	• MDM • LIC	• Cryofracture • PRH • PAH (Hydrolysis) • SCWO
Metal Parts	• MPF	• HDC
Fuzes	• PMD • DFS	• PMD • ERH and/or HDC
Solid Process Wastes	• DUN	• Shredding • Hydropulper • SCWO
Liquid Process Wastes	• LIC	• Hydrolysis (if needed) • SCWO
Brine	• BRA	• Brine concentrator • Evaporator/crystallizer

Figure 4-1: GATS Block-Flow Diagram



Source: General Atomics

The GATS technology is designed to demilitarize all of the munitions in the Pueblo Chemical Disposal Facility (PUCDF) stockpile as well as all dunnage and non-process related wastes (see Tables 4-2 and 4-3). This includes the ability to reconfigure the boxed munitions and destroy the propellants associated with them. The General Atomics design is based on reconfiguring the munitions within the Munitions Demilitarization Building (MDB) and destroying the munitions and propellant immediately. The GATS design is intended to destroy all the dunnage materials associated with the boxes as it is generated. The need to reconfigure the munitions and destroy the resultant dunnage was changed by PMACWA after the Engineering Package was received; therefore, the assessments are based on the ability of the process to handle reconfigured munitions only.

Table 4-2: GA Design Basis – PUCDF Munitions and Munitions Related Dunnage[1]

Item	Munitions designation			
	M110HD/ M104HD	Palletized M60HD	Boxed M60HD	M2HT/ M2HD
Munitions				
Diameter	155 mm	105 mm	105 mm	4.2 in
Number in stockpile	**299,554**	**355,042**	**28,376**	**97,106**
Munition feed materials				
Projectile body (steel), lb/rnd	80.25	28.05	28.05	14.58
Agent, lb/rnd	11.7	3.17	3.17	6.0
Burster tube, lb/rnd	0.43	0.25	0.25	0.47
Burster energetic material	Tetrytol	Tetrytol	Tetrytol	Tetryl
Burster, lb/rnd	0.41	0.26	0.26	0.14
Fuze well cup (Al.), lb/rnd	0.06	0.06	0.06	---
Nose closure	Lifting ring	M78 fuze body	M51A5 fuze	M8 fuze
Nose closure material	Steel	Steel, aluminum	Steel, aluminum, energetics	Mostly aluminum
Nose closure, lb/rnd	1.75	1.85	2.14	0.78
Total projectile, lb/rnd	**94.6**	**33.64**	**33.93**	**21.97**
Firing cartridge, lb/rnd	---	---	5.8	---
Propellant, lb/rnd	---	---	2.75	0.43
Mortar tail piece, lb/rnd	---	---	---	0.78
Total munition, lb/rnd	**94.6**	**33.64**	**42.08**	**24.3**
Munitions storage dunnage				
Number, rnds/box	---	---	2	2
Box fiber and wood, lb/rnd	---	---	11	10
Box metal, lb/rnd	---	---	0.25	0.25
Number, rnds/pallet	8	24	20	48
Pallet wood, lb/rnd	5.25	1.75	1.63	0.94
Pallet metal, lb/rnd	0.5	0.17	0.18	0.13
Total wood, lb/rnd	**5.25**	**1.75**	**12.63**	**10.94**
Total metal, lb/rnd	**0.5**	**0.17**	**0.43**	**0.38**

1 There are discrepancies between the General Atomics design basis and the PMCD design basis for PUCDF.

Source: Table 2-1-1, General Atomics Document 123002/2

Table 4-3: General Atomics Design Basis – Non-Process Related Wastes

Waste • RFP/amendment description • General Atomics assumption	Engineering Package Design basis, lb/round
Dunnage • Mixture of glass, plastic, wood, metal bands, paper and packaging material not related to munitions storage. • Assumed to be 30% wood, 20% plastic, and 50% metallic and not contaminated with agent	1
Decon solution • NaOH, NaOCl • 5.5% NaOCl	5
DPE suits • Chlorinated PVC, PVC, latex, butyl rubber • Chlorinated polyethylene, PVC, latex, rubber	0.7
Spent carbon • Generated by CDF building and control systems • Same	0.3
Waste oils • No description • Assumed to be heavy oil for lubrication. Heat content assumed to be equal to kerosene.	0.3
Trash, debris, protective clothing • No description • Assumed to be solid, non-metallic, non-plastic. Treated like wood.	0.2
Miscellaneous metal parts • Non-munition scrap metal • Metallic tools and parts. Assumed to be non-aluminum.	0.4
Spent hydraulic fluid • No description • Light oil for hydraulic machinery operation. Heat content assumed to be equal to kerosene.	0.2

4.1 GATS Technology Description

Munitions are transported by forklift or truck from the Munitions Storage Building (MSB) to the Munitions Demilitarization Building (MDB). The munitions are unloaded in the vestibule area of the MDB for inventory check and inspection prior to moving them into the Unpack Area (UPA). The UPA is sized to provide a minimum of 4 hours of munition storage. In the UPA, there are two munitions loading stations where the palletized munitions are unpacked manually. If reconfiguration is needed, the munitions are transferred to the Projectile Reconfiguration Room (PRR) where the munitions are unboxed and propellant is removed. The boxes and fiber tubes from reconfiguration are sent to dunnage handling; the propellant is sent to the energetics rotary hydrolyzer. (Note that the PRR is no longer needed if the munitions have been reconfigured.)

After unpacking, the projectiles and mortars are conveyed to the Energetics Containment Room where the fuzes and bursters are removed in a baseline Projectile/Mortar Demilitarization (PMD) machine. The PMD machine removes the nose closure (lifting ring or fuze), the aluminum fuze well cup (if present), and the whole burster. There are two independent PMDs, each feeding an independent follow-on processing train – one for energetics and one for agent.

The bursters are fed to two parallel Energetics Rotary Hydrolyzers (ERH). The ERH is a rotating drum (about 4 ft in diameter and 20 ft long) filled with hot (105 °C) caustic. Aluminum parts (fuze well cups and mortar fuzes) are diverted around the ERH and sent to the agent Heated Discharge Conveyor (HDC). Propellant from the prior reconfiguration of the boxed munitions is also fed to the ERH. Energetic materials are hydrolyzed by the caustic in the ERH. The resulting energetics hydrolysate is then sent to a continuously stirred tank reactor to allow further reaction time to ensure that all energetic materials have been hydrolyzed. After hydrolysis is complete, acid is added to the tank reactor to neutralize the caustic and to precipitate any aluminum hydroxide formed in the ERH. The precipitated solids are then filtered out during the transfer of the hydrolysate to a holding tank. The remaining undissolved metal parts from the ERH are transported through the ERH HDC in which they are electrically heated for 5X treatment (1000 °F for 15 minutes) before disposal.

The ERH is purged with air to avoid a potentially hazardous buildup of hydrogen from aluminum. The HDC is operated under a slight vacuum and with a nitrogen atmosphere. The gases from the ERH and HDC are scrubbed, cooled and condensed (recycling condensate back to the ERH), and passed through a carbon filter system before being sent to the MDB HVAC system.

After removal of the fuze and burster, the projectile/mortar body is sent to one of two cryofracture units in the Projectile Agent Removal (PAR) area, where the munition shell is cooled by being conveyed through a bath of liquid nitrogen. The cold and brittle munition body is then fractured by a hydraulic press to access the agent inside. The shell fragments and agent are then sent to a Projectile Rotary Hydrolyzer (PRH). The PRH is similar in design and concept to the ERH. It is a rotating drum filled with hot water where the residual agent is washed from the metal parts and the hydrolysis reaction for agent is begun. The metal projectile/mortar fragments from each PRH are sent to the PAR HDC for 5X treatment before disposal. Both pairs of PRH plus HDC share a single gas scrubbing system similar to that used for each energetics ERH plus HDC train.

The liquid effluent from the PRH is sent to the Projectile Agent Hydrolysis (PAH) system. The PAH system consists of several parallel stirred tank reactors, where the agent hydrolysis (or neutralization) process takes place. Once it has been verified that agent hydrolysis is complete, the hydrolysate is fed to the agent hydrolysate Supercritical Water Oxidation (SCWO) system. In the SCWO reactor, the organic constituents in the hydrolysate are oxidized to carbon dioxide, water, diatomic nitrogen, and salts. The gaseous effluent from the SCWO system is passed through carbon filters and then to the MDB HVAC system. The liquid effluent is sent to the Brine Recovery System (BRS), which consists of a brine concentrator unit, followed by an evaporator/crystallizer and a solids filter/dewatering unit. The net water produced in the GATS process is evaporated as a vent from the brine concentrator condensate tank. Water used for processing is condensed and recycled back to the process.

Wood dunnage, spent activated carbon, used DPE plastic/rubber suits, boots, and gloves, and non-process wastes such as hydraulic oil are processed in the energetics SCWO. Considerable feed preparation in the Dunnage Shredding and Handling (DSH) system is required:

- The wood dunnage, consisting of wood pallets, is sent to a series of commercial shredding units that reduce the size of the material. The wood is processed through three shredding units in series, each one producing a smaller average particle size until a final product having the consistency of fine sawdust or flour is achieved.
- After removal of any metal components, the DPE plastic/rubber components are coarsely shredded, cryocooled with liquid nitrogen, and then granulated to achieve the desired final particle size. During the course of the shredding processes, magnets remove ferrous metal from both the wood pallets and DPE suits. This tramp metal and any other solid materials that are not shredded, are sent to the PAR HDC for 5X treatment before disposal.
- Spent activated carbon from the various carbon filters is size-reduced and slurried. At the time of their final Engineering Package submission, General Atomics intended to pump the carbon slurry to the Hydropulper unit, where it would be blended with the shredded wood, shredded DPE, energetics hydrolysate, non process wastes, and additives to form a slurry for processing through SCWO. Because inclusion of carbon in the energetics/dunnage hydrolysate feed during EDS testing of SCWO resulted in difficult operating conditions and inadequate destruction of carbon, General Atomics removed carbon from this SCWO feed. As a result, General Atomics must determine an alternate means of carbon destruction/ decontamination (see Section 4.2.2).

The shredding units and two parallel hydropulpers make up the DSH. When ready, a high-pressure pump is used to pump the combined slurry from a hydropulper to the energetics/dunnage hydrolysate SCWO system, where the feed is oxidized similarly to that described above for the agent hydrolysate feed. The gaseous effluent is passed to carbon filters and the SCWO building HVAC system, while the liquid effluent is sent to the Brine Recovery System (BRS).

4.2 General Atomics Testing during ACWA Program

Three technology providers were selected for ACWA Demonstration I testing: Parsons/ Honeywell, Burns and Roe, and General Atomics in 1998. During their Demonstration, General Atomics tested the following three unit operations:

- The Energetics Rotary Hydrolyzer (ERH) was tested to determine its effectiveness and the time required to hydrolyze energetic bursters and M28 propellant in heated caustic.
- The Dunnage Shredder/Hydropulper System (DSHS) was tested to demonstrate shredding of wood and plastic/rubber to an adequate size for treatment in SCWO after mixing into a slurry.
- Supercritical Water Oxidation (SCWO) of agent hydrolysate and energetics hydrolysate/dunnage was tested to demonstrate the destruction of Schedule 2 compounds and organic components.

The test objectives for the General Atomics unit operations are presented in Table 4-4, and the Demonstration I Test Program for each of the three unit operations is discussed in Section 4.2.1.

At the conclusion of the demonstration testing, PMACWA selected General Atomics to continue the development of the GATS process during the EDS Program. During the EDS Program, General Atomics tested two unit operations based upon the additional data needed to prepare the Engineering Design Package for PUCDF. Tested unit operations include:

- Dunnage shredding of wood and plastic/rubber, along with wet grinding of activated carbon.
- Supercritical Water Oxidation (SCWO) of HD hydrolysate and tetrytol hydrolysate/dunnage.

The ERH was also further tested during the EDS Program, but only with M28 propellant. The test objectives for the General Atomics unit operations tested during the EDS Program are presented in Table 4-5, and the EDS Test Program for each of the two unit operations is discussed in Section 4.2.2. The following discussions include testing and test results through 16 March 2001.

4.2.1 General Atomics Demonstration Test Program

Energetics Rotary Hydrolyzer. The ERH was demonstrated at the Chemical Agent Munitions Disposal System (CAMDS) of the Deseret Chemical Depot, Utah in 1999. The main focus in testing the ERH was not on munitions handling, but rather to verify dissolution and hydrolysis of energetics in a reasonable time period. As a result, the ERH unit that was tested was a batch-scale unit designed only to replicate the chemistry and mixing expected in the continuous full-scale version. The tested unit had a drum diameter of 4 ft (2/3 full-scale) and an axial length of 2 ft, and could accommodate 100 liters of caustic (heated via steam coils attached to the exterior of the drum). The main difference between the unit tested and the full-scale design was that there was no significant axial component for lateral movement of the munition down the drum as intended in the full-scale design. Thus, the lifting flights in the tested unit were designed only to tumble the munition through the hot caustic as the drum. A sample tray was installed to provide a way to remove the munition from the drum for inspection at intermediate times and at the completion of the run.

The demonstrated ERH system consisted of the following major equipment items: the ERH drum, a ventilation fan to remove gaseous vapors from the ERH, and a muffle furnace to deactivate residual energetics in fuzes not accessed by caustic. In addition, other smaller test support equipment was utilized during testing, such as a munition scale, drum pump for loading/emptying the ERH, and video cameras for remote observation of munition hydrolysis. To meet the objectives established for the demonstration of the ERH, a series of test runs was established as summarized in Table 4-6.

A sampling and analysis program for ERH testing was developed to analyze the gaseous effluent and liquid hydrolysate remaining in the ERH drum. Process monitoring of the system during operation included measurement of the following: initial munition weight, drum liquid temperature, drum rotation speed, air sparge flow rates, ventilation flow rate, steam pressure, caustic concentration, liquid level in the drum, and on-line effluent H_2 and N_2O concentrations.

Table 4-4: General Atomics Demonstration I Test Objectives[1]

Test Objectives	Outcome of Testing
Energetics Rotary Hydrolyzer (ERH)	
• Demonstrate effective dissolution of aluminum and energetics in fuzes and bursters to allow subsequent downstream processing in the CSTR (continuously stirred tank reactor), SCWO, and HDC (heated discharge conveyor) • Determine the deactivation of energetics in fuzes and bursters from the ERH process • Validate the retention time for dissolution of aluminum and energetics in fuzes and bursters • Characterize the gas, liquid, and solid process streams from the ERH	• Met. The ERH demonstrated adequate dissolution and hydrolysis of all energetics tested. • Met. No unhydrolyzed residual energetics were discovered in liquid effluent or solid debris • Met. Retention times of four hours or less were sufficient for hydrolysis of aluminum and energetics in bursters. • Met. The gas, liquid, and solid process streams were characterized.
Dunnage Shredder/Hydropulper System (DSHS)	
• Validate the ability of the shredders and the hydropulper to adequately prepare the dunnage for downstream processing in the SCWO unit operation (< 1 mm particle size for wood, and < 3 mm particle size for plastics/rubber) • Qualitatively evaluate the operability of the shredder/hydropulper unit operations with particular focus on material handling • Validate the ability of the shredders to process 1,000 lbs/hr of pallets and, separately, 250 lbs/hr of plastics	• Met with reservation. Target particle sizes achieved after shredding, but plastic/rubber particles had to be sieved to remove all particles > 1 mm before SCWO processing; no hydropulper validation conducted. • Met. Operability was adequate, although significant modifications of equipment and processing procedures were required. • Met with reservation. Met target feed rates, but required extensive manual intervention from operators on wood shredding and pre-removal of metal from plastic in order to do so.

Table 4-4: General Atomics Demonstration I Test Objectives[1] (continued)

Test Objectives	Outcome of Testing
Supercritical Water Oxidation System (SCWO)	
Agent hydrolysate testing:	
• Validate the ability of the agent hydrolysis process and SCWO to achieve a DRE of 99.9999% for HD	• Met. Target DRE achieved during agent hydrolysis process.
• Validate the ability of the SCWO to eliminate the Schedule 2 compounds present in the hydrolysate feed	• Met. No Schedule 2 compounds were detected in liquid effluent.
• Demonstrate the long-term operability of the SCWO reactor with respect to salt plugging and corrosion	• Failed. Both corrosion and salt plugging occurred during testing due in part to testing of an unlined inconel reactor instead of the intended but unavailable platinum lined reactor.
• Characterize the gas, liquid, and solid process streams from the SCWO process	• Met. The gas, liquid, and solid process streams were characterized.
Energetic hydrolysate/dunnage testing:	
• Validate the ability of the ERH process and SCWO to achieve a DRE of 99.999% for tetrytol	• Met. Target DRE achieved during agent hydrolysis process.
• Determine the impact of the aluminum from the ERH process on SCWO operation	• Met. Aluminum caused significant plugging in the reactor. GA decided to minimize sources of aluminum to the ERH and filter out aluminum that is hydrolyzed before SCWO in the full-scale design based on these results.
• Determine the extent to which the organics in the shredded dunnage are oxidized in the SCWO process	• Met. All organic components from dunnage were oxidized.
• Characterize the gas, liquid, and solid process streams from the SCWO process.	• Met. The gas, liquid, and solid process streams were characterized.

1 These objectives have been edited to focus only on feeds pertinent to PUCDF.

Source: Arthur D. Little, Inc.

Table 4-5: General Atomics EDS I Test Objectives[1]

Test Objectives	Outcome of Testing
Dunnage Shredding and Handling (DSH)	
• Demonstrate all changes (relative to PMACWA Demonstration I Test Program) to the dunnage shredding equipment proposed for the full-scale design, and verify improved efficiency and uninterrupted operation (e.g., avoiding nesting and unit overloads) while meeting a particle size of < 1 mm for wood and plastics/rubber, and < 0.5 mm for carbon.	• Met with reservation. Target particles sizes achieved (> 99%) after shredding, but plastic/rubber particles had to be sieved to remove the small but non-negligible percentage of particles > 1 mm before SCWO processing.
• Generate information required for design of the dust and agent vapor emission control system.	• Met. Air velocity measurements were taken from several potential points of emission from all shredding units during testing.
• Verify carbon size-reduction in carbon grinder sufficient for downstream SCWO processing	• Met with reservation. Although carbon particle sizes were sufficient for passing through the SCWO feed nozzle, unoxidized particles were observed in the liquid effluent before General Atomics decided to remove carbon from the tetrytol hydrolysate/dunnage SCWO feed.
• Verify feasibility of DPE metal parts removal fixtures for full-scale facility.	• Met in full-scale design package.
Supercritical Water Oxidation System (SCWO)	
• Verify long term, continuous operability (i.e., operation for the full length of the test without unintended shutdown) of the SCWO system as proposed for full-scale with no plugging for HD hydrolysate/simulant and tetrytol hydrolysate/aluminum hydroxide/dunnage.	• Met. Demonstrated reasonably reliable operation for both feeds at approximately 80% availability with a reactor flush performed every 22 hours and liner change (for HD hydrolysate) every 66 hours.
• Verify that corrosion protection offered by platinum-lined reactor and Hastelloy C-276 heat exchanger is sufficient for: • avoiding through-wall failures of equipment and tubing or conditions that would result in premature failure. • Yielding an acceptable rate of general corrosion consistent with intended lifetime and maintenance of the full-scale system	• Met with reservation. Met for heat exchanger but platinum liner failed to provide adequate corrosion protection or mechanical stability. Had to switch to a titanium liner that did provide adequate corrosion protection and an acceptable rate of corrosion.
• Verify that feed additives for salt transport control prevent salt plugs and do not accelerate corrosion.	• Met, but additive choice and concentration had to be customized for each feed.
• Determine a maintenance schedule and frequency of flushes and shutdowns based on the results of long term EDS testing.	• Met. An effective flushing frequency was determined and demonstrated; maintenance activities were documented.

1 These objectives have been edited to focus only on feeds pertinent to PUCDF.
Source: Arthur D. Little, Inc.

Table 4-6: Demonstration Test Runs for the ERH[1]

Test Type	Feed Characteristics	Purpose of Test	Number of Runs
Workup	M557 Fuzes	Determine optimum operating conditions and time necessary for dissolving aluminum booster cup and hydrolyzing tetryl contained; Determine time and temperature necessary in muffle furnace to deactivate unaccessed energetics	2
Validation	M557 Fuzes	Validate the dissolution of aluminum booster cup and hydrolysis of tetryl; validate the deactivation of residual energetics in muffle furnace	5
Workup	M83 burster (1/4 length aluminum tube filled with Comp B)	Determine optimum operating conditions and time necessary for dissolving aluminum burster tube and hydrolyzing Comp B	4
Validation	M83 burster (1/4 length aluminum tube filled with Comp B)	Validate the dissolution of aluminum burster tube and hydrolysis of Comp B	5
Workup	M6 burster (half-size lengths of steel tube filled with tetrytol)	Determine optimum operating conditions and time necessary for hydrolyzing tetrytol	3
Validation	M6 burster (half-size lengths of steel tube filled with tetrytol)	Validate hydrolysis of tetrytol	5
Workup	M14 burster (1/5 or 2/5 length steel tube filled with tetryl)	Determine optimum operating conditions and time necessary for hydrolyzing tetryl	3
Validation	M14 burster (1/5 or 2/5 length steel tube filled with tetryl)	Validate hydrolysis of tetryl	5

1 Tests shown are only those pertinent to munitions at PUCDF.

Source: Arthur D. Little, Inc.

Video recording of the drum internal and muffle furnace exterior for the entire test duration was also included.

The ERH clearly demonstrated its ability to effectively hydrolyze energetic materials contained in burster segments (M6, M14, and M83) and fuzes (M557) in a controllable and consistent fashion. Based on visual observations during the workup and validation runs, all energetics were effectively removed from the steel or aluminum tubes or casings. In most cases, the caustic dissolved the energetics contained in the fuzes or burster pieces in one hour or less (although the full test duration in each validation run was 2 to 4 hours).

Although the ERH testing proceeded in a predictable manner, three unexpected events occurred:

- When the M557 fuze was placed in the muffle furnace and heated, a loud "pop" was heard. After the fuze was removed during the first workup, the furnace was inspected and a small hole in the interior of the back insulation was observed in addition to some discoloration on the inside of the front door of the furnace. After this test, the hole was filled with Kaowool® insulation, the back wall of the muffle furnace was reinforced with a metal plate, and all subsequent fuzes tested were wrapped in Kaowool® to dampen the impact of any shards unleashed during heating. After the modifications, no subsequent deterioration to the muffle furnace or uncontrolled deactivation events were observed.

- When energetics were added to insufficiently heated caustic, partially dissolved energetic solids were prone to sticking to the ERH lifting flights which would occasionally lift the solid out of the caustic bath. During one run, an M83 burster was added at a lower temperature, resulting in the deposit of a particularly viscous and not fully hydrolyzed Comp B material. Some deposits ignited while stuck on an ERH flight, yielding two small fires. The fires were quickly extinguished. Precautions were taken in subsequent tests to use a hot water spray to wash any residual material from the flights back into the caustic bath upon observance, and no other fires occurred during testing. The importance of proper bath temperature was also demonstrated during a later test with an M83 burster where a malfunctioning water heater resulted in addition of ambient temperature makeup water to the bath. This resulted in a lump of partially dissolved Comp B material discovered in the bath at the end of the test.
- During testing with the small diameter M6 bursters, a burster on one occasion became wedged between the flight and drum wall and had to be removed manually.

The following findings pertinent to a full-scale design were observed as a result of the Demonstration I ERH testing:

- The configuration of the ERH flights caused the munitions to spend more time out of the caustic than planned and as a result some of the more viscous energetics would occasionally stick on a flight. The flight design for a full-scale system should take appropriate measures to minimize, or if possible, eliminate, the time munitions are out of the caustic solution. Additionally, the full-scale system should consider design measures to prevent test pieces from becoming jammed or wedged in the ERH flights.
- The inclusion of a hot water spray in the ERH to wash off drum flights should be an integral part of a full-scale design. This would minimize the potential for fires in the ERH and would help control the build-up of partially dissolved energetics on the flights.
- The ability to observe the internal portions of a full-scale ERH using remote video or similar technology would be an important process monitoring control to help ensure that the system is performing in a safe manner.
- The use of liquid level sensors to initiate the addition of make-up water in the caustic bath in a full-scale system would help to ensure that proper caustic levels are maintained.

Dunnage Shredder/Hydropulper System. The DSHS was demonstrated at Dugway Proving Ground, Utah in 1999. The DSHS was designed to prepare dunnage materials (i.e., size reduce and slurry) for destruction via SCWO. The DSHS tested was composed of two subsystems: shredding units for wood and plastics/rubber, and the hydropulper for slurrying shredded dunnage, carbon, aluminum, and energetics hydrolysate. The wood shredding units consisted of a low-speed shredder for coarse shredding, hammermill for further size reduction, and micronizer to pulverize the wood to a consistency of flour. The plastics/rubber shredding unit consisted of the low-speed shredder and a granulator, with a cryocooling step in between the two. In the testing program, the plastics/rubber was transferred from the shredder and cooled batchwise in liquid nitrogen prior to loading in the granulator. The hydropulper subsystem consisted of a large, open hydropulper tank with agitator, a recycle loop through a grinder pump (for further size reduction), and heat exchanger. A line off of the recycle loop allowed transfer of the hydropulper slurry to a holding tank for subsequent processing in the SCWO system. All DSHS equipment was full-scale in size.

To meet the objectives established for the demonstration of the DSHS, a series of test runs was established as summarized in Table 4-7. Test runs were planned to consist of two workup runs and two validation runs with each of the following operations and feeds:

- Wood shredding - wood pallets
- Plastics/rubber shredding - combination of DPE suits, plastic bags, and sheets of butyl rubber (to represent boots and gloves)
- Hydropulper - mixture of shredded wood, plastics/rubber, carbon, and caustic

The shredding tests occurred as planned, but no hydropulper validation runs were performed.

A limited sampling and analysis program for DSHS was conducted primarily to determine particle sizes of materials at the end of shredding and hydropulping. Samples of solid product were taken after the micronizer (wood) and granulator (plastics/rubber) for particle size determination and physical characterization. Physical characterization consisted of a sieve analysis to determine particle size distributions along with photographing and assessment of maximum dimensions of particles.

After an extensive period of systemization for the shredding equipment, General Atomics was able to control system and feed variables well enough to achieve their target feed processing rates and obtain the proposed size-reduction objectives (<1 mm for wood and <3 mm for plastics). Wood shredding required considerable manual intervention to meet the desired throughput rate due to plugging or “nesting” of particles in the units and sensitivity of the micronizer to overloading. Plastic/rubber shredding in general encountered fewer problems than wood shredding, but only after all metal components were removed from the DPE suits prior to initial shredding. Due to schedule delays related to the SCWO and shredding units, the hydropulper system did not go through a formal validation process as planned. The primary observations/issues/problems that occurred during DSHS testing are as follows:

Table 4-7: Demonstration Test Runs for the DSHS

Test Type	Feed Characteristics	Purpose of Test	Number of Runs
Workup	Wood shredding (wood pallets)	Determine optimum operating conditions and procedures for achieving a final particle size < 1 mm at a processing rate of 1000 lb/hr	2
Validation	Wood shredding (wood pallets)	Validate size reduction of wood down to < 1 mm at a rate of 1000 lb/hr	2
Workup	Plastics/rubber shredding (DPE suits, plastic bags, and butyl rubber sheets)	Determine optimum operating conditions and procedures for achieving a final particle size < 3 mm at a processing rate of 250 lb/hr	2
Validation	Plastics/rubber shredding (DPE suits, plastic bags, and butyl rubber sheets)	Validate size reduction of plastics/rubber down to < 3 mm at a rate of 250 lb/hr	2
Workup	Hydropulper (slurry mix of shredded wood, shredded plastics/rubber, carbon, caustic, and additives)	Determine the extent of additional size reduction achieved in the hydropulper and the amount of time necessary for achieving a blend acceptable for SCWO processing	1 (2 intended)
Validation	Hydropulper (slurry mix of shredded wood, shredded plastics/rubber, carbon, caustic, and additives)	Validation of hydropulper operation	0 (2 intended)

Source: Arthur D. Little, Inc.

- There was a frequent problem with "nesting" of accumulated shredded wood in the chute of the hammermill. The nesting problem appeared to be related to a combination of several factors, including: the size of the hammer mill chute (relatively small) in relation to the width of the conveyor (relatively large), the rate of feed into the hammer mill, variations in wood pallet density and moisture content, the configuration of the hammer mill chute, and the dimensions of the shredded wood from the low-speed shredder. Numerous modifications were made to the system components in an attempt to control this nesting. However, the modifications, individually or collectively, did not solve the problem. Nesting also occurred to a lesser extent in the micronizer, but feed overloads when a nest in the upstream hammermill was dislodged were a problem.
- A magnetic head pulley, installed to remove metallic objects from the shredded DPE suits, was not completely effective. As a result, small pieces of metal were occasionally directed to the plastics granulator. The metal nicked and dulled the dicing blades in the granulator, significantly reducing their ability to achieve the target size reduction. This problem required General Atomics to remove metal components from the DPE suits before initial shredding.
- Despite meeting the target particle size for > 99% of plastic/rubber, all particles > 1 mm had to be removed by sieving to allow successful subsequent processing through SCWO.
- Although no validation of the hydropulper occurred, systemization of the unit revealed that no significant further size reduction of particles was obtained in the unit.

The following findings pertinent to a full-scale design were observed as a result of the Demonstration I DSHS testing:

- A hold tank with auger should be added to the wood shredding system before the hammermill (and possibly the micronizer) to provide a more steady and reliable feed to both the hammermill and micronizer to reduce nesting and overloads.
- A method is needed to remove metal from DPE suits before shredding.
- The shredding equipment must be chosen/sized to provide all size reduction for all dunnage components (including carbon, which was supposed to be size-reduced in the hydropulper) down to the acceptable level for SCWO processing. The hydropulper only functions as a mixer.

Supercritical Water Oxidation. The SCWO system was demonstrated at Dugway Proving Ground, Utah in 1999. The purpose of the SCWO system is to destroy the remaining organic components in the hydrolysate feed via oxidation. The dense, high temperature environment characteristic of supercritical conditions (with respect to water) within the reactor leads to a rapid and complete oxidation of organics to CO_2, water, N_2 and mineral acids (or salts when the feed is preneutralized). General Atomics' plan to minimize corrosion in the high temperature/pressure environment originally involved the use of platinum liners in the preheater, reactor, and heat exchanger. A platinum-lined reactor and preheater could not be fabricated and brought to working condition in time for this test program, however. Instead, a titanium-lined preheater and heat exchanger were used, along with an Inconel 718 unlined reactor for all testing.

The SCWO system used in testing was representative of full scale with respect to the components used, but 1/20-scale with respect to flow processed. The system consisted of four skids: the agent hydrolysate feed skid, hydropulper skid (for feeding agent hydrolysate and energetics hydrolysate/dunnage feeds, respectively, as well as other components), the reactor skid (which contained the preheaters, reactor, heat exchanger, and pressure letdown subsystem), and the air compressor/cooling tower skid. In the tests, water, kerosene, and agent hydrolysate feeds were pumped separately up to operating pressure and transferred to the reactor skid. Energetic hydrolysate/dunnage feed components were first blended and then pumped up to operating pressure. These feeds met just before entering the reactor, where they were joined by compressed air and kerosene. Effluent leaving the reactor was cooled prior to entering a gas/liquid separator. Both phases were then reduced to ambient pressure and recombined prior to entering the effluent storage tank.

To meet the objectives established for the demonstration of SCWO, a series of test runs was established as summarized in Table 4-8.

An extensive sampling and analysis program was developed for the SCWO to analyze the hydrolysate feed stream, gaseous effluent and liquid effluent for various organic and inorganic constituents. Analyses included agent, Schedule 2 compounds, dioxins, furans, metals, anions, total organic carbon (TOC), volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). Process monitoring of the system during operation consisted of system temperature and pressure measurements, feed component flow rates, continuous on-line gaseous

Table 4-8: Demonstration Test Runs for the SCWO[1]

Test Type	Feed Characteristics	Purpose of Test	Number of Runs
Workup	HD hydrolysate (consisted of 3.8 wt% HD hydrolysate to which General Atomics added additional caustic and proprietary additives)	Determine optimum operating conditions and feed recipe to allow effective oxidation (i.e., clean effluent) without significant corrosion or salt plugging.	1
Validation	HD hydrolysate (consisted of 3.8 wt% HD hydrolysate to which General Atomics added additional caustic and proprietary additives)	Validate the destruction of HD hydrolysate	3
Workup	Tetrytol hydrolysate/dunnage (consisted of slurry of tetrytol hydrolysate, shredded wood, shredded plastics/rubber, carbon, caustic, pentachlorophenol (PCP) and proprietary additives)	Determine optimum operating conditions and feed recipe to allow effective oxidation (i.e., clean effluent) without feed nozzle or reactor plugging.	2[2]
Validation	Tetrytol hydrolysate/dunnage (consisted of slurry of tetrytol hydrolysate, shredded wood, shredded plastics/rubber, carbon, caustic, pentachlorophenol (PCP) and proprietary additives)	Validate the destruction of tetrytol hydrolysate/dunnage (without aluminum)	3

1 Tests shown are only those pertinent to munitions at PUCDF.
2 Numerous additional workup runs were performed with just tetrytol hydrolysate or dunnage components, along with aluminum hydroxide.

Source: Arthur D. Little, Inc.

effluent analysis of O_2, CO_2, CO, and N_2O, and pH and conductivity measurements of liquid effluent.

The SCWO system performed reasonably well overall during testing, except with respect to corrosion and salt plugging. All organic compounds, including Schedule 2 compounds, were destroyed to satisfactory levels, with TOC concentrations below detection limits. Despite the complexity of operation, the system was fairly stable during normal operation. All alarms and interlocks appeared to work properly, triggering automatic shutdowns when necessary. Severe corrosion experienced while processing HD hydrolysate was exacerbated due to the unintended use of the unlined inconel reactor. Although not experienced with HD hydrolysate, reactor salt plugs occurred while processing other agent hydrolysate feeds. Extensive time was needed to determine effective operating conditions and feed recipes for energetics hydrolysate/dunnage feeds. Removal of aluminum from the feed and removal of feed line diameter restrictions and reductions are the two main actions that allowed successful processing of slurry. The primary observations/issues/problems that occurred during SCWO testing of feeds applicable to PUCDF are as follows:

- Significant corrosion occurred while processing HD hydrolysate based on the green/yellow color of the effluent, which was evidence of nickel and chromium (components of inconel) corrosion. A weld failure in the heat exchanger also occurred during one of the systemization tests.

- For energetic hydrolysate feeds, the problematic component appears to have been $Al(OH)_3$. No run with $Al(OH)_3$ in the feed was able to last very long without plugging. Results suggest that operationally the SCWO system can treat all energetic hydrolysate feed components with the exception of $Al(OH)_3$. Fortunately, $Al(OH)_3$ is not hazardous and does not need to be treated by SCWO. However, removal of the $Al(OH)_3$ is an extra step that would have to be considered in General Atomics' full-scale design.
- Dunnage plugging was generally more sudden than the relatively slower salt buildup that caused plugging during energetic hydrolysate runs. Although it was not conclusively identified if one particular component was responsible for the plugs, the reconfiguration of the nozzle to minimize feed line diameter reductions or restrictions appears to have been the most important change out of all the variables explored. Whether the redesigned feed nozzle alone can ensure long-term operation with dunnage components is unclear based on the pressure fluctuations still observed in these validation runs.

The following findings pertinent to a full-scale design were observed as a result of the Demonstration I SCWO testing:

- Although Inconel can be an viable material of construction in some cases, an unlined Inconel reactor is not acceptable for processing agent hydrolysates due to excessively high corrosion.
- General Atomics will need to filter out aluminum hydroxide from the energetic hydrolysate before mixing it with dunnage and feeding it to the SCWO. Because of the significant time spent identifying conditions that would allow operation without plugging in Demonstration I, General Atomics was not able to establish what maximum concentration of $Al(OH)_3$ the SCWO system would be capable of handling, and therefore, how difficult a filtration technique and process would be needed.
- Plugging in the preheater and feed nozzle with dunnage slurry feeds is sensitive to the feed delivery design and could be a problem for long term operation. The full-scale design must minimize pipe restrictions, diameter changes, and unnecessary bends.

4.2.2 General Atomics EDS I Test Program

Energetics Rotary Hydrolyzer. ERH EDS testing consisted solely of optimizing conditions to decrease the required time to hydrolyze M28 propellant contained in rocket motors. As this munition is not stored at PUCDF, no discussion of ERH EDS testing is included in this report.

Dunnage Shredding and Handling. The DSH EDS testing was performed at Dugway Proving Ground, Utah and vendor sites. Note that between Demonstration I and EDS testing, General Atomics changed the name of the dunnage shredding and hydropulper subsystem from Dunnage Shredder/Hydropulper System (DSHS) to Dunnage Shredding and Handling (DSH). This change was meant to reflect the reduced role in size reduction that the hydropulper was found to have in Demonstration I. The focus in EDS testing was solely on dunnage shredding, with the goal being to demonstrate acceptable size reduction for SCWO while avoiding the problems encountered in Demonstration I testing.

The wood shredding equipment was the same as that used in Demonstration I and was located in the same building at Dugway. The main difference from the configuration used in Demonstration I was the addition of a screw conveyor between the low speed shredder unit and the hammermill in order to provide a continuous feed to the hammermill for avoidance of nesting. All modifications made to equipment during Demonstration I testing were removed with the exception of vibrating motors which were kept in place on the hammermill to help dislodge potential nesting. The plastic/rubber shredding process was revised for EDS testing and only used the granulator unit from Demonstration I testing. In the revised two-step process, bagged DPE suits (without metal) and rubber sheets were fed to the granulator first (rather than last) for rough shredding. This part of the EDS testing was conducted at Dugway in the same building as in Demonstration I. The rough shredded plastic/rubber was then further size-reduced down to the final particle size in a new cryocooled micronizer. This unit was manufactured by Pulva Corp., and this portion of the testing was conducted at their facility in Saxonburg, PA. The unit consisted of a combined screw conveyor and hammermill all cryogenically cooled with liquid nitrogen. An additional series of tests conducted during DSH EDS testing that was not performed in Demonstration I testing was carbon grinding. New testing was required because the grinder pump and associated hydropulper proved to be ineffective for carbon particle size reduction in Demonstration I. The carbon grinding process devised for EDS testing was a wet grinding procedure performed by a colloid mill manufactured by Bematek Systems. Carbon grinding tests were performed at this vendor's facility in Beverly, MA.

To meet the objectives listed in Table 4-5, a series of test runs was established as summarized in Table 4-9. Sampling and analysis was similar to that performed in Demonstration I, focusing on particle size distribution determination and characterization. Based on the Demonstration I experience of having to sieve plastic/rubber particles to < 1 mm for SCWO testing, the final particle size for plastic/rubber particles in EDS tests was reduced to 1 mm or less. The final particle size for wood remained at 1 mm or less, while the final particle size for carbon was set at 0.5 mm or less. Target shredding rates were different from that of Demonstration I testing to reflect processing rates required for the GATS design at PUCDF.

The EDS wood shredding tests successfully demonstrated steady operation without hammermill nesting or micronizer overloads. Similar to Demonstration I test results, 99.9% of product wood particles were < 1 mm. In order to achieve these results however, General Atomics could not meet the target processing rate of 1250 lbs/hr. Throughput rates varied between 850 and 1050 lbs/hr during the tests performed. The achieved rate was heavily dependent on the nature of the wood pallets being processed (e.g., type of wood, moisture content, hardness, weight) and the current ambient weather conditions (i.e., percent humidity). Because it is now known that the boxes from non-reconfigured munitions will not have to be processed, the EDS-demonstrated processing rates are acceptable for meeting full-scale requirements.

The EDS plastic/rubber shredding tests demonstrated a finer grind than was achieved in Demonstration I tests. Both the granulator and cryocooled micronizer functioned well in demonstrating reliable operation and meeting target particle sizes. The very small but finite number of oversized particles > 1 mm, however, still required sieving for removal before the

Table 4-9: EDS I Test Runs for the DSH

Test Type	Feed Characteristics	Purpose of Test	Number of Runs
Workup	Wood shredding (wood pallets)	Determine optimum operating conditions and procedures for achieving a final particle size < 1 mm at a processing rate of 1250 lb/hr without nesting or overloads.	2
EDS	Wood shredding (wood pallets)	Demonstrate continuous, reliable operation without nesting or overloads while achieving a final particle size < 1 mm at a processing rate of 1250 lb/hr.	2
Workup	Plastics/rubber shredding (DPE suits, plastic bags, and butyl rubber sheets)	Determine optimum operating conditions and procedures for achieving a final particle size < 1 mm at a processing rate of 70 lb/hr.	2
EDS	Plastics/rubber shredding (DPE suits, plastic bags, and butyl rubber sheets)	Demonstrate continuous, reliable operation while achieving a final particle size < 1 mm at a processing rate of 70 lb/hr.	2
Workup	Carbon grinding	Determine processing parameter values necessary for wet grinding of carbon particles down to < 0.5 mm at a processing rate of 30 lb/hr..	2
EDS	Carbon grinding	Demonstrate continuous, reliable operation while achieving a final particle size < 0.5 mm at a processing rate of 30 lb/hr.	2

Source: Arthur D. Little, Inc.

plastic/rubber could be processed by SCWO. Because the full-scale SCWO reactor will have a larger nozzle diameter than the smaller EDS unit, this problem may not exist with a full-scale system at the level of size reduction already demonstrated.

Carbon grinding was successful in achieving the target particle size in a relatively simple and fast process. However, subsequent processing through SCWO during tetrytol hydrolysate/dunnage workup runs revealed that the carbon could not be fully destroyed under the chosen operating conditions. Carbon particles also contaminated and eroded downstream pressure letdown valves and filters during these tests. As a result, General Atomics elected to remove carbon particles from the tetrytol hydrolysate/dunnage SCWO feed for EDS testing, and will have to determine another method of treatment for the GATS design.

Supercritical Water Oxidation. The SCWO EDS testing is being performed at Dugway Proving Ground, Utah in the same location and using the same equipment (with some modifications) as Demonstration I testing. The main equipment changes incorporated for EDS testing were:

- Use of a reactor with a removable, corrosion-resistant liner

- Addition of a duplicate agent hydrolysate feed skid, slurry feed skid, pressure let-down subsystem, and air compressors for redundancy and consequently more reliable operation
- Addition of a high pressure liquid oxygen subsystem
- Addition of a high pressure liquid nitrogen subsystem (nitrogen is used as a liner purge)
- Addition of a hydrocyclone between the reactor and pressure letdown system for effluent solids removal

The overall goal of the EDS SCWO testing has been to demonstrate long term continuous operability in a manner consistent with the intended full-scale operation. In particular, the focus has been on developing and demonstrating operating equipment and procedures to eliminate or minimize the main problems of corrosion and salt plugging which have been associated with SCWO in the past and were observed in Demonstration I testing.

To meet the objectives listed in Table 4-5, a series of test runs was established as summarized in Table 4-10. The EDS test for each feed consisted of a single 500-hr run. This duration was chosen as a way to assess the viability of long term operation and the effectiveness of the chosen means of corrosion and salt plugging control. Due to Treatability Study limitations, only the first 12 hours of the HD hydrolysate test were performed with real agent hydrolysate. The remainder of the test was performed with HD hydrolysate simulant consisting of thiodiglycol and sodium chloride. Both the HD hydrolysate and tetrytol hydrolysate/dunnage feed recipes were different than that used in Demonstration I in order to reflect concentrations consistent with munitions found at PUCDF and/or the GATS schedule. For these reasons, 15 wt% HD hydrolysate was utilized instead of the 3.8 wt% used in Demonstration I testing. The tetrytol hydrolysate/dunnage recipe had much less tetrytol hydrolysate than that used in Demonstration I testing. Sampling and analysis was similar to that conducted in Demonstration I except at a lower frequency and number of analyses – except during the 12 hrs of actual HD hydrolysate testing.

An extended period of time was required (June-December 2000) before the 500-hr test with HD hydrolysate/simulant could be performed due to several issues that arose during workup runs:

- The choice of fuel had to be changed from kerosene to isopropanol when using oxygen as the oxidant to avoid premature ignition and burnout within the feed nozzle. Although the oxidant was later changed back to air, the fuel has remained isopropanol.
- The original material choice for the removable liner was platinum. The liner consisted of a thin platinum cylinder mounted and welded at both ends to a Hastelloy C-276 backing. The platinum layer suffered severe buckling and degradation during several workup runs performed with HD hydrolysate simulant, due to problems with both mechanical integrity and corrosion in the chloride environment. As a result, General Atomics abandoned the use of the platinum liner and switched to titanium.

Table 4-10: EDS I Test Runs for SCWO

Test Type	Feed Characteristics	Purpose of Test	Number of Runs
Workup	HD hydrolysate/simulant	Determine optimum additive concentrations, liner material, and operating procedures to allow reliable and continuous operation.	57
EDS	HD hydrolysate/simulant	Demonstrate continuous, reliable operation consistent with full-scale operation.	1
Workup	Tetrytol hydrolysate/dunnage (dunnage consists of shredded wood, shredded plastics/rubber, caustic, and slurry thickener)	Determine optimum feed recipe and operating procedures to allow reliable and continuous operation without plugging.	46
EDS	Tetrytol hydrolysate/dunnage (dunnage consists of shredded wood, shredded plastics/rubber, caustic, and slurry thickener)	Demonstrate continuous, reliable operation consistent with full-scale operation.	1

Source: Arthur D. Little, Inc.

- Initial workup runs with a titanium liner showed that it was susceptible to corrosion at high pH values and at high concentrations of the salt transport additive used. Thus, optimal concentrations of caustic and additive and effluent pH had to be determined to balance acceptable levels of corrosion and salt transport through the reactor General Atomics originally started with a fabricated, more expensive Grade 7 titanium liner, but later found that a more readily available and less expensive Grade 2 titanium pipe was adequate for the job. The change of liner material to titanium required a change in oxidant from oxygen to air to avoid the possibility of a titanium fire.

The 500-hour EDS test with HD hydrolysate/simulant was performed with the titanium pipe liner over a four-week period from 3 to 29 January 2001. General Atomics demonstrated reliable operation by performing 22-hr run segments of steady state feed followed by a flush of the reactor with subcritical water to remove accumulating salts. With the final feed concentrations of caustic and additive determined, this operating scheme of 22-hour cycles of feed processing and flushing resulted in stable operation without salt plugging or corrosive failures. A system availability value of approximately 80% was achieved during the test. The liner was inspected for corrosion every 66 hours. Most of the corrosion occurred within a band from 7 to 12 inches down from the top of the liner and consisted of both pitting and general corrosion. The liner was replaced or its orientation was inverted every 132 hours, when corrosion had penetrated through about half of the original liner thickness. Apart from cloudiness in the liquid effluent due to titanium dioxide (from liner corrosion), no discoloration or char particles were observed in the effluent, indicating no other corrosion and likely good oxidation of organic species. Other observations relevant to full-scale operation made during the testing are as follows:

- Due to a reaction that occurs when the salt transport additive is added to the feed, the additive is transformed to a less soluble species that can precipitate out in the feed tank. This results in unacceptably low levels of soluble additive in the feed to the reactor, resulting in salt plugs.

To rectify the situation, the SCWO feed tank and feed lines to the reactor had to be heated to 110°F to keep the additive in solution. An inline heater was also used.

- Because of the sensitive balance in concentration required for feed species to avoid severe corrosion and salt plugging, the means for accurate determination of caustic, sulfur, and salt transport additive concentrations in the feed must be available.
- Titanium dioxide solids from liner corrosion can buildup over time in downstream pressure let-down valves and components, impeding operation. A means of periodically backflushing these components is necessary.
- Corrosive failure of thermocouples in the reactor interior (including those with platinum sheaths) occurred in less than 66 hours during tests with HD hydrolysate or simulant. As a result, titanium thermowells were installed around each thermocouple to prolong their life. The 3/8 inch OD titanium thermowells also suffered severe corrosion over 66 hours, including through wall failure. The thermowells lasted long enough, however, to protect the platinum sheathed thermocouples. The thermowells had to be replaced every 66 hours. In some cases where corroded thermowell segments broke off and fell to the reactor bottom, the thermowell fragments impeded effluent flow out of the reactor.

Workup runs with tetrytol hydrolysate/dunnage slurry feed began in February 2001 and continued until mid-March. As of 16 March 2001, the 500-hr test had not yet begun, but most of the major issues had been identified and an effective feed recipe and operating procedure developed to allow the start of the 500-hr test. All workup tests have been performed with a titanium pipe liner and air as the oxidant, similar to that utilized in HD hydrolysate tests. The following issues were identified during workup runs:

- Frequent slurry feed line plugs were experienced initially due to line diameter restrictions and non-optimal piping configurations. Revamping the piping greatly improved performance, but occasional feed line plugs were still encountered. These plugs did not cause system shutdown, however, and were easily cleared within several minutes by backflushing the line.
- The presence of the same salt transport additive compound used during HD hydrolysate (which had been added to the tetrytol hydrolysate during its production in 2000) was found to interact with metal cations contained in dunnage components. The result was the formation in the reactor of a hard salt that was insoluble in subcritical temperature water, and therefore could not be removed by flushing. Buildup of this insoluble salt occurred primarily at the top of the reactor, causing temperature and pressure fluctuations. The problem became manageable after the dunnage loading was reduced (see bullet below) and no additional salt transport additive was used.
- A decision announced by PMACWA that all PUCDF munitions would be reconfigured before processing greatly reduced the wood loading that General Atomics needed to include in the SCWO recipe. The discovery that General Atomics had been using incorrectly high loading values of plastic/rubber at the same time resulted in overall lower concentrations of dunnage required for the slurry feed recipe. Because General Atomics wanted to maintain the same percentage of solids in the slurry for ease of pumping, they accounted for the reduced dunnage loadings by decreasing the slurry flow rate by a factor of three (appropriately adjusting the tetrytol hydrolysate quantity). This reduction in flow rate has significantly slowed the rate of accumulation of insoluble salts to allow stable operation in 22-hr cycles.

- Because of the relatively small amount of soluble salts (i.e., those soluble in subcritical temperature water such as sodium chloride) expected in the feed, General Atomics believes that no salt transport additive is necessary and none will be added to the feed for the 500-hr test. If this is incorrect, a different salt additive tested during some workup runs (but not optimized) could be used.
- Because of poor oxidation of carbon particles and the fact that they are a source of metal cations contributing to insoluble salt formation, General Atomics has decided to remove carbon from the feed recipe for the 500-hr test. An alternate means of treatment of the carbon will need to be determined by General Atomics.
- Because of the minimal amount of corrosive species in the tetrytol hydrolysate/dunnage feed, very little corrosion was observed in the titanium liner throughout the entire set of workup runs. It is likely that the same liner will last the entire 500-hr test.
- The presence of insoluble salt particles and solids has required periodic cleaning of the gas/liquid separator filter screens in the effluent lines.
- Screening of plastic/rubber particles has still been necessary for removal of the small but finite number of oversized particles before processing through the present test-scale SCWO reactor.

5.0 Design Assessment

5.1 Objectives, Scope and Approach

5.1.1 Objectives

The Design Assessment had four overall objectives with regard to review of the design itself and the supporting Engineering Package.

1. Consistency with the requirements of the disposal facility design as set forth in the Design Basis and the results of the Engineering Design Study I (EDS) testing.
2. Completeness in addressing all necessary aspects of the facility and, in particular, in terms of providing a "total solution".
3. Core process viability in terms of operational efficacy and capability to consistently achieve both required levels of agent and energetics destruction as well as environmental performance.
4. Adequacy to support the +/- 20% cost estimate and to justify the proposed schedule (with modifications as required).

5.1.2 Scope and Approach

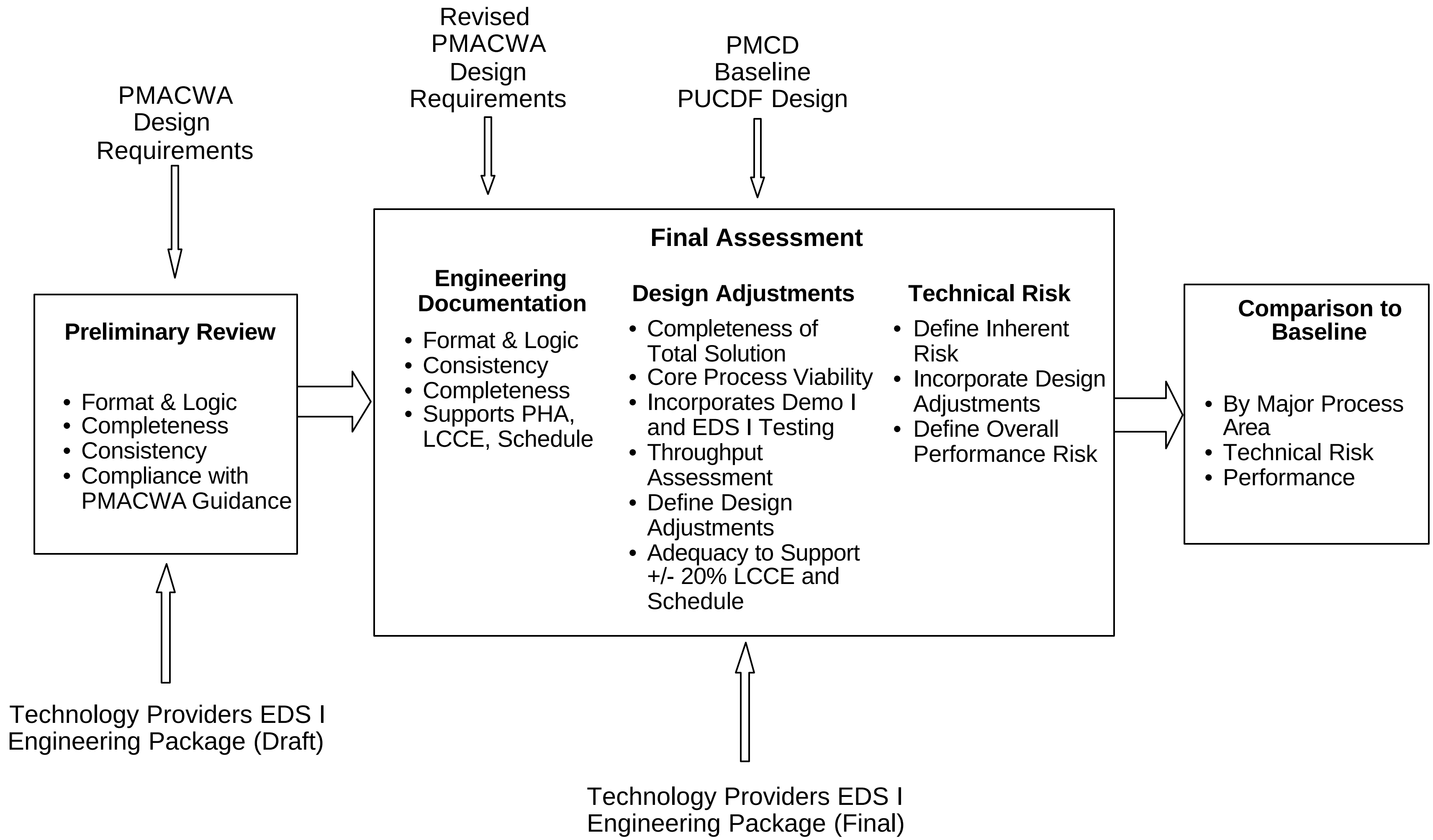
In order to achieve these objectives, the Design Assessment (see Figure 5-1) was conducted in concert with the Preliminary Hazards Analysis (PHA) Review, Schedule Assessment, and Cost Assessment as discussed in later sections. The coordination, and in some cases integration, of these activities was to ensure that the results would present a uniformity of concept and consistency in implementation.

It is recognized that the design package is still in the early stages of development and in many aspects has not yet attained a 35% level of completion. As such, the design package does not contain all design products needed to verify detailed design adequacy. Specifically, lack of supporting calculations and analyses require the assumption of correctness of information included in the package. Therefore, it is important to recognize that the Design Assessment does not constitute a "design review" in the traditional sense. There have been no structured, detailed discipline reviews of design studies or drawings. The design package would not support such a review, nor would such a review be warranted at this stage. However, where rudimentary checks could be performed to validate data or design results without the governing calculation, they were performed. Important examples include verification of the throughput core process and capacity of auxiliary and ancillary systems.

The Design Assessment focused on the following aspects of the General Atomics Total Solution (GATS) design:

- Shares common elements of overall plant design basis and assumptions with those of the Baseline.
- Contains all the processing units necessary for munitions handling and treatment of agent, energetics and dunnage as well as all emissions, effluents and wastes to the extent required.
- Incorporates all design concepts derived from and consistent with the results of the testing conducted under Demonstration I and the EDS I Test Programs.

Figure 5-1: Design Assessment Methodology



Source: Arthur D. Little, Inc.

- Provides sufficient definition of the design and operating parameters of the major core process equipment and equipment interfaces to support a Throughput Assessment.
- Incorporates equipment selection and configuration (including layouts) that offer ease of operation and maintenance.
- Provides definition of equipment and facilities in sufficient detail to support the cost estimate.
- Delineates operating and control philosophy in sufficient detail to support the PHA.
- Provides all necessary information to support the assessment of environmental impacts required for the National Environmental Policy Act (NEPA) documentation and the Resource Conservation and Recovery Act (RCRA) Part B permit application.
- Projects comparable, if not enhanced, performance relative to Baseline.

It should be noted that, where design weaknesses or inconsistencies were identified, compensating design adjustments have been made for cost estimating purposes. These include equipment enhancements, replacements and additions as well as modifications to facilities (e.g., buildings). These changes have not been incorporated in the General Atomics Engineering Package, but are included and discussed in this report.

The results of the assessment are discussed in two parts. The first part is the documentation provided in the Engineering Package provided by General Atomics. The second part is the design of the core process itself and the principal auxiliary subsystems.

5.2 Engineering Documentation

Table 5-1 lists the engineering documentation (broken down by discipline) that was required to be provided by General Atomics as a part of their Engineering Package. Table 5-1 also indicates if the documentation was included in the January 2001 Engineering Package submittal.

The design package includes three major categories of documents:

- Basic Process Engineering Documents – These are the key engineering documents that define the overall process requirements, which then form the basis for detailed design, procurement, and construction. These documents are the focus of the Design Assessment.
- Safety Analysis Documents – The Preliminary Hazards Analysis and the Fire Hazards Analysis included in the package are semi-quantitative in nature and will evolve with the design. Their use at this stage of the design provides assurance that plant hazards have been identified for resolution. It is not expected that the defined resolutions have been incorporated into the design.
- Production Documents – These documents support the construction effort and are used in the package primarily to support both cost and schedule estimating.

Table 5-2 illustrates both the relationship of the documents to different facets of the design package as well as how they were used in the assessment efforts.

Table 5-1: Engineering Design Package Submittals

Included in Submittal	Engineering Package Requirements*		
	Drawing/Document	Level of Completion	Comments
Process & Mechanical			
Yes	Process (and Facility) Design Basis	F	Defines: performance requirements; raw material and utilities characteristics
Yes	Process Flow Diagrams	C	Complete for all systems within the scope of supply (Rev 0)
Yes	Material & Energy Balances	C	By campaign - sustained maximum and annual average conditions
Yes	Water Balance Diagram	C	With flows for sustained maximum and average conditions
No	Throughput Analysis	C	Preliminary analysis of the availability and reliability of process subsystems and/or major pieces of process equipment to support equipment sizing, configuration and schedule
Yes	Process Description	C	Preliminary description including overall operating and control philosophy
Yes	Emissions and Effluents Lists	C	Characteristics & quantities of air emissions, water discharges & solid wastes
Yes	Equipment Lists	C	Major equipment with dimensions, capacities, materials, & preliminary loads
Yes	P&IDs	C	Shows line sizes and materials; primary instruments; control interconnects
Yes	Major Equipment Specifications	P	Data sheets/equipment specifications to support PHA and costs
Yes	General Arrangements	P	Basic plans and sections showing location of major equipment
Partial	Tanks/Vessels Data Sheets	P	Dimensions, capacities, materials, internals, pressure and special requirements
In P&IDs	Line Lists/Piping Schedules	P	Not required if pipe sizes and materials are given on P&IDs for major lines
Yes	Process Hazards Analysis	P	Preliminary for the core process plus adjustments as required to that prepared for the Baseline
Yes	Fire Hazards Analysis	P	
Civil, Structural & Architectural			
No	Site Development/Drainage Plan(s)	P	Only as required to support cost estimates (or PHAs), especially if new buildings are proposed or there are significant modifications to existing Baseline buildings
Yes	Plot Plan(s)	P	
No	Foundation Designs/Studies	P	
No	Structural Steel Designs	P	
Partial	Building/HVAC Designs	P	

Table 5-1: Engineering Design Package Submittals (continued)

Included in Submittal	Engineering Package Requirements*		
	Drawing/Document	Level of Completion	Comments
Electrical			
Yes	Motor Lists	C	Complete
Yes	Major Equipment Lists	C	Complete
Yes	Electrical Area Classifications	P	Complete
Instrumentation & Controls			
In P&IDs	Loop Definitions/Functional Descriptions	C	In sufficient detail to support preliminary PHAs and operability analyses
Yes	Instrument Lists	P	Principal instruments by type and function
Yes	Control System Mini-Specifications	P	Basic requirements for central control panels & DDCS System to support costs

* U.S. Army SBCCOM: Statement of Work, Engineering Design Package
P - Preliminary (Sufficient to support PHA and cost estimate)
C - Complete (Full set of drawings for major eq't/systems, but not yet fully detailed)
F – Final

Source: Arthur D. Little, Inc.

Table 5-2: Utilization of Engineering Documentation

Drawing/Document	Design Assessment	PHA Review	Cost Assessment
Basic Process Engineering Documents			
Process (and Facility) Design Basis	●	●	●
Process Flow Diagrams	●	❍	❍
Material & Energy Balances	●	❍	●
Water Balance Diagram	●		❍
Throughput Analysis	●		●
Process Description	●	●	❍
P&IDs	●	●	❍
Control System Philosophy	●	❍	
Process Equipment Lists	●		●
Tanks/Vessels Data Sheets (Lists)	●		●
General Arrangements	●	❍	●
Emissions and Effluents Lists	●		●
Safety Analysis Documents			
Process Hazards Analysis		●	
Fire Hazards Analysis		●	

Table 5-2: Utilization of Engineering Documentation (continued)

Drawing/Document	Design Assessment	PHA Review	Cost Assessment
Electrical Area Classification Plan		●	
Production Documents			
Major Equipment Specifications	❍		●
Site Development/Drainage Plan(s)			❍
Plot Plan(s)	❍		●
Foundation Designs/Studies			❍
Structural Steel Designs			❍
Building/HVAC Designs			❍
Motor Lists			●
Electrical Equipment Lists			●
Instrument Lists			●
Control System Mini-Specifications			●

Key: ● Primary information source
❍ Secondary information source/reference

Source: Arthur D. Little, Inc.

5.2.1 Basic Process Engineering Documents

The Basic Process Engineering Documents together provide a complete, concise description of the process and facilities, establish design criteria and design basis information, provide engineered definition to each system, or specify/repackage the criteria and bases to support detailed design development (presented in production drawings), procurement, and permitting. The Design Assessment focused on these drawings and documents. Commentary is provided below.

Process (and Facility) Design Basis. A Design Basis should clearly and succinctly identify design criteria and requirements at the highest level input to the design. These criteria and requirements should include: site-specific conditions; battery limits interfaces and constraints; performance objectives; applicable industry, discipline, and government codes, standards, and documents; design philosophies (e.g., equipment sparing); and possibly contractor developed or client imposed operating parameters and bounding conditions (e.g., use of certain technologies, processes or design parameters).

Overall, the General Atomics Design Basis is much too expansive. There is a considerable amount of descriptive material as well as results of design activities that should be located in design development documents such as the Process Description. Consequently, it is difficult to identify the important elements that are critical to the design effort.

In addition, there are a number of omissions from or errors in the Design Basis.

- Some important site-specific conditions have not been defined. While there are several Baseline documents that support and complement the Design Basis by reference and serve as alternative sources for this information, there are notable omissions. Examples include: assumptions regarding the source, quantity and quality of raw water available, upon which water treatment system designs are predicated; location-specific (state and local) environmental requirements; and assumptions regarding climate conditions used in developing cooling water requirements and preparing water balances.
- Not all process chemical requirements are identified and there are no specifications for process chemicals, some of which may be critical for proper operation of the Supercritical Water Oxidation (SCWO) reactors.
- Where the Design Basis identifies design parameters, a source reference or justification is generally not included. For example, there is a reference to calculated destruction and removal efficiencies (DREs), yet the calculation is not identified. No discussion of risk and acceptable bounding conditions was provided should the parameter prove to be incorrect.
- Specific design parameters developed through government testing for hydrolysis of agent and energetics are not clearly articulated nor adequately referenced. These are a prerequisite for all designs utilizing hydrolysis-based systems.
- It is not noted that EDS I Testing had not been completed for treatment of energetics and agent hydrolysates prior to submittal. These new results and lessons learned need to be factored into the design for slurry transport, slurry composition, process additives, and effluent changes. These test results may impact equipment selection and system performance, mass and energy balances, effluent summaries, and environmental permitting consideration.

The Design Basis needs to be tailored to the Pueblo Chemical Agent Disposal Facility (PUCDF) and address all site requirements. Of equal importance is the lack of a clear statement of government imposed requirements. In this regard, Arthur D. Little did not perform a detailed design review of industry and discipline codes and standards or Corps of Engineers Technical Manuals to determine whether the list is complete and appropriate. The importance of this list will increase as the design progresses.

In summary, the Design Basis needs to be revised for completeness and accuracy of requirements provided and the sourcing of those requirements. Nevertheless, the inadequacies of the Design Basis do not preclude an assessment of the design.

Process (and Facility) Descriptions. The Process and Facility Descriptions were primarily presented as part of the Design Basis with several supporting (sub) system level documents. General Atomics delineated performance objectives, requirements, sizing, bounding conditions, and supporting justification at the process (sub) system and equipment component levels. While these documents adequately described how systems are configured and how the components would function, there are some deficiencies which are noted below.

- There is a lack of identification of reference or source documents for many parameters. For example the Dunnage Shredding and Handling (DSH) System process description identifies design criteria at the system level but not for all system equipment. No supporting calculations or references are identified. Additionally, the hydropulper design criteria are included in this document, but no calculational basis or source references are provided; and there are no supporting calculations or trade-off studies justifying selection. Rudimentary calculational checks were made during the Design Assessment to verify the use of many of these parameters. The lack of calculations and/or other justification, however, did hamper the review.

- Where design parameters are not sourced or justified, discussion of risk and acceptable bounding conditions have not been provided should the parameter prove to be incorrect.
- There is some inconsistency in the level of detail provided. For example, there is little detail provided for operations upstream of the Projectile/Mortar Disassembly Machines (PMDs) and for the Brine Reduction System (BRS).
- Many secondary flows have not been included in the descriptions or are not well categorized.
- Start-up, shutdown and upset conditions have not been addressed to the extent that it is clear that the design of the subsystems or process units incorporate the necessary provisions to accommodate upstream and downstream interfaces and that supporting utilities are properly sized.

Significant revision to these documents is required to provide source, reference, and supporting justification and to completely describe each system. Supporting calculations are needed to ensure the equipment has been adequately sized. This was an area of focus in performing the required Throughput Assessment as discussed later in this Section.

Process Flow Diagrams (and Utility Diagrams). Process Flow Diagrams (PFDs) and Utility Diagrams (UDs) should present the logical construct of each (sub) system by identifying all major pieces of equipment and equipment interconnections as well as connections between subsystems. In this regard, the PFDs and UDs generally provide an adequate definition of each (sub) system, although, there are inconsistencies and omissions. For example:

- There is no PFD for the Munitions Demilitarization Building (MDB) Heating, Ventilation and Air Conditioning (HVAC) filtration system;
- Many air emissions streams are not shown on their respective PFDs (e.g., cooling tower evaporation and drift, boiler emissions);
- Some utilities have not been included; and
- There are some inconsistencies with drawings provided as a part of vendor packages.

Material and Energy Balances. In general, the Material and Energy Balances were found to be adequate, although several omissions and inconsistencies are noteworthy, many of which parallel the deficiencies noted above for the PFDs.

- As is the case for the PFDs, a number of air emissions streams have not been included, such as: air discharges from building vent systems (MDB Filters, SCWO Building); cooling tower drift; and boiler flue gases.
- Again as discussed with the PFDs, a number of utility streams are not included.

- A typographical error has been noted in the mass flow exiting the agent hydrolysis reactors.

The Material and Energy Balances will require updates to incorporate the missing streams identified above, correct minor inconsistencies, and accommodate changes associated with ongoing testing as well as design evolution such as related to the design adjustments recommended in Section 5.3.

Water Balance Diagram(s). The Water Balance Diagram serves three purposes. First, it is to ensure that sufficient attention has been given to the water balance that the goal of a zero water discharge facility has been appropriately factored into the overall design. Second, it supports the Throughput Analysis in demonstrating that the coupling and decoupling of operations incorporates adequate surge and storage capacity both for routine operations as well as startup/shutdown requirements and anticipated upset conditions. And finally, the balance serves as a checkpoint for completeness and accuracy of the overall material and energy balances.

The initial versions of the water balance that were submitted had several omissions and inconsistencies. The latest version provided, although not balanced, is within about 1%. However, it is only for steady state conditions and does not encompass all water flows. For example, cooling tower blowdown and drift, and water treatment blowdown streams are not included; and these water balance constituents (sanitary, cooling tower, and demineralized water) appear to have been omitted from the overall process balances. Further, no water balances have been prepared for seasonal variations or startup and shutdown conditions.

Updates and revisions to the water balance diagram are required to incorporate all water requirements and conditions when large fluctuations can be anticipated. However, the balance provided was determined to be adequate for overall assessment of the design including what additional requirements might be necessary to handle surges. This is discussed in more detail in Section 5.3.

Throughput Analysis. A Throughput Analysis is required to demonstrate that, based on equipment and system availability, reliability, and capacity, plant operations will meet both performance objectives and the proposed schedule. General Atomics did not submit a Throughput Analysis. This is considered a major deficiency in their Engineering Package and is a key issue discussed in more detail in Section 5.3.

The lack of a Throughput Analysis led to much confusion about how the plant would or could be operated or what its throughput capacity would be. For example, in the Design Basis it was stated that the plant would operate 24 hours per day, six days per week with one day off line each week. But within the process calculation section of the Design Basis, operations are assumed for 100% capacity to be 12 hours per day, six days per week. No information is provided supporting this mode of operation rather than operating 24 hours per day, seven days a week with scheduled maintenance as required. Additionally, all equipment must be operated at 100% capacity, simultaneously and on demand, to meet performance objectives on a 12-hour per day basis. Furthermore, no supporting information or justification was given for the assumed availability, reliability and capacity of various pieces of equipment or process subsystems. All data provided appeared to be predicated upon the assumption that both equipment and plant availability would be sufficient to meet the predefined schedule.

Without any form of Throughput Analysis, it was also difficult to determine whether the design incorporated the operational requirements between coupled and decoupled equipment (e.g., surge capacity, shutdown sequencing). A prime example is the BRS. The reliability and operability of the BRS has not been tested, yet only one train is included, and it is assumed to be available 168 hours per week except for clean-out (boil-out). There is no consideration of the unscheduled outage times required nor surge capacities.

Therefore, to evaluate the design, it was necessary that Arthur D. Little undertake a new, independent Throughput Assessment. As discussed in Section 5.3, this analysis was used to identify required adjustments to specific equipment capacities, numbers, size, and operating schedules. While the analysis prepared by Arthur D. Little is considered sufficient to complete the Design Assessment, a more thorough analysis must be prepared prior to continuation of a detailed design effort.

Piping and Instrumentation Diagrams (P&IDs). The P&IDs were used primarily in the review of process operability and performance of the PHA review. In general these were found to be satisfactory; however, a complete set of P&IDs was not provided. There are no P&IDs for the BRS as well as a number of the utility water systems such as demineralized water distribution and some cooling water systems. In addition, subcontractors provided a number of the P&IDs. In these cases, interfaces among a different sets of drawings could be improved by use of inter-drawing tags that include both General Atomics and subcontractor (e.g., Parsons) numbers.

Control System Philosophy. The Control System Philosophy was utilized in conjunction with the process descriptions and P&IDs. It is considered adequate for normal operations and provides a rudimentary sequencing for startup, shutdown and steady state. However, a more expansive discussion of the provisions for interfaces between subsystems during startup, shutdown and upset conditions would be useful, especially in concert with a Throughput Assessment.

Process Equipment List. The Summary Equipment List is generally complete for all but equipment supplied as a part of vendor packages (e.g., BRS, water treatment, and utility systems). The information provided is not always complete but is sufficient for cost estimating purposes.

Tanks/Vessel Data Sheets. Basic dimensional data, capacities and materials of construction were provided for all the core process vessels but not all tanks within the facility. Excluded, for example, were utility storage tanks. The data were provided in the form of lists within the subsystem process descriptions. With a few exceptions, this information was sufficient for the Design Assessment. Complete data sheets, though, will be required as a next step in the design evolution.

Building Arrangement Drawings. Only two new buildings of significance were proposed in the GATS design, the MDB and SCWO enclosure. Arrangement drawings for these were used primarily in the Cost Assessment for comparing and reconciling estimates for different facilities and developing costs for recommended expansions to accommodate additional equipment. In the Design Assessment, they were also used in evaluating space allocations for operations and maintenance access. However, no drawings were provided for the Process and Utilities Building (PUB). This is an existing Baseline building that is to be retained. Because the equipment within this building differs from that in Baseline, drawings are required for this building.

Emissions and Effluents List. The Emissions and Effluents List provided by General Atomics is basically a material balance level document that lacks details in characterizations of most streams. It also is incomplete in identifying all point source and potential fugitive emissions and effluents.

- Incomplete characterizations – Many of the streams lack complete characterizations, particularly at the trace levels for contaminants of interest. Characterization data from the EDS I testing complemented process knowledge and engineering judgement need be factored into all streams shown in the Emissions and Effluent List
- Omitted Streams – Numerous streams are not included in the Effluents and Emissions List. These are primarily solid wastes and air emissions since the design is predicated upon zero wastewater discharge. Examples of air emissions that have not been included are: volatile organic compounds from fuel storage; evaporation and drift from cooling towers; boiler flue gas; and the BRS vent. Many solid wastes generated by maintenance activities are also not included such as SCWO liners and thermocouples and thermocouple wells. One possible liquid waste that has been identified is boil-out from BRS evaporator maintenance. This water cannot be readily returned to the system because of the scale potential within the BRS itself. It is expected that it would have to be disposed offsite.

It is recognized that this is a preliminary listing, but it must be complete to the extent information is available. This is considered a significant deficiency in the Engineering Package. A full list of effluents, emissions, and wastes must be prepared to support environmental permit and cost estimating.

5.2.2 Safety Analysis Documents

The Preliminary Hazards Analysis, Fire Hazards Analysis and Electrical Area Classification Plan were used primarily in conjunction with the PFDs, P&IDs and selected other drawings such as Building Arrangements for conducting the PHA review. These were generally found to be consistent with this phase of design and adequate. The PHA is discussed in Section 6.0.

5.2.3 Production Documents

For this level of review, the following drawings have been identified as Production Drawings. They are mainly used to support cost estimates, although a number would certainly also be part of environmental permitting submittals. These include:

- Engineered Diagrams (Electrical Single Lines, HVAC, Instrumentation);
- Equipment Outline and Design Specifications for Major Process Equipment;
- Equipment Details, Interface Control Drawings, and Specification Control Drawings;
- Summary Motor Load List;

- Summary Instrument List and I/O Count;
- Site Plot Plans;
- Structural and Foundation Drawings; and
- Building Architectural Drawings.

These drawings are adequate for the use intended.

5.3 Key Issues and Resolutions

The Arthur D. Little review of the General Atomics Total Solution (GATS) design submittal was intended to determine its adequacy in supporting capital and operating cost estimates and the proposed schedule. Part of the Design Assessment included the following steps:

- A review of the submitted documents to evaluate the feasibility of the overall GATS process design and its ability to process the munitions according to the submitted cost estimates and schedule.
- Adjustment of the process to "fix" design errors and flaws noticed in the review of documents. The focus was on major problems that would affect capital and operating costs and schedule.
- Adjustment of the process to assure adequate throughput, mainly by increasing reliability and capacity. The focus was on plant components that were potential bottlenecks that would extend the schedule and increase life cycle costs.
- Adjustments to the process to address results from the ongoing EDS I testing in support of the GATS design. The purpose of these adjustments was to incorporate information produced from EDS I testing subsequent to the January 2001 Engineering Package submittal, and to reduce the perceived risk from uncertainties still remaining due to the ongoing EDS I testing. Testing up to 16 March 2001 was incorporated into the Design Assessment.
- Adjustments to the process to reflect changes to the GATS design basis made by PMACWA in response to questions that arose out of the Design Assessment.

This section discusses the key design issues and the resolutions made by Arthur D. Little as a consequence of the review steps described above, and an assessment of the technology risks still remaining in the GATS process.

Because the GATS process is integrated, it was difficult to present a clear *a priori* precedence order of issues. Table 5-3 presents a summary of the major issues in the order in which they were identified and discussed during the assessment. Table 5-3 also includes the potential options and

Table 5-3: Issues from the Design Assessment

Issue Area	Issue Description	Options for Resolution	Selected Resolution
1. Throughput Analysis			
	A Throughput Analysis was not submitted, nor was justification provided for equipment availability and reliability. GA assumes that ample availability exists for individual processes and the plant as a whole to meet its schedule.	A simplified Throughput Analysis based on critical-path equipment availability was prepared to identify required adjustments to specific equipment capacities, number, operating schedule etc.	See Issues 2, 3, 5, 7a, 15. PMD rates reduced from General Atomics design rates. Schedule modified.
2. Wood Dunnage Shredding			
a. Explosions and fires	The wood dunnage size reduction system that was EDS tested should be enclosed to reduce dust contamination of the room and dust loading on the MDB HVAC system. Enclosing the equipment increases the likelihood and severity of dust explosions.	1. Add spares if appropriate for items that would be damaged . 2. Procure damaged parts as needed and extend the processing schedule. 3. Upgrade HVAC system. 4. Add fire protection and suppression equipment. 5. Increase capacity to allow recovery.	Install fire protection and suppression equipment.
b. EDS vs. full-scale processing rate	The wood dunnage processing rate in the GA design is 1250 lb/hr. This processing rate was needed to finish the mortar dunnage by the time the mortar bodies were processed. Actual EDS processing rates have been 850 to 1050 lb/hr, limited by the micronizer.	1. Increase current design capacity of the micronizer. 2. Extend processing schedule. 3. Run mortars earlier. 4. Increase buffer capacity. See Issue 15.	With the decision to reconfigure the munitions prior to operations was made, the current wood processing rate is sufficient. It is only necessary to add a shelf spare micronizer to ensure no extension of General Atomics schedule is required.
3. SCWO			
a. Agent SCWO liner integrity	The viability of liners and requirements for design and O&M of SCWO agent reactors needs to be re-examined in light of the results of the EDS testing. The current design basis for the liner life is 132 operating hours.	EDS testing recently completed demonstrates liner life of ~132 hours with flushout every 22 hours of operation.	Utilize 22-hour flush cycle. Inspect liner after 66 hours (this applies to agent SCWO only - see Issue 3(f)) and replace as necessary.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
3. SCWO (continued)			
b. Overall availability	Overall availability factors have yet to be developed or demonstrated since testing was not completed prior to EDP submittal.	Linked to all other issues under 3. Estimated availability based on EDS testing, but with two SCWOs.	No action required. Estimated availability is sufficient to meet the GA schedule.
c. Reactor replacement	Certain conditions may lead to shortened life of the SCWO reactor (shell), such as flow into the annulus, for which there appears to be inadequate detection. What provisions are needed, if any, to preclude an extended SCWO reactor loss affecting throughput?	1. Add spare SCWO shell to spare parts. 2. Install another SCWO train 3. Implement enhanced "early warning" monitoring with adequate replacement fabrication lead time	1. Add shell to spare parts. 2. Install more annular temperature detectors. 3. Conduct nondestructive evaluation during liner change-out.
d. TiO2 solids and other fine solids from corrosion	What are the solids fate and effects in the pressure letdown system and BRS (see BRS)? Can this lead to plugging or emissions issues?	Determine if periodic flushing used during EDS Testing is adequate to protect letdown system.	1. Add periodic flushing of letdown valves. 2. Coat letdown valves with titanium nitride to resist corrosion
e. Thermocouple and thermocouple well corrosion	During EDS Testing of HD hydrolysate, thermocouple wells experienced through-wall corrosion, sometimes breaking free and falling to the bottom of reactor, which caused flow restrictions and increased differential pressure.	1. Use low-cost thermocouples and replace frequently before failure. 2. Factor failures into materials of construction. 3. Determine frequency of replacement and add to O&M costs.	Utilize thermocouple wells with thicker titanium and replace during each liner replacement.
f. Energetics SCWO - slurry feed line plugging	Periodic plugs between the slurry feed pump and preheater have been experienced during SCWO EDS workup tests of energetics/dunnage hydrolysate. Energetics/dunnage hydrolysate SCWO testing was not completed prior to the GA submittal. Testing is ongoing.	Await results of completed EDS testing. Results of testing in late February 2001 indicate that changing the piping geometry may have solved the plugging problem. 500-hour EDS test not yet completed.	No action required at this time

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
3. SCWO (continued)			
g. Energetics SCWO - salt plugs	Significant buildup of water insoluble salts inside the reactor has occurred during SCWO EDS workup tests of energetics/dunnage hydrolysate. Energetics/dunnage hydrolysate SCWO testing was not completed prior to the GA submittal. Testing is ongoing.	Results of testing in February and March 2001 indicate that interactions between dunnage components and additives to form metal salts are responsible. Try: 1. Adjustment of additive amounts 2. Adjustment of the solids eutectic by other additives. 3. Another method to remove metal cations, e.g., send carbon to the HDC	No action required at this time
4. Hydrolysis/SCWO Interface			
	During EDS Testing, agent hydrolysate SCWO feed had to be heated to avoid precipitation. Need to verify that the full-scale design incorporates provisions to preclude precipitation of solids and plugging problems.	1. Heating buffer/storage tank 2. Heat tracing of interconnecting piping.	Added cost for: • Heating buffer tank. • Heat tracing of interconnecting piping.
5. Hydrolysate Analysis Requirements			
a. Caustic, sulfur and chloride	Provisions for analysis of caustic (Na+), sulfur and chloride and control of these concentrations for both agent and energetics hydrolysis needs to be carefully reviewed to ensure that the methods are realistic and have been adequately factored into the design and schedule.	1. Extend schedule. 2. Improve sampling/analysis methodology. 3. Add another hydrolysis line. 4. Increase tech support staffing. 5. Add more analytical equipment. 6. Improve caustic feed control.	1. Added cost for: • Caustic feed weigh tanks. • Load cells on reactors. 2. Improve analytical equipment and procedures for sulfur.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
5. Hydrolysate Analysis Requirements (continued)			
b. Addition of agent or energetics additives	Current feed of agent additive is flow controlled and may not be adequate for agent SCWO feed. Provisions for control of additive feed may need to be upgraded or routine analysis implemented. Similar problem may exist for the energetics/dunnage SCWO.	1. Institute sampling/analysis and extend schedule to cope with reduced throughput. 2. Improve sampling/analysis methodology. 3. Increase tech support staffing. 4. Add more analytical equipment. 5. Improve additive feed control.	Added cost for feeding additives to the agent SCWO buffer tank (or hydropulper) by weight using load cells. Added agent additive analysis equipment. No action yet for energetics hydrolysate feed.
c. Energetics analyses	Will analyses of nitrocellulose or nitroglycerine delay scheduling of operations?	Determined not to be a problem.	No action required.
6. PAR HDC Materials of Construction			
	Do materials of construction adequately reflect the potential for a corrosive environment from HCl that may be encountered?	Factor in higher cost for upgraded materials both for initial investment and spares.	Switched conveyor (and other internals) from stainless steel to Hastelloy C276 for costing. Testing is required to confirm proper materials.
7. Brine Reduction System (BRS)			
a. General availability	There is only one BRS train and its reliability and operability have not been tested or adequately justified. This may be a significant "pinch point" affecting the water balance and overall availability. In addition, several flows have been omitted (e.g., boiler blowdown, demineralizer waste) from the water balance.	1. Add a duplicate train. 2. Install two smaller trains. 3. Larger capacity with more storage buffer. 4. Use (viability of) offsite liquid HW disposal. 5. Use offsite nonhazardous waste disposal (if acceptable).	Converted to two complete (100% of current BRS size, 75% of new flow) trains. Adjusted the cost of the BRS and the cost of the PUB to accommodate this equipment.
b. Heat exchanger fouling potential	The potential for fouling of the exchanger surfaces has not been tested or otherwise addressed.	1. Redundant heat exchangers. 2. Extend schedule. 3. More frequent boilouts. 4. Increase capacity.	Added redundant exchangers per 7a.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
7. Brine Reduction System (BRS) (continued)			
c. TiO_2 solids from corrosion and other fines	Fate and effects of TiO_2 in BRS. Could this lead to plugging or emissions? No data exist.	Determine whether significant particulate emissions are a problem and add controls as required.	1. Added redundant unit per 7a. 2. Test for particulate 3. If needed, add demister, reheat and filter.
d. Performance with propellant	Are there any performance issues related to processing the organics vis-à-vis the BRS?	1. Use concentrator alone and dispose of concentrate. 2. Install redundant capacity.	Added redundant unit per 7a.
8. Propellant and Energetic Handling/Processing			
a. Co-processing	Verify that co-processing is consistent with current schedule and plans. Verify that propellant movement and accumulation/storage are per military requirements and in PHA.	This has been determined by PMACWA to be acceptable.	No action required.
b. Energetics mass limit in the ERH	Does the amount of energetics in the ERH at steady state violate any imposed safety limits (self-imposed or military standards)? Note that current levels of energetics assuming no destruction exceed the 11-lb limit in the GA design basis. There is also inconsistent information regarding the capability of the ERH to withstand explosions.	1. Determine that hydrolysis is sufficient to meet any TNT equivalent restrictions. 2. Add more ERHs to meet safety requirements 3. Make the ERH explosion-proof or increase explosion resistance of the ERH room.	Assuming 100% destruction by hydrolysis within one hour, the limit is not exceeded. Added: 1. Engineering controls on caustic flow and water; temperature; and possibly effluent density. 2. Administrative controls on propellant feed. 3. Clarify in design criteria that the room design is the blast barrier, not the ERH that coincidentally would contain the blast. See 8c.
c. Blast overpressure from the ERH	Can a pressure wave from an ERH blast affect plant HVAC equipment?	Note that this is linked to Issue 8(b).	Resolved per 8(b). Probably will not detonate anyway given that the energetics are in a water solution/slurry.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
8. Propellant and Energetic Handling/Processing (continued)			
d. Propellant loads	GA and Parsons have different propellant loads for 4.2-in mortars (GA at 0.43 lb versus Parsons at 0.62 lb).	Determine the correct propellant loads and if the General Atomic figure is incorrect, determine if any schedule adjustment is required.	No action required. The GA numbers are correct.
9. Leakers			
	Insufficient details have been provided as to how leakers are to be handled, stored and processed. How will leakers affect the operation or maintenance provisions for the cryogenic bath?	It will be assumed that all leakers in each campaign will be processed at the end of each campaign after which baths will be cleaned and decontaminated during changeover.	No action required.
10. Lab Provisions			
a. Design adequacy	Need to verify that there are adequate provisions to accommodate required analytical work for air (HVAC and emissions) and process operations and that these provisions are reflected in the capital costs.	1. Increase existing capital costs with a "factored" allowance. 2. Add new capital costs for additional lab space. 3. Add capital cost for new equipment.	Added costs for properly outfitting the MLA and NMR in the MDB: two NMRs, four GCMSs, three ICPs, three AAs, two elemental sulfur analyzers, plus miscellaneous support equipment.
b. Operating costs	Need to verify that there are adequate provisions for handling required analytical work for air (HVAC & emissions), building, and process operations and that these provisions are reflected in the O&M costs.	1. Increase staffing requirements for tech support. 2. Add costs for other operating requirements as required.	1. Added staff (12 people) 2. Added cost for lab service agreements. 3. Added cost for increased training and systemization
11. Instrumentation and Control Design			
	The complexity of the I&C systems relative to plant operability needs to be re-evaluated in light of interfacing requirements between subsystems/plant areas.	Evaluate in concert with 3, 5, 8b, and the Capital Cost Estimate	No design action required at this stage. Needs to be addressed in detailed engineering/design phase. A contingency has been added to the Capital Cost Estimate.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
12. Water Balance			
	The water balance is incompletely presented.	Clarifications and corrections from General Atomics did not resolve all inconsistencies and it appears that makeup water may be required. Check to see if makeup water is properly addressed in O&M costs.	1. Set 50-gpm maximum makeup water to the facility. 2. Increased BRS capacity per Issue 7. 3. For detailed design, provide water inlet and process water specifications
13. Heat and Material Balances			
	On the PFDs for agent neutralization, less material seems to exit than enters, possibly causing errors in equipment sizing from neutralization onward through the BRS.	Check H&MBs as best as possible to verify equipment sizing.	No action required. Clarifying information on intermittent flow available on electronic version of drawing but not hard copy.
14. Agent Validation			
	No validation program has been submitted or specific provisions incorporated in the design.	This issue has been deferred to detailed engineering/design in concert with later treaty considerations.	No action required.
15. Dunnage Processing			
a. Wood discrepancy	There is a 50% difference in the design basis for wood destruction requirements between WHEAT and GATS.	Resolve the discrepancy and make appropriate adjustments in the schedule and/or equipment requirements, as required.	The wood rates utilized by GA are correct. However, the recent decision regarding reconfiguration obviates processing of boxes and 105-mm projectile tubes.
b. Requirement for processing uncontaminated wood	There may be no need to process uncontaminated wood pallets and boxes especially since: 1) the Baseline does not process them; and 2) pallets may be required for transporting 5X munition bodies.	Resolve the need to process uncontaminated wood and make appropriate adjustments in the schedule and/or equipment requirements, as required.	The current assumption is that all pallets will be processed. Due to reconfiguration (see 19), boxes are not processed. No extension of the schedule is required.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
15. Dunnage Processing (continued)			
c. DPE discrepancy	There is a five-fold difference between GA and Parsons regarding the amount of DPE required to be processed -- 0.7 lb/round by GA and 0.15 lb/round by Parsons.	If the decision cannot be resolved based upon design instructions, select an appropriate amount based upon TOCDF operations and evaluate the impacts on the costs and schedules of two technologies.	Based upon the experience at TOCDF, use the Parsons figures and adjust operating costs and schedule accordingly.
16. Auxiliary Fuel Storage			
	The P&IDs refer to a site tank for IPA storage, which is not on the equipment list. The PFDs refer to tanker storage. Tanker storage is not considered acceptable.	Add costs for onsite tank storage.	Added costs for a 7-day storage tank.
17. LPG Storage			
	Only 24 hours of LPG storage is provided. This is not considered acceptable.	Increase the tank size.	Added costs for a 7-day storage tank.
18. Effluents and Emissions			
	The Effluents and Emissions List is still incomplete and lacks proper characterization of streams -- e.g., VOCs from fuel storage; evaporation from cooling towers; SCWO liners thermocouples and wells; BRS vent.	No cost or schedule impacts have been identified except that permit delays could be encountered if incomplete data are submitted.	Alerted PMACWA that supplementary characterization data should be provided as soon as possible. Identified additional major effluents and wastes.

Table 5-3: Issues from the Design Assessment (continued)

Issue Area	Issue Description	Options for Resolution	Selected Resolution
19. Munition Reconfiguration			
	Subsequent to submittal of the final EDS design package, the decision was made that all munitions would be reconfigured by the Depot prior to operations. This impacts numerous design issues and costs, including: • wood dunnage to be treated; • need to treat fiber tubes; • PHA issues relating to the PRR; • cost of the MDB; and • operating labor and material requirements.	The impacts of this decision cascade through the PHA, design, cost and schedule reviews. Impacts and options are discussed relative to each issue.	See Issues 1, 2(a), 3(b) and (f), 8(b), 15, 18 and the Capital Cost Estimate.
20. Cryobath Conveyors			
	If a cryobath conveyor malfunctions, a considerable amount of time will be required for repair, reducing plant availability and throughput. Protocols and costs associated with repair should evaluated.	1. "Do nothing." Wait for nitrogen to boil out before repair 2. Pump out liquid nitrogen, decon the area, especially agent frozen in bath, then repair. 3. Remove munitions and conveyor from the bath for repair with overhead hoist/crane 4. Other options	Leave issue details for detailed design. Add cost allowance per train for additional equipment.
21. Treatment of Non-process Wastes			
	GA and Parsons have made different assumptions regarding treatment of non-process wastes: waste oils and lubricants; hydraulic fluids; misc. metal wastes; misc. trash. GA assumes treatment during campaigns and Parsons assumes disposition during Closure.	1. Leave as is and add costs for waste disposition for WHEAT. 2. Assume WHEAT must process these wastes and add cost and schedule as required. Remove treatment of these wastes from GATS and adjust schedule and costs accordingly.	Retain GA assumptions and add costs for waste disposition to WHEAT.

Source: Arthur D. Little, Inc.

the action items taken on these issues with respect to cost and schedule. The following discussion presents the major design issues in order of importance with respect to their effects on the design, costs and schedule, after the issues were resolved. Major issues that did not require modifications are discussed last. The discussion is referenced back to the numbering system used in Table 5-3 by the number in parentheses at each heading.

It is important to note before the discussion that the operating costs of the GATS facility are high compared to the incremental capital costs of most potential modifications (see Section 8.0 Cost Assessment) to improve reliability and throughput. The typical weekly operating costs, mainly for labor, make the trade-off between increased capital costs versus reduced operating costs easy to determine in favor of capital cost modifications.

5.3.1 Design Issues and Resolutions

5.3.1.1 Throughput Assessment (Issue 1). General Atomics did not submit a Throughput Assessment, nor were any data on equipment availability or reliability submitted to justify the General Atomics assertion that ample availability of individual processes and the plant as a whole will allow it to meet its schedule. General Atomics assumed that the facility would only need to be operated at the PMD design basis rates (45 munitions per hour per PMD for mortars, 50 per hour per machine for projectiles) 38% of the time per calendar year. Consequently, Arthur D. Little prepared a preliminary Throughput Assessment.

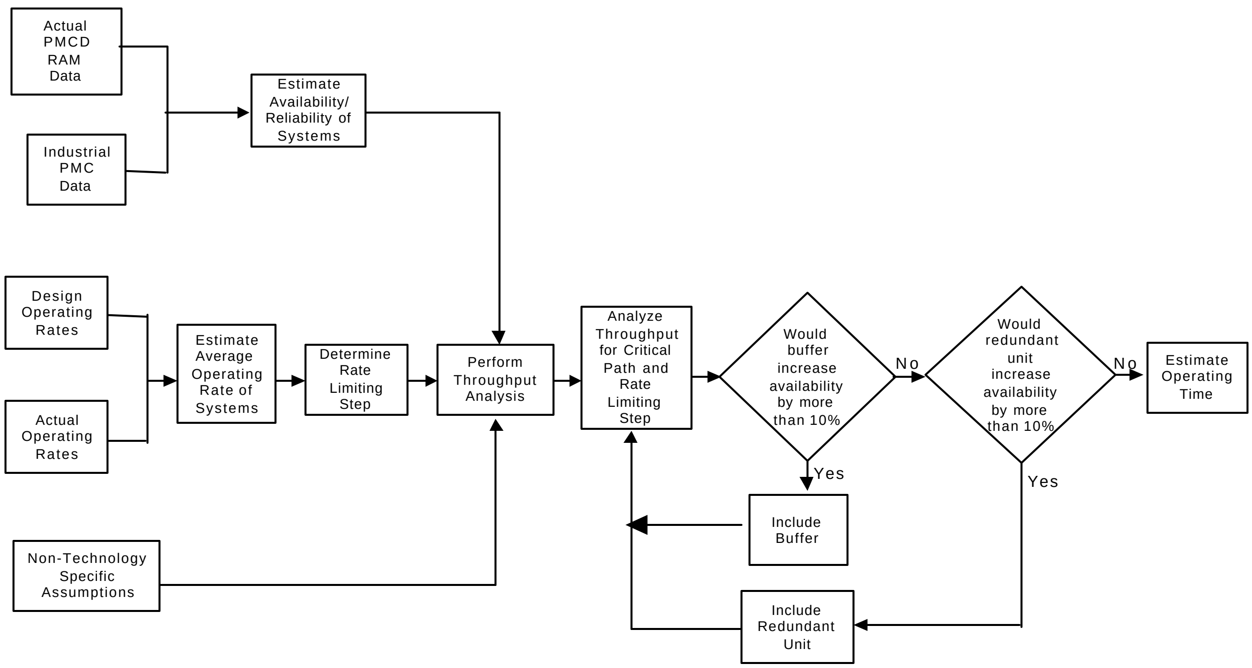
The Throughput Assessment for the General Atomics GATS process, as well as for Parsons/Honeywell Water Hydrolysis of Energetics and Agent Technology (WHEAT) and Baseline, is not intended to be a detailed availability/reliability analysis of the PUCDF based on a Reliability/Availability/ Maintainability (RAM) study. Rather, this assessment is intended to put all three technologies on the same basis to allow a comparison to be conducted. As such, the results of this assessment cannot be taken and compared directly to another technology unless the basis for the new technology is modified to incorporate the assumptions in this assessment. The non-technology specific assumptions for this assessment are presented in Table 5-4. The overall approach for the Throughput Assessment is presented in Figure 5-2.

Table 5-4: General Throughput Assessment Assumptions (External Causes of Downtime)

Description	Assumption
Holiday Shutdowns	• Christmas to New Years Day – 9 days • Thanksgiving Weekend – 5 days
Unplanned and Scheduled maintenance downtime	• 70 days/yr
Externally-Caused Shutdowns	• Power outages, requiring orderly shutdown – 3 times/yr x 16 hrs/occurrence = 2 days/yr • Weather related – 4 days/yr • Munition delivery problems – 6 days/yr • Other – 2 days/yr
Operating Mode	• 7 days/wk
Maximum Annual Availability	• 73.2%

Source: Arthur D. Little, Inc.

Figure 5-2: Throughput Assessment Approach



Source: Arthur D. Little, Inc.

The first step in the Throughput Assessment was to review the General Atomics PUCDF design and determine the major unit operations in GATS. The result of that review is presented in Figure 4-1 and discussed in Section 4.0. After agreement was reached on each of the unit operations, the units were reviewed to determine which were coupled and which unit operations were uncoupled based on a buffer between them. For those units that were separated by a buffer, an analysis was performed to determine whether the normal operation, including start-up, shutdown and upstream shutdowns, would have the buffer filled or empty and how long it would take the upstream unit to fill the buffer or the downstream unit to empty the buffer. This information formed the basis for tailoring the Throughput Model to GATS.

Using either PMCD operating data (see Appendix A), PMACWA demonstration test data, and/or industrial data, average operating rates (the average rate when operating) and availabilities for each of the unit operations was estimated (see Table 5-5). The estimated operating rates and availabilities were then entered into the GATS Throughput Model. The results of the Throughput Model were, in turn, reviewed to determine which system was the limiting step, where the critical path through the facility was, and which systems caused a major reduction in availability. For those systems with low availability, three types of adjustments were considered:

1. Increasing an existing buffer capacity or adding a new buffer capacity to decouple operating equipment/systems from the rest of the facility.
2. Addition of a new piece of equipment or system to increase availability and/or operating rate.
3. Increasing the size/capacity of an existing piece of equipment or system.

Table 5-5: Operating Rates and Availabilities

Unit Operation	Operating Rate Average, mun/hr[1]	Operating Rate Peak, mun/hr[1]	Availability[2]	Comments
PMD	30	50	70.0%	Same operating rate and availability as Baseline - see Appendix A.
ERH	30	45 mortars, 50 projectiles	93.8%	Parallel to PAR+PAH. Mortar peak rate limited by General Atomics' energetics limit in ERH (see 5.3.1.16). Based on expected number of outages and duration per outage.
PAR +PAH	30	50	90.6%	Critical path. Based on the number of outages expected and the time to repair.
Agent SCWO	30	50	94.4%	Based on coverage provided by two units less expected number of outages of other equipment and time to repair.
Energetics SCWO	30	50	94.4%	Based on coverage provided by two units less expected number of outages of other equipment and time to repair.
Agent HDC	30	50	93.4%	Based on expected number of outages and time to repair.
Energetics HDC	30	50	93.4%	Based on expected number of outages and time to repair.
BRS	30	50	100.0%	Two parallel trains, extra capacity and upstream buffer - see 5.3.1.3.
Utilities, Controls and Electricals	NA	NA	97.9%	Based on expected number of outages and time to repair for each area.
Overall Mechanical Availability[3]			54.5%	Product (joint probability that everything can operate) of the above estimates along the critical path.

NA – Not Applicable
1 - Per machine, two machines total, each feeding a parallel train
2 - Estimate rounded to one decimal place
3 - Mechanical Availability was calculated using the Throughput Model

Source: Arthur D. Little, Inc.

Downstream of the PMDs, the GATS facility was designed for the flows resulting from 45 to 50 munitions per hour per PMD, rather than the 30 per hour per machine utilized in the Throughput Model. Generally, the GATS average expected operating rate is the design rate. At the expected average facility rate of 60 munitions per hour, the GATS downstream systems are generally capable of handling flows generated by a peak of 100 projectiles or 90 mortars per hour with the exception of the BRS. The BRS was undersized due to omission of flows to the system, and did not have enough capacity to work off the upstream buffer/feed storage tank at its original design capacity (see Section 5.3.1.3). After adjusting the capacity of the BRS to meet the GATS design rate, the PMDs become the rate limiting step with respect to throughput. The critical path was then determined based upon the lower of the availabilities: either the equipment used to destroy energetics, or that used to destroy agent.

The critical path through the facility is through the PMD, PAR plus PAH, agent SCWO and BRS. The availabilities of the facility systems are shown in Table 5-5. The availability of the agent SCWO units is high because there is an in-line spare; only one agent SCWO unit is on-line at a time, leaving sufficient time for off-line maintenance of the other SCWO unit. Multiplying the availabilities along the critical path, including utility systems upon which the availability of the main plant systems is dependent, gives a mechanical availability of 54.5%. Factoring in the external sources of downtime listed in Table 5-5, the overall annual facility availability is 40.5%. This is slightly above the on-line factor of 38% at design capacity required by GATS to meet the General Atomic schedule. However, the average capacity estimated by Arthur D. Little is lower, because of lower average throughput of the PMDs. The operating schedule for each munition type, using an average throughput of 30 munitions per hour per PMD (60 total) and an availability of 40.5% is shown in Table 5-6.

Once the total availability was calculated, the average campaign throughput was calculated by multiplying the estimated average operating rate, of 60 munitions/hour, by the total availability. The resulting average throughput rate for GATS was 24 munitions/hour. This rate is approximately 25 to 40% higher than the average throughput rates observed at JACADS for the entire 4.2-inch mortar campaign (11.6 mortars/hr) and the entire 105-mm projectiles OVT (14.9 projectiles/hr, assumes maintenance of 15 hours/week during the off-shift). While the GATS average throughput is greater than the complete 4.2-inch mortar campaign or the 105-mm projectile OVT, it is lower than the best sustained rates observed during either campaign: 29 mortars/hr for 28 days during the a 4.2-inch mortar, and 25 projectiles/hr for 26 days during the Full Rate OVT. The throughput rates observed for JACADS are less relevant to the GATS process because of the elimination of the MDM which was the pinch point within JACADS. The replacement of the MDM with cryofracture has the potential to free up the reverse assembly process and therefore achieve higher average throughput rates. The unknown with GATS is the integration of the PMD, cryofracture, and rotary hydrolyzers. Because of this unknown, the average operating rate was kept the same as WHEAT and Baseline. The calculated average throughput rate was used as the basis for the adjusted GATS schedule (see Section 7.0) and the operating schedule for each munition is presented in Table 5-8.

Table 5-6: GATS Throughput Model Results

Munition Type	Number of Munitions	Avg. Campaign Throughput[2]	Operating Time[3]
4.2-inch mortar	97,106	24 munitions/hr	23.8 weeks
155-mm projectile	215,244[1]	24 munitions/hr	47.7 weeks
105-mm projectile	383,418	24 munitions/hr	94 weeks

1. 104,906 155-mm projectiles are assumed to be destroyed during a one year startup and pilot test period
2. Based on 2 PMDs in operation and estimated facility availability
3. Operating time does not include time for changeovers between munition type or for rejected munitions

Source: Arthur D. Little, Inc.

In order to further evaluate the reasonableness of the Throughput Assessment, a quick sensitivity analysis was performed to determine how the operating schedule was impacted based on the range of average throughput rates observed at JACADS. Table 5-7 presents the sensitivity of the operating campaign schedules to a potential high and low average campaign throughput. For GATS the high average throughput rate was based on the observed throughput for the PMD during the Full Rate 105-mm OVT. The analysis shows that as much as 1.6 years could be saved if the GATS process operated at the best sustained rates observed at JACADS for the PMD and as much as 2.1 years could be added if the GATS process operated at the lowest sustained rate observed at JACADS.

Table 5-7: Throughput Assessment Sensitivity Analysis

Munitions	High Throughput Rate		Moderate Throughput Rate		Low Throughput Rate	
	Rate (mun/hr)	Operating Schedule (weeks)	Rate (mun/hr)	Operating Schedule (weeks)	Rate (mun/hr)	Operating Schedule (weeks)
105-mm projectiles	50	45.7	24	94	15	152
155-mm projectiles	50	23.6	24	47.7	15	86
4.2-inch mortars	50	11.6	24	23.8	15	38
Total Operations	---	80.9	---	165.5	---	276

No attempt was made to reduce capital costs by reducing the scale and throughput of any of the facility equipment down to the average throughput rate based on the PMDs. The PMD average throughput rate is based on averaging higher and lower rates of processing munitions. If higher-than-current-average throughput capacity were removed, the average throughput would be reduced by the loss of ability to “catch up” and improve the average when a PMD is operating at a higher-than-average rate.

Finally, in its design documentation, General Atomics should eliminate references to operating “theoretically” 12 hours per day with 12 hours available downtime, since random or unanticipated downtime cannot be scheduled on a daily basis. Tables in Section 2.4 of the GATS Design Basis (Document 123002) that confuse capacity with availability and throughput should be revised or eliminated, regardless of the average operating rate used for the PMDs.

5.3.1.2 Water Balance (Issue 12). The water balance presented in the GATS Engineering Package did not balance. General Atomics was notified, and a new water balance was issued, dated 7 February 2001. The current water balance does balance within about 1 percent around internal nodes and overall. This is sufficient for design purposes, but may lead to erroneous conclusions as to its accuracy for users accustomed to balancing "to the pound."

Of greater concern is the omission of sanitary, cooling tower, and demineralizer water usage from the GATS process balance. While the equipment to process all plant water requirements seem to be included in the design (except for cooling tower losses), the blowdown and drift from the cooling tower and demineralization/water treatment blowdown seem to have been left off of the facility water requirements. For the Design Assessment, the assumption has been made that the cooling tower and demineralizer blowdowns go to the BRS (see Section 5.3.1.3). While the process water balance shows that water is generated by the process and evaporated in the BRS, the facility actually requires considerable water for cooling water make-up and net demineralization product. The plant make-up water requirement was set at 50 gpm maximum for this assessment, depending on munition campaign.

Finally, there is no water specification provided in the design basis for either incoming water to the facility or process water requirements. The lack of specifications makes estimating accurate capital and operating costs for water treatment and cooling difficult.

5.3.1.3 Brine Recovery System (BRS) (Issue 7). In the current GATS design, there is only one BRS train rated at 100% of the flow of the combined agent and energetics/dunnage SCWO liquid effluent and boiler blowdown. In order to meet campaign schedules, when normally operating, one energetics/dunnage SCWO and one agent SCWO are on line 132 hours per 168 hour week. Upstream buffer tanks are used to provide a steady supply of feeds to the SCWO systems. The BRS is designed to operate 168 hours per week with two 16-hour periods for boilout to prevent fouling, or 136 hours per week at 100% capacity. When the BRS is in boilout, flow to the BRS is stored in a buffer tank (BRS-TANK-101) that has a 24-hour, normal-flowrate capacity.

One major problem is that once the buffer tank is full (or say 2/3 full after one boilout), it becomes difficult for the BRS system to catch up and empty the tank; only four hours per week (GATS basis) are available, assuming 100% availability of the BRS. If the BRS availability is less than 132 hours per week (97%), plant throughput will eventually be reduced, regardless of the size of the buffer tank, unless the capacity of the BRS is increased.

The second major problem is that some plant flows to the BRS have not been included in the design. These are the evaporative cooling blowdown and rejected water/blowdown from the process water demineralization system. It is unlikely that these flows can be discharged to the sewer because of the concentration of salts from the incoming water. Assuming blowdown rates of 25% for evaporative cooling and 25% for demineralization, at maximum design loads, this adds approximately 42% to the design flow to the BRS.

As part of the design adjustment, a second BRS train of equal capacity has been added to handle the extra load and assure availability. With two BRS trains, the boilouts would be staggered so that one BRS is always on line, processing some of the flow to the BRS Storage Tank depending on the capacity of the train. Regardless of the size of BRS Storage Tank, the flow of liquid to the

BRS system must be processed by the BRS on a regular basis (assumed weekly). When both trains are on line, liquid that has accumulated in the tank can be processed at twice the rate of a single train. By assuming an availability in terms of the number of hours per week that neither BRS train is operating (2 hours out of 168 hours), the number of hours per week that each train is in boilout (32 hours), and the number of hours the balance of plant is normally operating (GATS basis – 132 hours), the minimum size of each train in terms of the size of the original single train can be calculated algebraically without reference to actual sizes or flows. The minimum size of a single train is 63% of the current design. However, the capacity needs to be increased by approximately 42% to accommodate additional blowdown, resulting in a minimum size of about 90% of the current capacity. Increasing this to 100% for each train allows for lower needed availability of each train (from about 98.5% down to about 88%), not including standard boilouts.

As a result of adding a second BRS train, additional headroom will be needed in the PUB. An expansion of the "penthouse," which provides headroom for the original BRS, was included in the life cycle cost estimate.

There is a possibility that the titanium dioxide (TiO_2) fines from corrosion of the SCWO liner may end up in the BRS vent gas. Actual determination will require testing. The life cycle cost estimate includes a contingency for equipment to remove particulate fines from the BRS vent in the event testing confirms the carryover of TiO_2 to the BRS.

5.3.1.4 SCWO (Issue 3). The EDS I 500-hour HD hydrolysate SCWO test was finished after the General Atomics January 2001 Engineering Package was submitted; therefore, the design changes resulting from that test were not incorporated. In addition, some design changes to the energetics/dunnage SCWO reactors may be required based on early findings in workup runs performed to prepare for the EDS I 500-hour energetics/dunnage test.

The 500-hour HD hydrolysate SCWO test demonstrated that a liner life of 132 hours seems feasible with flushing every 22 hours of operation. To be conservative, the Design Assessment has assumed that the liner will be inspected every 66 hours of operation and replaced as needed. For life cycle costs, the assumption is that the liner for each agent hydrolysate SCWO reactor will be replaced every 132 hours of operation.

The 500-hour HD hydrolysate SCWO test demonstrated an availability of about 80% for a single SCWO reactor. Given the cycle times, flush time, and estimated time to inspect and/or replace a liner, the availability of two SCWO reactors working together was estimated to be 97%. With the availability of the other components in the SCWO reactor area factored in, the resulting availability of the agent SCWO system was 94.4%. This availability was used for both the agent and energetics SCWO systems.

The 500-hour HD hydrolysate test also indicated that certain conditions may lead to shortened life of the SCWO reactor (shell), such as flow into the annulus for which there may be inadequate detection. Because of the long lead time to obtain a new shell, and the loss of throughput while operating with a single SCWO, a shelf spare shell was included in the capital cost estimate. Also recommended are more annular temperature detectors and non-destructive testing during liner replacement to better monitor shell integrity.

The 500-hour HD hydrolysate test also indicated that corrosion of the titanium liner occurs, creating TiO_2 solids in the effluent. These solids are small enough to avoid settling in the SCWO gas/liquid separator and hydrocyclone, and pass along with the effluent through the pressure control (letdown) valves. The TiO_2 solids buildup over time and will eventually inhibit proper functioning of the valves. EDS I testing used periodic direct flushing of the pressure control valves with water plus titanium nitride coating of the valves to resist possible erosion, to control this potential problem. These modifications should be added to the GATS design.

Use of bare platinum-sheathed thermocouples during HD hydrolysate workup runs resulted in unacceptable corrosion rates of the thermocouples, i.e., less than the time between liner inspections when the thermocouples could be replaced. Titanium thermowells (3/8 inch OD) used during the 500-hour EDS I test also suffered considerable corrosion, but protected the thermocouples long enough to last until the next inspection, with no interruption of reactor temperature data. However, corroded thermowells occasionally broke free and fell to the bottom of the SCWO reactor, causing flow restriction and increased reactor pressure drop, giving a false indication of salt buildup. Thermowells were replaced at every 66-hour inspection (thermocouples were replaced as necessary). As breakthrough of the thermowells occurred in less than 66 hours, platinum thermocouples were still needed to minimize thermocouple corrosion during the time they were exposed to process fluid. Arthur D. Little suggests that thicker thermowell tubes (e.g. ½" OD) be specified to withstand corrosion breakthrough between inspections, and that the thermowells be replaced during every liner inspection (66 hours). Better thermowell integrity should allow the use of lower-cost, inconel-sheathed thermocouples. One year's worth of spare thermocouple wells has been added to the spare parts inventory for the capital cost estimate.

General Atomics has begun work-up runs and part of the 500-hour test for the tetrytol hydrolysate/dunnage slurry feed, and as of 16 March 2001, was ready to start the 500-hour test with this feed. Test experience to date has identified problems with slurry transport to the reactor consisting of:

- Plugging of slurry feed piping prior to the preheater;
- Plugging within the preheater or section just before the reactor nozzle; and
- Difficulties with feed pumps (syringe pump and low pressure booster pump).

Although definitive causes to each of these issues have not been determined at the present time, General Atomics has considered probable causes and adjustments have been made to the test facility. As a result of these adjustments, some performance improvement has occurred. However, reliable performance will require additional improvement to meet stated goals. Adjustments made and which continue to be made to reach stated goals fall into the following categories:

- Slurry recipe – the slurry recipe has been adjusted, through changes in identity and/or concentration of additives and dunnage feed components. These changes have been made to maintain dunnage particulate suspended in the slurry, to obtain a flowable slurry, and to ensure eutectic salt production (see below), after oxidation occurs within the reactor.

- Plumbing and piping – The test system design and associated equipment have resulted in non-optimal configurations and equipment failures. This has occurred due to lack of space, lack of a well-designed test unit, and selection of test components that do not meet their intended need. To date slurry feed pipe segments have been adjusted to the extent possible to obtain a uniform pipe ID from the slurry skid to the reactor nozzle, to remove unnecessary pipe bends, and to improve system design allowing equipment to function properly.

It is not clear whether these changes made to date are sufficient to eliminate slurry feed plugging, as General Atomics has not yet demonstrated (as of 16 March 2001) trouble-free operation for significant periods of operation. Design options that may need to be considered are periodically backflushing the slurry feed line, and screening dunnage particles to remove oversize particles before addition to the hydropulper or achieving a finer grind during shredding. The Design Assessment has made no adjustments to the GATS design based on energetics/dunnage SCWO testing at this time.

Test experience to date (16 March 2001) has resulted in salt deposition at the bottom of the SCWO reactor and within exit piping. These salts are hard and insoluble in ambient temperature water, so periodic flushing is ineffective at removal. The salt buildup eventually forms a plug that forces shutdown of the reactor. Significant, unplanned time is required to chip out salt deposits and perform other associated repairs. This salt behavior is different from the normal salts expected to form from this feed (e.g., sodium chloride), which dissolve in subcritical temperature water. Difficulties have also been experienced with reactor temperature fluctuations caused by salt buildup at the top of the reactor.

Analysis of the hard salt deposits has indicated the presence of certain metal cations that are known to form insoluble salts when combining with one type of salt transport additive used. The source of these metals seems to be the activated carbon. With the presence of these unexpected metal cations, the original salt transport additive may do more harm than good. In this case, another additive may be needed to avoid buildup of sodium chloride (formed during reaction) in the reactor. GA has not resolved this issue at the present time. One option is to not process the carbon through SCWO, but instead, run the carbon (still in its holders) through the PAR-HDC for 5X treatment. Further evaluation of this option, as well as of the following related issues (not necessarily comprehensive), is needed:

- Steam-carbon reactions in the HDC from moisture brought in from the PRH.
- The volume of material and time-to-temperature for the carbon. Is the operation of the HDC with carbon compatible with its primary mission of treating metal?
- Cooldown of the heated carbon to prevent ignition after exiting the HDC.

5.3.1.5 Hydrolysis/SCWO Interface (Issue 4). When the salt transport additive used with HD hydrolysate is added to the SCWO feed tank, it reacts with caustic to form a slightly different compound that has a much lower solubility under ambient conditions. If this compound is allowed to precipitate out and settle to the bottom of the feed tank, the feed to the SCWO will not have the necessary amount of additive in solution to control salt transport in the reactor, resulting in eventual salt plug formation. The feed tank and piping between the tank and SCWO reactor had to be heated during EDS I testing up to 110 °F in order to prevent the additive from settling out. An inline heater was also used to further augment heating of the feed. These modifications were made after the General Atomics' January 2001 Engineering Package submittal. During the Design Assessment, the ability to heat the agent hydrolysate buffer tank and heat tracing to the piping connecting the tank to the SCWO reactor were added. These modifications have been accounted for in the capital cost estimate. A similar solution may be needed for the energetics/dunnage slurry from the hydropulper to the SCWO reactor, depending on the outcome of the current 500-hour testing.

5.3.1.6 Hydrolysis Analysis (Issue 5). After the HD agent has been hydrolyzed in the agent hydrolysis reactor tanks, the concentrations of chloride (in the form of hydrogen chloride [HCl]) and sulfur (contained in the thiodiglycol hydrolysis product) are measured. The results are used to determine the amount of caustic needed for neutralization of the HCl and preneutralization (98% stoichiometric) of the sulfur. It was found during EDS I testing that SCWO operability is sensitive to the amount of caustic added. Too much caustic results in formation of hard sodium carbonate salts at the top of the reactor. Too little caustic results in effluent that is too acidic and does not interact properly with the salt transport additive necessary for good salt transport. Having an accurate measure of the amount of chloride and sulfur in the hydrolysis vessel is critical in determining the right amount of caustic to add for proper SCWO operation. The analysis for chloride and sulfur should be performed at the same time the vessel contents are being analyzed and cleared for agent. The amount of caustic added needs to be verified; knowing the exact amount of sodium is critical to adding the correct amount of salt transport additive in the SCWO feed tank.

The caustic header feed to the agent hydrolysis reactors should be replaced with weigh feed tanks. Load cells should be placed on the agent neutralization reactors. The analytical equipment and procedures for measuring sulfur should be improved. Capital costs for these modifications have been added.

An additive is necessary for good salt transport through the SCWO reactor when processing HD hydrolysate. Sodium salts of sulfate and chloride formed during reaction interact with the additive to form a eutectic under SCWO operating conditions. This results in a molten salt that flows down the reactor, avoiding continual buildup and plugging. EDS I testing showed that knowing the correct amount of additive to use is critical. Too little additive results in poor salt transport, while too much additive causes excessive corrosion of the titanium liner. The correct amount of additive is dependent on the amount of sodium present in the hydrolysate. During EDS I testing, the optimal concentration of additive was determined to be 20% of the total salt concentration in the reactor.

Additive feed control should be improved by measuring weight differences. Load cells should be added to the Hydrolysate Storage Tank and the Additive Feed Tank. Analytical equipment needs to be added to the laboratory to perform the appropriate analysis for the additive. These modifications have been accounted for in the capital cost estimate.

5.3.1.7 Laboratory Provisions (Issue 10). The GATS design and cost estimate includes retaining the freestanding Baseline Laboratory facility as well as space for a wet laboratory in the MDB. The Baseline laboratory is dedicated to air sample analyses and, while the GATS technology does not involve incineration, a considerable amount of air sampling and analysis is still required to support both ambient and building air monitoring as well as the stacks (e.g., MDB filter farm, BRS vent). The MDB laboratory is to provide the additional analytical capability required for liquid samples to support operations. The final round of EDS I testing has determined that turnaround times on the order of one-hour are required for chloride, sulfur, sodium, additive, agent, and energetics analyses. The costs for outfitting the MDB laboratory with the required equipment were not included in the GATS cost estimate. General Atomics assumed that the equipment cost would be a “trade off” against the equipment in the freestanding laboratory that would not be needed. However, the Baseline Laboratory was determined to be required for air samples and no costs could be diverted for outfitting the MDB laboratory. A capital cost allowance was developed based upon estimates for the Aberdeen Chemical Agent Disposal Facility (ABCDF) laboratory and independent checks of the costs for the anticipated major equipment items, including: Gas Chromatography/Mass Spectrometers (GC/MS), Inductively Coupled Plasma, and Atomic Absorption Analyzer, elemental sulfur analyzers, and analyzers for the salt transport additive. An annual service contract for the equipment was added (in the conduct of the Cost Assessment) to the operating costs, and additional personnel were added to operate the equipment.

5.3.1.8 Dunnage Wood Shredding (Issue 2). The wood dunnage size reduction system should be enclosed to reduce dust contamination of the room and dust loading on the MDB HVAC system. Enclosing the equipment increases the likelihood and severity of dust explosions. A Fenwall-type explosion suppression system has been added to all prone subunits, and the cost for explosion suppression has been added to the capital cost estimate.

With boxed munitions to process, the GATS design wood dunnage processing rate was 1250 lb/hr. This processing rate was needed to finish the mortar dunnage by the time the mortar bodies were processed. Actual EDS I processing rates have been 850 to 1050 lb/hr, depending on the variables tested (e.g., type of wood, wood moisture content). The micronizer has limited processing rates, and increased micronizer capacity seemed necessary. However, munition boxes were eliminated from the dunnage, when PMACWA assumed (after the General Atomics January 2001 Engineering Package submittal) that all boxed munitions will have been reconfigured before munition destruction begins. With the elimination of munition boxes, the maximum wood shredding capacity required (as per PFD 121300) is 855 lb/hr (at 11% moisture content, wet basis) for the 155mm projectile campaign, which is within the EDS I tested capacity. However, a spare micronizer should be added to avoid schedule slippage, if the micronizer is damaged. The cost of the spare micronizer is considerably less than the operating cost incurred for an outage of only a week due to the micronizer. An inventory micronizer was added to the capital cost estimate.

5.3.1.9 Dunnage Processing (Issue 15). There is a 50% difference in the submitted design basis amount of wood to be processed/destroyed between Parsons WHEAT and GATS. The GATS basis was much higher. At the time of submittal, the amount of wood to be processed that was submitted by General Atomics was, with a minor error, correct. This amount included all of the pallets and all of the boxes (and fiber tubes) from unreconfigured munitions. Subsequent to the General Atomics January 2001 Engineering Package submission, PMACWA determined that all Pueblo munitions would be reconfigured prior to the start of munitions destruction and that the Depot would dispose of all dunnage resulting from reconfiguration. PMACWA reconfirmed that all wood pallets would have to be processed and 5X treated. The new quantities of wood per round (for the General Atomics Design Basis) are listed on the line “pallet wood per round” in Table 4-2.

Consequently, some wood processing issues that required design and cost changes became moot, and some availability issues, e.g., agent SCWO availability with only a single reactor while processing mortars, became moot or improved. For example, wood processing is no longer a limiting design factor in the 4.2-inch mortar campaign; a third SCWO is no longer needed to process dunnage during the 4.2-inch mortar campaign to finish processing wood and agent at the same time. The use of two SCWO reactors for agent hydrolysate and two SCWO reactors for energetics hydrolysate plus dunnage can be maintained for all three campaigns. The SCWO interconnecting piping and any controls can be eliminated, if desired.

There is a five-fold difference between the Parsons/Honeywell and General Atomics in the amount of Demilitarization Protection Ensemble (DPE) to be processed. GA assumed 0.7 lb per munition; Parsons/Honeywell assumed 0.15 lb per munition. Based on the experience at Tooele Chemical Agent Disposal Facility (TOCDF), the Parsons/Honeywell number of 0.15 lb of DPE per munition is more correct. However, there are no design changes required. DPE processing equipment is already very small. The amount of DPE added to the hydropulpers is small compared to the amount of material being processed. There is no need to try to reduce the size of any of the equipment to match the reduced amount of DPE being processed. The manner in which DPE is metered into the hydropulper can be left to the detailed engineering design.

5.3.1.10 Cryobath (Issue 20). If a cryobath conveyor malfunctions, a considerable amount of time will be required to access the conveyor and fix it since it is in a Category A area and will require removal of the liquid nitrogen. This could reduce plant overall availability, as where a change in the design of the cryocooler could reduce overall costs by limiting the loss of throughput due to a conveyor being down. Possible design changes to the cryobath to speed up repair access are:

1. Pump out liquid nitrogen. Decontaminate the area, especially liquid agent frozen at the bottom of the bath;
2. Remove munitions and the entire conveyor from the bath for repair; or
3. Other options (not identified).

The selection of the appropriate design modification will be left to the detailed engineering design. However, a cost allowance for the additional equipment ($250,000 per train x 2 trains to WBS 01.04.46) has been added.

5.3.1.11 PAR Heated Discharge Conveyor (Issue 6). The currently specified material of construction is 316 stainless steel. HCl will be present at the PRH end of the conveyor. As a precaution, the HDC conveyors and other internals have been switched from stainless steel to

Hastalloy C276 for costing the HDC. Testing is required to confirm actual proper materials for construction.

5.3.1.12 Auxiliary Fuel Storage (Issue 16). The P&IDs refer to a site tank for isopropyl alcohol (IPA) storage, but the tank is not on the equipment list. The PFDs refer to tank truck storage for IPA. Tank truck storage is not considered acceptable, given the amounts required. A storage tank is more appropriate. A seven-day (at design flow) storage tank for IPA has been added to the design and cost estimate.

5.3.1.13 LPG Storage (Issue 17). Only 24 hours of LPG storage is provided as a backup fuel for the boilers in the event that natural gas is curtailed. The amount of storage capacity is not considered acceptable. The tank size has been increased to seven days of normal operation with natural gas. The incremental cost of the tank has been added to the capital cost estimate. Flow through evaporation and air mixing is unchanged.

5.3.1.14 Instrumentation and Control (Issue 11). I&C systems have yet to be thoroughly worked out, which is to be expected at this stage of a design. There are areas where control schemes appear overly complicated with several levels of cascaded controls. In other areas there appear to be additional controls required. The most important areas for further development will undoubtedly be between equipment interfacing the different subsystems. Nevertheless, it is difficult to assess the adequacy and appropriateness of control systems lacking a detailed discussion and a thorough review of P&IDs that are not yet complete. An overall cost contingency of 20% has been assigned to WBS 01.04.21 to include requirements for the control room itself, communications systems and process I&C systems.

5.3.1.15 Effluents and Emissions (Issue 18). The GATS Effluents and Emissions list (Document 123003) is incomplete and lacks proper characterization of the streams, e.g., volatile organic compounds (VOCs) from fuel storage, evaporation from cooling towers, disposal of SCWO liners, etc. Table 5-8 contains emissions sources that should be added to the GATS list. General Atomics should review the facility emissions for all point sources, composition of sources and annual and maximum projected flows.

5.3.1.16 Propellant and Energetics Co-Processing (Issue 8). The basis for the trinitrotoluene (TNT)-equivalent inventory restriction placed on the ERH of 11 lb when co-processing bursters and propellant was not clear from the documentation. Some of the assumptions regarding TNT equivalency were not included. It was also not clear from the documents that the blast barrier is the ERH room wall and not the ERH. These items are clarified below.

The General Atomics design rates for munitions are 50 rounds per hour per PMD for projectiles and 45 rounds per hour per PMD for mortars. Each PMD feeds a single Energetic Rotary Hydrolyzer (ERH). The General Atomics limit is a 25% safety margin below the facility design basis of 14 lb of TNT equivalent. In testing, GA has found that 100% of the energetics are hydrolyzed in one hour. For the ERH design, *GA has assumed zero-order kinetics* and the

Table 5-8: Omitted Effluents, Emissions, and Wastes

Source	Stream Number	Add
Solid Emissions		
PAR HDC	710	Aluminum, etc conveyed into HDC (stream 721)
BRS	1053	~ 20% more salts from blowdowns, etc.
SCWO	none	Solids discharged from solids/liquid separator
SCWO	none	Used liners, thermocouples and wells
Gas Emissions		
BRS	1056	Vent gas (water plus VOCs not trapped by carbon filter)
Cooling Tower	none	Evaporation and drift, trace metals in water supply
IPA Tank	none	Vent VOCs if not recovered
IPA Tank	none	Loading VOCs if not recovered
LPG Tank	none	Vent VOCs if not recovered
LPG Tank	none	Loading VOCs if not recovered
Boilers	none	Stack NOX, CO, VOCs
Boilers Deaerator	none	Water + boiler condensate absorbed gases
Liquid Emissions		
BRS	none	Boilout liquids
Storm Water and Site Drainage	none	From Baseline
Sanitary sewage	none	From Baseline

Source: Arthur D. Little, Inc.

energetics inventory is equivalent to 50% of the first hour's feed rate. Based on conversations with PMACWA, a TNT equivalent for tetrytol of 1.11 lb TNT per lb tetrytol was used, and that the TNT equivalent of propellant is 0.72 lb TNT per lb propellant (60% Nitroglycerine [NG] x 1.2 TNT equivalent per unit NG).

For 155-mm projectiles with no propellant at 50 rounds per hour, the TNT equivalent in the ERH is 11.38 lb = 50 rounds/hr x .5 x 0.41 lb tetrytol/round x 1.11. This is slightly over the General Atomics' limit, evidently due to the use of a higher TNT equivalent for tetrytol, but still with a safety margin of 23%.

For the 105-mm projectiles, the boxed munitions will now be reconfigured, and the propellant can be "metered" in evenly over the campaign. About 7.4% of the munitions came with propellant. At 50 rounds per hour the TNT equivalent in the ERH is 10.88 lb = 50 rounds/hr x .5 x (0.26 lb tetrytol/round x 1.11 + 0.074 x 2.75 lb propellant/round x 0.72).

For the 4.2-inch mortars, all mortars have propellant. At 45 rounds per hour (General Atomics' basis), the TNT equivalent in the ERH is 10.46 lb = 45 rounds per hour x 0.5 x (0.14 lb tetrytol/round x 1.11 + 0.43 lb propellant/round x 0.72).

The Design Assessment indicated that the PMD peak rate for mortars can be raised from 45 rounds per hour to perhaps 50 rounds per hour (average rate is 30 rounds per hour). Based on the above analysis, this is not feasible with the 11 lb TNT equivalent limit. However:

- The "50% of the first hour's feed" energetics inventory is very conservative. The actual kinetics are second order, not zero order.
- The mortars have been previously reconfigured. The propellant is in storage and can be run at any time, e.g., when a PMD is down, in order to not exceed the limit. In any case, an administration control to limit propellant rate should be implemented.
- It is unlikely that the solution/slurry can detonate given the small quantity of energetics and the relatively large quantity of caustic.

To ensure that process upsets do not result in exceeding the design inventory limit, other safeguarding systems are needed, including:

1. Low ERH bath and water feed temperature interlock to shutdown system.
2. Caustic make-up and water low flow and/or flow ratio interlock to shutdown system.
3. Continuous caustic strength indication and alarm (possibly based on solution density).

No cost items need to be added at this time; the additional costs are in the general contingency for I&C.

Documents 123501 and 123002 (Section 2.2.3 of the General Atomics January 2001 Engineering Package submittal) do not make it clear where the TNT equivalent restriction comes from and what the TNT equivalents loadings are. It appears that General Atomics is using the room housing the ERH as the blast barrier, and not the ERH itself. If this is true, it is unclear if General Atomics is implying that the ERH itself could not contain such a blast.

Finally, an explosion from energetics in an ERH would propagate upstream to the scrubber system for the ERH and possibly to the plant HVAC system. An explosion damper could be placed between the ERH and the ERH scrubber, and the blower could be strengthened to allow for the additional pressure drop. However, the likelihood of an explosion of the hydrolyzed/slurry material in the ERH is remote. Full evaluation of this issue is required in the detailed engineering design. No design or cost modifications are currently required.

5.3.1.17 Leakers (Issue 9). Insufficient detail has been provided as to how munitions that are leaking agent are to be handled, stored and processed. What is the likelihood of leakers occurring during PMD operations and how will leakers affect the operation or maintenance of the cryogenic baths?

During the Design Assessment the assumption was made that all leaking munitions in each campaign will be processed at the end of each campaign, after which the cryogenic baths, etc. will be cleaned and decontaminated during changeover. A procedure for any leakers occurring between the PMD and cryopress will be left to detailed design. Prior to processing, leaking munitions will remain in the storage igloo, or be overpacked and sent back to an igloo for storage. Note that General Atomics proposed that leakers discovered during reconfiguration (no longer required) were to be processed immediately and not overpacked and stored.

5.3.1.18 Agent Validation (Issue 14). No validation program has been submitted or specific provisions incorporated into the design. If, for example, General Atomics intends to measure agent destruction by weight difference of munition body in minus weight of metal out of the heated discharge conveyor (HDC), no provision has been made for weighing munition bodies, other metal feed to the HDC and metal discharged from the HDC. This issue has been deferred to the detailed engineering design that must reflect current and future Chemical Weapon Convention (CWC) Treaty considerations.

5.3.1.19 Munition Reconfiguration (Issue 19). Subsequent to the submittal of the January 2001 Engineering Package by General Atomics, the decision was made by PMACWA to assume that the depot would reconfigure all munitions prior to pilot testing. This affects numerous design issues for GATS, including:

1. The amount of wood dunnage to be treated,
2. The need to treat fiber tubes,
3. PHA issues relating to the PRR,
4. Cost of the MDB, and
5. Operating labor and material requirements.

The impacts of this decision cascade through the Design, PHA, Cost, and Schedule Assessments. The impacts are discussed relative to (and at) each issue.

5.3.1.20 Treatment of Non-Process Wastes (Issue 21). Parsons/Honeywell and General Atomics make different assumptions regarding treatment of non-process wastes including waste oils and lubricants, hydraulic fluids, miscellaneous metal wastes, and miscellaneous refuse. General Atomics assumes treatment in the Supercritical Water Oxidation (SCWO) reactor and Parsons/Honeywell assumes disposition during Closure. No change in approach is needed, but costs for disposal of these wastes was added to the WHEAT cost estimate.

5.3.2 GATS Technology Risk Assessment

The objective of the Technical Risk Assessment was to determine what subsystems within the GATS design had the potential to significantly affect the proposed cost or schedule. These subsystems could then in the future be the focus of additional design effort or be replaced by another approach. The Technical Risk Assessment was performed in two steps. The first step was to determine an “inherent performance risk” based on the maturity level and complexity for each major subsystem. The second step was then to consider how each subsystem fit within the General Atomics GATS design, including the Design Assessment adjustments, and to determine an “evaluated overall performance risk” for each subsystem within the GATS process.

The inherent performance risk is the technical risk associated with each subsystem independent of how that subsystem was used within the GATS design. The only design specific information included in this assessment was the agent category where the equipment would be installed.

Then, to assign an inherent performance risk, a group of Arthur D. Little engineers was convened to discuss the maturity and complexity level of each major GATS subsystems. The group considered whether the subsystem had been used in a similar application within the Chemical Stockpile Disposal Project or industry and, if so, at what scale. The group then considered whether the subsystems that had been operated on full-scale had been modified and the scale of testing for those subsystems that had not been operated at full-scale. Finally, the group considered the complexity of each of the subsystems and where the subsystems would be located within the facility. (The presence of agent can greatly increase the complexity of maintaining even simple systems and make complex systems impractical.) Table 5-9 presents the assigned inherent performance risks for each major subsystem.

Once the inherent performance risks were assigned, the application of that subsystem within the GATS design was considered in order to assign an evaluated overall performance risk. See Table 5-10. The major inputs to this analysis were the issues and resolutions of the Design Assessment. After the analysis, four of the subsystems continue to present a level of risk greater than low. These are the Agent SCWO, the Energetics SCWO, the ERH and the PRH. A contingency was added to the Cost Assessment for each of these subsystems with the assumption that an additional investment in design, capacity or configuration will prevent an impact on schedule. The analysis of these four subsystems is discussed below.

Projectile Rotary Hydrolyzer (PRH). The PRH design is based on commercial rotary dryer and kiln designs. It is similar in concept to the ERH, which was tested in a shortened version (overall length) during Demonstration I and EDS I. A full-length design of either the PRH or ERH, however, has not been tested. Consequently, travel time of the projectile fragments has not been experimentally verified. Mechanical reliability of the unit should be high, and it can be easily put in a heated standby mode. Access to the internals was not discussed in the submittal. The current mode of emptying the vessel is to use a portable pump. Additional thought needs to be put into servicing the PRH, if a problem occurs, to avoid extensive and unnecessary duration of outages due to the agent area classification or lack of access.

Control of the PRH with respect to proper agent concentration is another source of risk, because it has not been tried on a full-scale unit. Variation in the PMD rate will cause transients in the PRH concentration and feed to Agent Hydrolysis. While Agent Hydrolysis is designed for final agent destruction, loss of throughput could occur if the transients cannot be controlled.
The risk associated with the PRH also derives from integrating the PRH with upstream and downstream processing, especially the heated discharge conveyor. These operations have not been coupled and tested.

Energetics Rotary Hydrolyzer (ERH). The ERH design is based on commercial rotary dryer and kiln designs. While a shortened version (overall length) has been tested during Demonstration I and EDS I, a full-length design has not been tested. Consequently, travel time of the metal pieces has not been experimentally verified. Mechanical reliability of the unit should be high, and it can be easily put in a heated standby mode. Access to the internals was not discussed in the submittal. The current mode of emptying the vessel is to use a portable pump. Additional thought needs to be put into servicing the ERH, if a problem occurs, to avoid extensive and unnecessary duration of outages due to lack of access.

Table 5-9: GATS Inherent Performance Risk

Equipment or Subsystem	Agent Category Designation	Equipment/Subsystem Development Maturity Level									Inherent Performance Risk[1]
		High			Medium			Low		Very Low	
		Full Scale Chem Demil Operations	Full Scale Chem Demil Operations Modified (Tested)	Commercial Directly Applicable (Tested)	Full Scale Chem Demil Operations Modified (Untested)	Commercial Directly Applicable (Untested)	Commercial Modified (Tested)	Commercial Modified (Untested)	Customized (Tested)	Customized (Untested)	
MSB	**A/B**	●									**Low**
UPA	**C**	●									**Low**
PRR	**C**				●						**Low**
PMD	**A**	●									**Low**
Cryocooling	**A**		●								**Low**
Cryofracture	**A**		●								**Low**
PRH	**A**							●			**Moderate**
Agent Hydrolysis	**A**			●							**Low**
Agent HDC	**A**	●									**Low**
ERH	**C**						●				**Moderate**
Energetics Hydrolysis	**C**			●							**Low**
Energetics HDC	**C**	●									**Low**
Dunnage Prep.	**C**			●							**Low**
Dunnage Pulping	**C**			❍							**Low**
Agent SCWO	**D**								●		**Moderate/High**
Energetics SCWO	**D**								●		**Moderate/High**
BRS	**D**					❍					**Moderate**

● Proven in Full-Scale operations or testing, or otherwise justifies high performance credibility

❍ Incomplete or partially successful testing or issues regarding performance

1. Inherent Performance Risk refers to the likelihood of significantly affecting proposed cost or schedule based upon Maturity Level, Application Level, and complexity of the equipment.

Source: Arthur D. Little, Inc.

Table 5-10: GATS Evaluated Overall Performance Risk

Equipment or Subsystem	EDS Design Submittal			Final Evaluation Configuration[2]		Evaluated Overall Performance Risk[3]
	Number of Units (Trains)	Capacity per Unit (Train)[1]	Comments	Number of Units (Trains)	Capacity per Unit (Train)	
MSB	1	100%	---	1	100%	**Low**
UPA	1	100%	---	1	100%	**Low**
PRR	1	100%	---	1	100%	**Low**
PMD	2	50%	---	2	50%	**Low**
Cryocooling	2	50%	---	2	50%	**Low**
Cryofracture	2	50%	---	2	50%	**Low**
PRH	2	50%	Potential mechanical problems should be resolvable during Systemization	2	50%	**Moderate**
Agent Hydrolysis	4	25%	---	4	25%	**Low**
Agent HDC	2	50%	---	2	50%	**Low**
ERH	2	50%	Potential mechanical problems should be resolvable during Systemization	2	50%	**Moderate**
Energetics Hydrolysis	4	25%	---	4	25%	**Low**
Energetics HDC	2	50%	---	2	50%	**Low**
Dunnage Prep.	1	100%	Shelf spare micronizer	1	100%	**Low**
Dunnage Pulping	2	50%	---	2	50%	**Low**
Agent SCWO	2	75%	Built in excess capacity plus low availability required reduces risks	2	75%	**Moderate**
Energetics SCWO	2	75%	Built in excess capacity plus low availability required reduces risks	2	75%	**Moderate**
BRS	1	100%	Significant potential for lower availability/reliability than assumed	**2**	**100%**	**Low**

1. Capacity is approximate based upon evaluated performance capability for the limiting campaign throughput
2. Bold face indicates an increase in number and/or capacity of equipment
3. Risk impact refers to likelihood of significantly affecting proposed cost or schedule based upon Inherent Performance Risk, capacities, redundancy and nature of issues.

Source: Arthur D. Little, Inc.

Control of the ERH with respect to proper caustic concentration is another source of risk, because it has not been tried on a full-scale unit. Variation in the PMD rate will cause transients in the ERH with respect to the ratio of energetics to caustic. While Energetics Hydrolysis can be used for final tuning of energetics destruction, loss of throughput could occur if the transients cannot be controlled. Another control issue is maintenance of a high enough liquid temperature to assure good solubility of the energetics. This is coupled to the design of the flights. Demonstration I testing (see Section 4.2.1) indicated that incomplete hydrolysis due to low liquid temperature coupled with removal of the burster from the caustic bath could lead to fires. Appropriate engineering design and control should eliminate the potential for this problem.

The risk associated with the ERH also derives from integrating the ERH with upstream and downstream processing, especially the heated discharge conveyor. These operations have not been coupled and tested.

Agent and Energetics SCWO. The agent and energetics SCWO subsystems received an inherent performance risk of moderate/high because the SCWO reactors are custom-designed, complex pieces of equipment subject to the reliability problems that occur with equipment operated at supercritical temperatures and pressures. While SCWO reactors have been under development for over 20 years, they are not considered common or standard. SCWO testing was conducted under Demonstration I and continues under EDS I testing. Conservative maintenance schedules have been established but overall reliability under variable feed conditions (rate and composition) has not. The Design Assessment identified several design (e.g., more feed and discharge buffer capacity and thicker titanium thermocouple wells) and operational (e.g., spare shells, non-destructive investigations, and flushing) modifications that reduced the risk level to moderate.

Brine Recovery System (BRS). A commercial vendor will provide the BRS. The risk involved with using a brine concentrator and crystallizer is the lack of testing with an accurate representation of the feed material. This is due to the SCWO salt composition(s) still being subject to EDS I testing and lack of a facility water specification (a source of salts). While extrapolation from glassware tests using small quantities of sample is often used for sizing brine concentration/evaporator equipment, there is a risk that the solids formed will foul heat exchanger surfaces and be difficult to remove. Frequent boilouts to clean the heat exchanger surfaces have been incorporated into the specification. As part of the Design Assessment, Arthur D. Little has added a second BRS train to the design to accommodate additional BRS input not accounted for by General Atomics, and to improve BRS availability for the required throughput. This reduces the BRS risk by increasing the BRS capacity. A lower operating rate due to unanticipated downtime for cleaning or other problems, still provides processing at close to the design capacity. However, a severe unanticipated fouling problem or difficulty in crystallizing out the salts could severely reduce the throughput of the BRS, hence the moderate risk rating.

5.4 Design Assessment Conclusions

5.4.1 Viability of the GATS Process

After incorporation of the Design Assessment adjustments into the General Atomics’ design, the GATS process is considered to be viable in terms of operational efficacy and capability to consistently achieve the required levels of agent and energetics destruction as well as environmental performance. In addition, the Engineering Package with the Design Assessment adjustments, are adequate to support the +/- 20% cost estimate and to justify the proposed schedule.

In the Baseline technology, the largest technical risk is in the reverse assembly process. GATS has minimized the technical risk in this area by using the equipment that worked fairly well at JACADS (PMDs) and replacing the equipment where significant problems arose (MDMs). While the PMDs are the rate-limiting process for GATS, the PMDs have been tested and operated by the Army at JACADS and TOCDF. In the Design Assessment, conservative average operating rates, that can take advantage of the higher design throughputs, and better estimated availabilities of the balance of the facility have been used. If the PMDs can operate at a higher average operating rate than the average rate used to establish the current schedule, the schedule can be shortened and operating costs can be reduced. The potential for the PMDs to achieve a higher average operating rate is good given that the average PMD operating rates at JACADS appear to have been limited due to the MDM.

GATS has substituted cryofracture for the MDMs used in the Baseline. By making this substitution, GATS has eliminated the issues related to agent accessing that were observed during the JACADS mustard campaign and significantly decreased the sensitivity of their agent accessing system to variations in the munitions. The maturity of the cryofracture system is considered to be moderate to high given the extensive testing that PMCD conducted on cryogenic cooling and pressing of munition bodies to access agent. The technical risk associated with cryofracture is further reduced by the GATS design to remove the energetic components prior to cryofracture. The risk with this system is in the ability to maintain and repair these subsystems, especially the cryogenic bath conveyor, and it does not appear that these needs have been factored into the GATS design. A capital cost contingency has been added for further design work to be performed in order to avoid incurring excessive downtime for repair that could extend the schedule (by a few weeks) and incur a much larger operating cost increase than the added capital cost.

The PMACWA has demonstrated the energetics hydrolysis (ERH) subsystem at a scale that clearly demonstrates its ability to deactivate the energetic material. In reality, the full-scale ERH does not need to achieve complete deactivation of the energetic materials because the hydrolysate and any remaining energetics are further processed in a standard energetic hydrolysate reactor.

While no direct demonstration of the PRH has been performed, the mechanical design of the agent hydrolysis (PRH) subsystem is very similar to the ERH which has been tested. The PRH is designed to remove the agents from the metal parts and hydrolyze the agent. However, the downstream PAH subsystem is designed to hydrolyze the agent assuming no hydrolysis in the PRH. The PAH is designed based on the Army’s extensive testing and demonstration of mustard hydrolysis.

Both the energetic and agent hydrolysis reactors are considered to be noncomplex and to have a high availability due to the relative simplicity of their design as reflected in the following: limited rotating equipment, highly reliable equipment, significant sparing, and limited sensitivity of the hydrolysis reaction to operating conditions. The agent hydrolysis reactors have the additional advantage that similar reactors are the primary destruction process for the HD ton containers at ABCDF. ABCDF should be operational in time to incorporate lessons learned into the PUCDF agent hydrolysis subsystem. The rotary hydrolyzers that are designed to remove agent and energetic feeds from the munitions metal part(s) and initiate hydrolysis are noncomplex rotary cylinders that should have a high availability. The heated discharge conveyors are similar in design to systems used at JACADS and TOCDF. There is some risk involved in operating the full-scale rotary hydrolyzers and integrating the rotary hydrolyzers to the respective feed systems and HDCs, because full-scale operation has not been tested. This risk deals mainly with control of concentrations in the rotary hydrolyzers and the movement of the metal parts through the rotary hydrolyzers and into the HDCs. However, the Schedule Assessment has included additional time for Systemization to account for such risk.

EDS I testing of SCWO is still ongoing, but sufficient mechanical availability to support the current schedule has been demonstrated. While maintenance requirements for SCWO may seem high, they have been factored into the Cost and Schedule Assessments. General Atomics has reduced risk by providing a second SCWO for both agent and energetics hydrolysate feeds to increase SCWO availability. Because the rate-limiting step in the GATS process is the PMD, improving SCWO availability or throughput is not necessary. Improvement would only shorten the schedule, if the PMDs could match the average SCWO throughput increase. Because EDS I testing is not complete, uncertainties still exist in how the energetics hydrolysate and dunnage are to be processed in the SCWO, but these uncertainties seem resolvable through testing.

The BRS system mechanical equipment is in commercial use; the risk in operation is due to the fact that the brine feeds to the BRS have not been tested at full scale. A second BRS train has been added to process additional material identified in the review and to provide additional processing capacity and availability in the event of additional outages due to unanticipated problems.

Overall, the largest source of risk, cost overrun or delay beyond the current schedule is due to the lack of prior integration of the entire system. The control of interactions between the facility subsystems has not been fully evaluated, especially how changes in the PMD throughput will be handled in the ERH without causing significant variations in the composition of the energetics hydrolysate. Additional Systemization and Pilot Test planning is required. Planning is needed to avoid extending the schedule and/or incurring additional costs due to unavailability of required resources, such as simulants and alternative components, and to have a complete understanding on how to commence "hot" operations in order to fully test the overall process.

5.4.2 Comparison of GATS to Baseline from a Design Perspective

While keeping the first part of baseline munitions disassembly – the PMDs, General Atomics has made a "paradigm" shift by replacing the MDM with cryofracture which could significantly reduce the technical risk for the PUCDF operations by eliminating the agent accessing problems (heel, champagning, etc) that occurred during mustard operations at JACADS. The use of cryofracture has the potential to reduce the operating schedule due to the increased reliability/availability of cryofracture versus the MDMs. Cryofracture of the munition bodies also allows better access to the interior of the munition than the other mechanical disassembly processes. By increasing the access to the interior of the munition, more of the agent heel can be removed from the metal parts and less agent heel will then be processed through the thermal treatment systems. Baseline will have to rely heavily on thermal removal of the agent heels unless the MDMs are redesigned to wash out the munition bodies.

The use of cryofracture in place of the MDMs has reduced the operations time for GATS in comparison to Baseline due to the increased availability of cryofracture. The operations time for GATS has the potential to be reduced further because the removal of the MDM downstream of the PMD should allow the PMDs to operate more freely and with a higher average operating rate than observed at JACADS, thus reducing the operations time. The operations time for GATS could be also be reduced by adding additional PMDs because currently the PMDs are the bottleneck in the facility. If the number of PMDs is increased the balance of the plant would have to be reviewed to ensure that it had sufficient capacity to handle the higher rates.

Beyond the PMDs, there is very little similarity between the balance of the GATS design and Baseline design, except for the use of heated conveying systems for 5X decontamination metal parts and a brine recovery step (BRA in Baseline, BRS in GATS) downstream of the oxidation (GATS) or incineration (Baseline). The area of major processing difference is the method chosen for the destruction of the agent and energetics. The GATS process uses a hot water hydrolysis process for the agent and a caustic hydrolysis process for the energetics with supercritical water oxidation of the hydrolysates. Baseline uses incineration for both agents and energetics.

The Baseline technology does have the advantage of more full-scale operational data; however, the advantage is not as great as one might envision due to the need to significantly redesign the Baseline MDMs to handle the mustard munition accessing problems experienced at JACADS and the Baseline MPF to handle significantly higher quantities of agent. The liquid incinerator (LIC) and the deactivation furnace (DFS) could be based on the JACADS operations with little change; however, GATS will have the advantage of the agent hydrolysis operations at ABCDF and SCWO operations at Newport Chemical Agent Disposal Facility (NECDF) and the extensive energetic water washout data for conventional munitions. In addition, extensive testing of the cryofracture has been conducted to demonstrate its operation and reliability. Therefore, the maturity of both technologies is considered to be similar.

In summary, GATS has a similar level of maturity to Baseline and has eliminated the issues regarding accessing the mustard munitions by using cryofracture instead of the MDMs. By removing the MDMs, GATS has reduced operations time necessary to destroy the agent munitions at PUCDF due to the higher level of availability and reliability of cryofracture. The GATS agent and energetic destruction systems are capable of meeting the same destruction levels as Baseline. In addition, GATS minimizes the quantity of agent or energetics that are thermally treated (via the HDC). GATS does still have an open question regarding the use of the SCWO units to process all the secondary wastes from the facility (especially the carbon) because the EDS I testing is not currently complete. However, if the carbon is found not to be compatible with the SCWO technology it can be processed in the HDC if that unit is redesigned to handle it.