A White Paper

HIGH THROUGHPUT EXPLOSIVE DESTRUCTION SYSTEM (HTEDS)

A Response to the Need for Increased Capacity for The Non-Stockpile Chemical Materiel Program

May 10, 2007

HIGH THROUGHPUT
EXPLOSIVE DESTRUCTION SYSTEM (HTEDS)

A Response to the Need for Increased Capacity for The Non-Stockpile Chemical Materiel Program

Recent Congressional attention to buried chemical weapon materiel has highlighted the need for remediation systems to destroy recovered munitions at a substantially faster rate than can be done with systems currently used by the Project Manager for Non-Stockpile Chemical Materiel (PM NSCM). The attention has highlighted the fact that the PM NSCM's inventory of mobile remediation systems – the Explosive Destruction System (EDS) and the Rapid Response System (RRS) – were originally designed to address only small volumes of recovered chemical warfare materiel (RCWM). These systems have worked very well and have achieved a significant degree of acceptance with the public and within the regulatory community. However, the near continuous use of the existing four EDS platforms and the extension of the Chemical Weapon Convention deadlines have shown the throughput of these systems is inadequate to address many of the identified burial sites.

Sandia National Laboratories developed the EDS for PM NSCM in the late 1990s to provide a self-contained, transportable capability to remediate small volumes of non-stockpile chemical munitions at recovery sites. The EDS has proven to be a flexible, capable, effective, and regulatory acceptable system to meet PM NSCM's mission requirements, as they were understood in the late 1990s. The successful operations of EDS P1, and the larger EDS P2, have proven the core technologies, but neither system was designed for high throughput or large quantity operations. Consequently, they cannot meet the emerging needs for higher volume processing expected for sites such as Tooele Army Depot, Redstone Arsenal, Aberdeen Proving Ground, or Black Hills, SD. However, the current limited process rate is not inherent in the EDS technology. It is entirely feasible to build a much faster system while retaining the proven benefits of the EDS process.

In response to this growing need, Sandia National Laboratories proposes a new High Throughput Explosive Destruction System (HTEDS) with a 20-fold increase in capacity. The system optimizes proven EDS technology to achieve the following:

- Process up to 60 munitions per day;
- Increase the size of munitions that can be treated;
- Improve instrumentation and automation to reduce operator workload;
- Maintain transportability and ease of set-up/tear-down operations; and
- Maintain the proven explosive access and chemical treatment process that has achieved public and regulatory acceptance.

Sandia proposes an 18-month program to complete the design of the HTEDS and construct an initial system. This system will provide PM NSCM with an order of magnitude increase in its capabilities to treat RCWM. This white paper describes the proposed HTEDS system and details how it optimizes proven technology to increase processing rates. A technical addendum provides design details and a processing timeline.

The projected 20-fold increase in throughput considers only the results of optimizing the EDS design to form the HTEDS. A companion white paper describes enhancements to the overall site remediation operation achieved by applying a "system of systems" approach. This approach considers all aspects of the operation from site characterization to final waste disposal including locating, characterizing and removing buried munitions; storage of munitions and explosives; munition destruction; monitoring and process control; and generation and disposal of dunnage or secondary waste. The result is an optimization of the entire process in terms of safety, throughput, and cost. Various technologies can be applied in a system of systems approach to move munitions seamlessly through the process. Robotics is one example. Sandia previously demonstrated robotic munition handling improvements at Aberdeen during the Hydrogen Cyanide Canister incident. Robotic handling offers safer and faster in situ removal of chemical munitions and placement in the EDS chamber. This technology improves the overall removal and remediation process timeline and is recommended as part of any overall process improvement. Such improvements are beyond the scope of this paper, which focuses exclusively on the benefits of the High Throughput EDS design, but they are detailed in the companion white paper.

OVERVIEW OF HIGH THROUGHPUT EDS OPERATIONS

The core process steps for the HTEDS are the same as those for the proven EDS P2:

- Munitions are bundled with explosive shaped charges and inserted into a containment vessel,
- The containment vessel is sealed and the shaped charges are detonated to open the munitions and destroy the bursters,
- The CWM thus released is treated using established chemical treatment or “neutralization” protocols,
- The effluent is removed for final disposal, and
- The system readied for the next batch of munitions.

The HTEDS achieves greater throughout in four ways. The detonation and subsequent chemical treatment are performed in separate vessels in a semi-continuous batch mode. A larger detonation containment vessel allows the processing of more munitions at one time. Redesigned components reduce the time for each step and allow the operators to work more efficiently. Finally, two detonation containment vessels provide increased throughput for the critical detonation process. The HTEDS as currently envisioned is shown in Figure 1.

In the current EDS, the chemical treatment of the munition contents is done in the detonation containment vessel after the detonation. This requires heating and continuously rotating the large containment vessel to agitate and mix the contents. This is time consuming not only due to the chemical reaction time but also due to the need to heat the very substantial mass of the vessel. In the HTEDS, the contents of the detonation containment vessel are washed into a separate treatment vessel where the chemical reactions occur. This approach frees the detonation containment vessel for the next batch. It also simplifies the overall design by eliminating the heavy equipment required to rotate the massive detonation containment vessel. The treatment vessel can be stirred internally because the hardware does not need to survive a detonation. Heating is also simpler because the vessel is smaller and it can remain at elevated temperature between batches.

The HTEDS detonation containment vessel has twice the volume of the EDS P2 vessel allowing it to handle more or larger munitions. The EDS P2 containment vessel is a thick walled cylinder with a swing-open door. When closed, the door is secured with large clamps and a metal gasket. The HTEDS vessel uses two cylinders, each the same size as the EDS P2 vessel, placed end-to-end. The result is a vessel of twice the length with the seal and closure clamps in the middle. Instead of a swing open door, the two cylindrical pieces spread apart axially. Since each half of the vessel is equivalent to the P2 vessel in diameter and wall thickness and it uses the same seal, the extensive explosive containment experience and design protocol from the EDS P2 are directly applicable to this vessel.

The process of closing and sealing the vessel is a time consuming element of current operations. Since the vessel on the HTEDS does not need to rotate, it uses a commercial off the shelf (COTS) clamp design that is both easier and faster to use. This, together with other improvements, reduces the time to load the munition and secure the door by about an hour.

Even with these improvements, the detonation containment vessel remains the rate-limiting step in the process. Therefore, the HTEDS employs two detonation containment vessels supported by a single reagent supply and a single chemical treatment vessel. The system layout and process sequence allows the operation of both vessels in an alternating manner by a single crew performing critical operations on only one vessel at a time. To guarantee the safety of these parallel operations, each detonation containment vessel is encompassed in a fume hood.

As detailed in the attached technical design document, HTEDS includes other innovations to speed and simplify operations, reduce operator workload, simplify system set up, and reduce fabrication and maintenance cost. These include increased automation, improved instrumentation, and skid mounting (vs. trailer mounting).

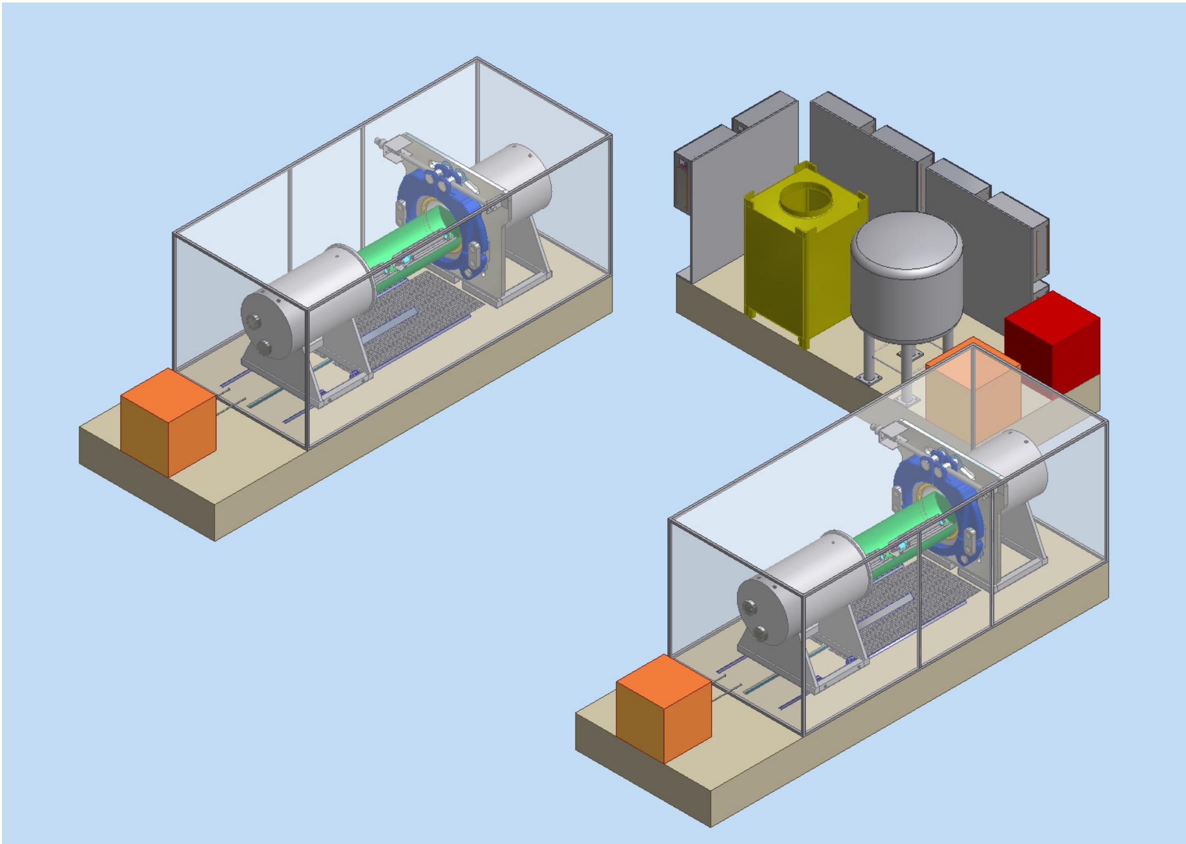

Figure 1. Conceptual Drawing of High Throughput Explosive Destruction System

OVERVIEW OF HTEDS PROCESSING TIMELINE

The top half of Figure 2 shows a simplified timeline for the current EDS P2 to process six 4.2-inch mortar rounds. Heating and agitating the containment vessel during the agent treatment step and again during the water rinse step consumes the most amount of time. The required time in both steps is driven by how long it takes to heat a vessel massive enough to contain the initial explosion. Other time consuming steps are closing and opening the vessel door, collecting samples, and preparing the vessel for the next run. Overall, it requires nearly 20 hours – split across two workdays – to process a single group of six 4.2-inch mortar rounds.

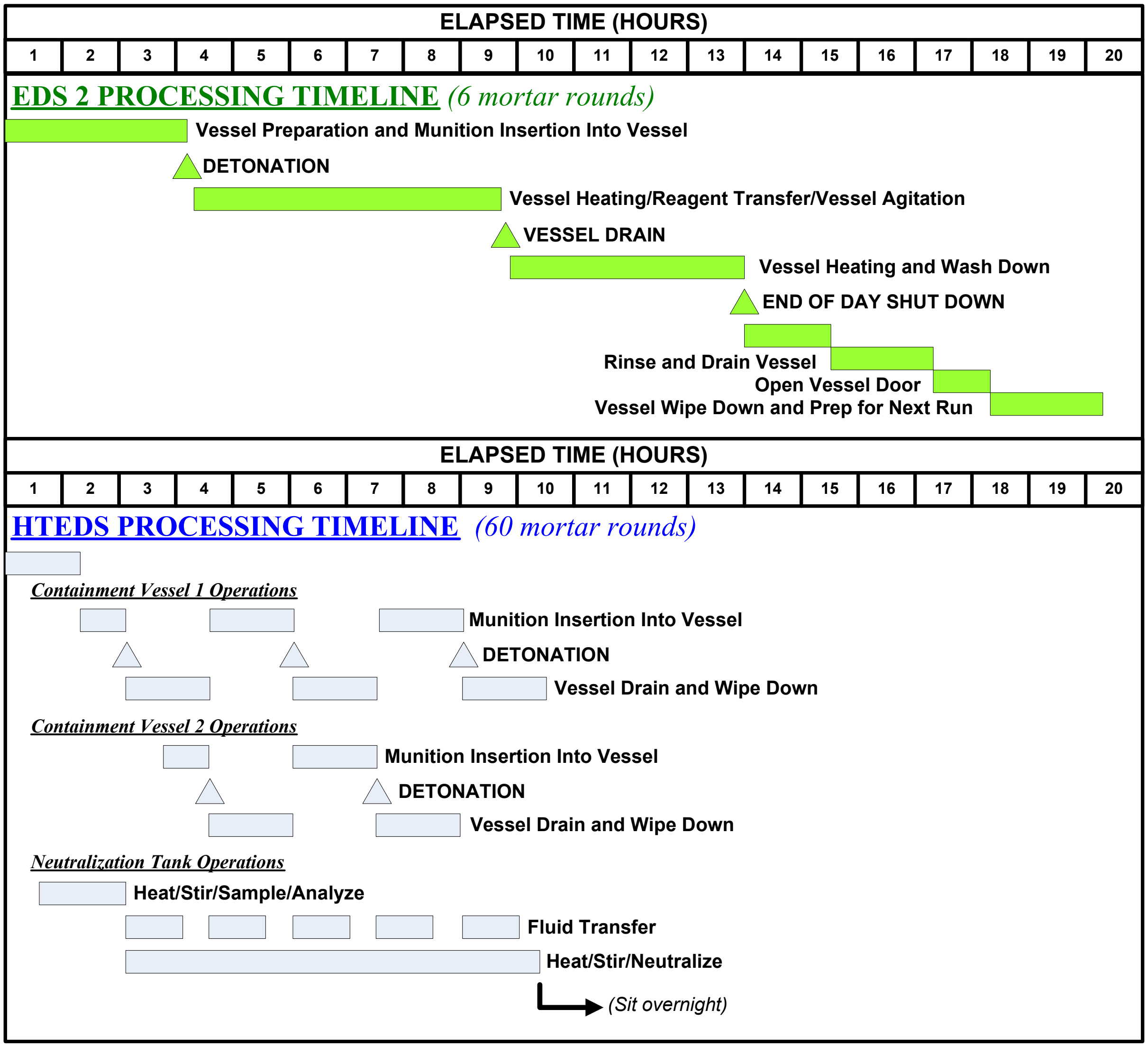

Figure 2. HTEDS and EDS P2 Processing Timelines Compared

The timeline for the HTEDS to process ***sixty*** 4.2-inch mortar rounds is illustrated in the bottom half of Figure 2 and compared to that of the EDS-2 to process only six rounds. This illustration highlights the throughput impacts of the design innovations of the HTEDS. The two detonation containment vessels are operated in parallel to enable five batches to be processed in a single 10.5-hour period. During this same period, the treatment chemistry is performed as a separate batch operation in the treatment vessel. Since the HTEDS detonation containment vessels are twice the size of the EDS P2 vessels, each can process twice the load of a single EDS P2 system. Also, note that individual steps in the process are much shorter. For example, the simplified clamp for the containment vessel enables much faster closure. The combination of the fume hood surrounding the containment vessel and an innovative steam rinsing process greatly shortens the time required to prepare the vessel for the next load of munitions.

The result of these design innovations is to achieve 20 times the processing rate of the EDS P2 system while still maintaining all of the characteristics that made the EDS approach so successful. The technical addendum attached to this white paper provides a more detailed description of the HTEDS design, process timeline and the benefits of other innovative features.

NEXT STEPS FOR HIGH THROUGHPUT PROCESSING CAPABILITIES

Sandia National Laboratories proposes an 18-month program to complete the HTEDS design and validate it with appropriate modeling and component testing. The result will be a total system design to provide PM NSCM with an initial HTEDS system for high volume processing of recovered chemical weapon materiel. Overall, this proposed program is relatively low risk because it relies on proven core technologies and key design features of the EDS P2. Nonetheless, there are a number of key program elements:

- Design, analyze, and procure the larger detonation containment vessel with its closure system
- Prototype and test the high throughput vessel wash down system to transfer the contents of the detonation containment vessel to the treatment vessel;
- Redesign and verify other key subsystems such as the fragment suppression system, for high throughput operations; and
- Complete the total system design to include the component specifications, transportation elements, instrumentation and control system, and complete bill of materials.

Sandia proposes to develop this design for approximately $7M.

Technical Design Description
HIGH THROUGH PUT EXPLOSIVE DESTRUCTION SYSTEM (HTEDS)

BACKGROUND

As first envisioned, the EDS had a specific mission: to treat explosively configured, recovered chemical munitions in emergency scenarios where the munition was not safe to transport or store. As such, EDS was to fill a critical, but limited role with no more than one or two uses per year. At the time, PM NSCM was designing other systems for higher throughput applications. Since that time, the role for EDS within the non-stockpile program has expanded substantially. It has proven to be a reliable and flexible workhorse for PM NSCM with good acceptance by both the public and the regulatory community. Several factors have contributed to its success:

- The process uses the Army's proven, low-temperature neutralization protocol to treat the CWM. It is not an incineration process and it does not rely on the uncontrolled fireball from the explosives to destroy the agents.
- The use of explosives to access the munition provides the flexibility to safely process many different types of munitions regardless of their condition. The use of explosive devices is also very reliable.
- The munition is entirely contained from the time it enters the system until there is positive confirmation, by sample analysis, of agent destruction. Consequently, there is time to handle unusual conditions and equipment problems calmly and methodically.
- The system is small and self-contained so it is easily transported.
- The system has redundancy and flexibility that have allowed it to handle munitions and agents well beyond the original scope.

Consistent with its intended application, the EDS design emphasized transportability, flexibility, redundancy, surety of destruction, and the simplicity of manual operation. There was no emphasis on process time or throughput. Recently there has been much discussion about the need for systems with higher throughput for potential applications such as large burial sites. In this context, some other technologies appear to offer advantages compared to the existing EDS. In fact, the EDS process is not inherently slow. The HTEDS described here provides an order of magnitude increase in throughput while maintaining all of the attributes and strengths that have made EDS successful. Besides increasing capacity, the HTEDS will reduce operator effort, increase capability in terms of the types and sizes of munitions, reduce effluent, and reduce unit munition cost.

This is an ideal time to develop such a system because of the confluence of several factors.

- Recent congressional attention on buried chemical weapon materiel and ocean dumping sites has highlighted the need for the capability to destroy recovered munitions at a faster rate than can be accomplished with current non-stockpile systems.

- There is a continuing demand to increase efficiency and reduce the costs of ongoing Non-Stockpile activities. This was evident in the push to handle multiple munitions in the EDS. By developing the HTEDS now, it can contribute to current Non-Stockpile operations
- Large cleanup operations are beginning at locations outside the USA that could benefit from the system.
- The system could potentially benefit the stockpile program for destroying non-standard munitions such as leaking M55 rockets.
- There is also the advantage of maintaining the R&D and operational capabilities of PM NSCM thereby allowing it to collaborate in new, expanded mission areas.

OVERVIEW OF EDS PROCESS

The current EDS process takes almost 20 hours over two days. The munitions are placed in the fragment suppression system with the shaped charges. The assembly is loaded into the vessel, the door is sealed, and the seal is leak tested. The shaped charges simultaneously open the munitions and destroy their bursters. Treatment or "neutralization" chemicals are then pumped into the vessel and the vessel is heated to 60°C with external resistance heaters. Liquid samples are collected and analyzed to confirm destruction of the agent after which the effluent is drained to waste drums and the vessel is filled again, this time with water. The water is heated to 100°C to destroy any remaining heel. During both heating steps, the vessel is continuously rotated on its axis to mix the contents and speed the reaction. After the vessel cools over night, a gas sample is collected and analyzed, the water is drained, the vessel is flushed with helium, and the vessel is opened. Solid debris is removed and the vessel is prepared for the next operation.

DESIGN CONSIDERATIONS FOR HIGH THROUGHPUT PROCESSING

Several of the advantages of the EDS derive from using a controlled batch process. The variability in both the types of munitions and their conditions make this a logical choice for non-stockpile. There are four basic approaches for increasing throughput of a batch operation. By using a combination of all four approaches we can achieve a dramatic improvement in throughput of the EDS while still using the same proven technology and building on the large, successful database.

- *Increase the batch size.* Depending on the munition, EDS P2 can handle up to six munitions simultaneously. The number is limited by the explosive containment capability of the vessel, by the space available within the vessel, and by the firing system. For the HTEDS, we propose to use a larger vessel to double the batch size.
- *Operate in a semi-continuous batch mode.* This refers to a series of batch operations that run sequentially in separate vessels. This approach maintains the advantages of batch operation but allows the second batch to start before the first one is complete. In EDS P2, the detonation and the subsequent chemical treatment are performed in the same vessel. HTEDS will use a separate vessel for the chemical treatment process.

- *Use parallel operations for critical steps.* The process of opening the munition in the detonation containment vessel is the rate-limiting step. The HTEDS therefore has two detonation containment vessels that feed a single treatment vessel. The two operate in an alternating sequence so that a single operating crew can support both vessels, performing safety critical operations on only one vessel at a time.
- *Decrease the process time for each batch.* HTEDS uses a combination of hardware improvements, process automation, and remote actuation of equipment from the control room to either eliminate steps in the process or complete them more quickly as described in a later section. Perhaps the most significant of these changes are improved vessel closure clamps and a fume hood around the detonation containment vessel.

HTEDS DESIGN AND OPERATION

Overall Configuration. Figure 1 shows the layout of the HTEDS. It consists of two detonation containment vessels that feed into a single agent treatment vessel. The system is mounted on three skids. Two skids hold detonation containment vessels; the third holds the treatment vessel, the fluid handling hardware, and the system controls. The skids eliminate the cost and complexity of the specialized trailer used on EDS P2 with its fold out wings and stairs. They can be easily transported on flat bed trucks so they have little impact on transportability. Connections between the skids are minimal so there is little impact on setup time. Everything is located close to the ground, making it easily accessible to the operators and eliminating much of the lifting of munitions and heavy hardware.

A significant difference from EDS P2 is that the vessels do not rotate. This drastically simplifies the design and operation. There is no rotation motor, no drive train, no electrical slip ring, no trolley wheels, and no paddle inside the vessel. The clamps do not have to disconnect from the clamp hangers. Consequently, the vessel closure system is much simpler. Fluid and electrical connections are hard plumbed and wired to the vessel in place of quick-connect fittings. The various interlocks and safety features associated with the rotation are all eliminated. The vessel is fastened directly to the skid instead of resting on castors so there is no need to secure it for transportation.

A second difference is that the vessel is located inside a fume hood that is vented through an activated carbon filter. The hood reduces the inherent hazards associated with removing a munition from an over pack and loading it in the system, particularly if the munition is leaking. It also eliminates the need for some time consuming steps in the process. Although some operations on the EDS P2 would be more difficult in a fume hood, HTEDS alleviates these issues with a combination of design changes and remote operation.

Vessel Design. A larger vessel is needed to increase the number of munitions that can be processed in a single batch. The existing EDS P2 vessel is about 2.5 feet in diameter by 4.5 feet long (inside dimensions). It consists of a cylindrical cup and a flat door secured with sliding clamps, hydraulic nuts, and a Grayloc metal seal.

There are two options for increasing the volume of the vessel. The choice will depend primarily on the fabrication cost and schedule. The option shown in the conceptual drawing has the same diameter as the EDS P2 vessel, but twice the length. This is achieved by using two cylindrical cups instead of one cup and a door. This vessel is easy to design and fabricate since it uses the body from the EDS P2 vessel. The effects of moving the seal from the end to the center of the vessel require additional analysis. Another option is to increase both the length and diameter by scaling the vessel dimensions as we did between the EDS P1 and EDS P2 vessels. To double the capacity, the outside diameter would increase from 36 to 45 inches. With this design, established scaling laws allow us to extrapolate data from the existing vessel to predict the performance of the new vessel.

Both options continue to use Grayloc's metal seal, which has proven to be highly reliable. Instead of a hinged door, one end of the vessel rolls on rails toward and away from the other half. This should eliminate ongoing difficulties with door alignment. It also makes loading and unloading the vessel easier. The munitions and shaped charges are assembled on a platform or tray between the two ends of the vessel. When the vessel ends come together, the tray slides into the vessel. Similarly, during vessel opening, the tray pulls the fragments out.

Since the vessel does not rotate, it is possible to use Grayloc's standard remote clamping system to secure the vessel instead of the custom-designed sliding clamps and hydraulic nuts from EDS P2. This eliminates the manual processes of sliding the two clamps together, tightening the hex nuts, actuating the hydraulic nuts, and securing the hex nuts, as well as the reverse processes at the end of the operation. This saves almost an hour and reduces the level of effort for the operators.

Munition Access. As with EDS P1 and P2, the HTEDS uses shaped charges to access the munition and attack the burster. We intend to replace the current disposable fragment suppression system (FSS) with a semi-permanent fragment barrier or liner in the vessel to reduce scrap and simplify assembly and loading. However, the existing FSS design remains an acceptable option.

Vessel Washout. Perhaps the most significant change with the proposed HTEDS is the use of a separate vessel to treat the agent. The keys to implementing the approach are the ability to knock down vapor phase agents and to effectively transfer the contents of the detonation containment vessel into the treatment vessel. This is done by circulating heated liquid from the treatment vessel to the detonation containment vessel and back. A closed loop recirculation path with a canned-motor pump ensures total containment at all times. Canned motor pumps are used routinely for pumping hazardous fluids. They handle slurries and particulate laden fluids at temperatures, pressures, and volumes appropriate for this application. The fluid is introduced into the detonation containment vessel through a series of spray nozzles that provide vapor knockdown and scrub the surfaces of the vessel and fragments. The vessel is then left to soak for period of time before the fluid is drained back to the treatment vessel.

This approach requires no new technology, but some development and testing is needed to optimize and validate the approach. We do not know how long it will take to wash the vessel adequately. The process timeline shown later conservatively allocates one hour. The process is clearly easier if there are fewer large metal fragments in the vessel to trap agent and shield areas from the jets. This is part of the motivation for replacing the FSS with a liner.

In designing the system, an important question is how clean the vessel needs to be before opening to load the next munitions. The longest step in the current process is the hot water rinse required to decontaminate the vessel to below the detection level. The hot water removes small residues of polymerized agent or “heel” from aged munitions that survives the normal treatment process. Repeated decontamination to this level is consistent with the expectation of treating a single munition and moving on. However, in a high-throughput scenario with back-to-back operations, this level of decontamination is only required at the end of a campaign or, at most, at the end of each day. Since the HTEDS vessel is secondarily contained in a fume hood residual concentration between batches of a few TWA from agent heel should be acceptable.

Vessel Cleanup. Even if the hot water rinse is not done after each detonation, it is still a required operation at the end of a campaign, and perhaps more frequently. Instead of pumping in warm water and heating it in the vessel, which takes several hours, the HTEDS uses a steam generator to inject steam into the vessel. The steam attacks the residual heel more effectively than hot water, it heats the vessel from the inside more quickly and efficiently than external heaters, and it contacts all vessel surfaces without rotating the vessel.

Treatment Vessel. The neutralization of the agent is completed in a 500 gallon heated and stirred treatment vessel. This is large enough to handle an entire day’s operation, with each batch of munitions adding to the contents. To use the time most efficiently, the last batch is added near the end of the day, the contents are left in the vessel overnight, and then the effluent is drained the following morning. This provides plenty of time to destroy the agent.

Automation and Remote Operation. Pumps, motors, heaters, valves, and numerous other components are actuated and controlled remotely from the control room and routine sequences of events such as vessel closure or transfer of reagents between vessels are automated to be completed with a single command. This speeds the operation, reduces the workload on the operators, reduces the inherent hazards, and minimizes the potential for operator error. Manual operation is always a backup option.

Process improvements. Figure 3 shows the steps in the EDS P2 process. Several of these steps have been eliminated or are completed more quickly:

Safety briefing and initial entry – This step is not part of the EDS operation per se so there is no improvement with the HTEDS. However, some operations such as heating reagents will be started remotely before the operators enter, thereby making more efficient use of the time.

Munition Unpack and FSS assembly – No change is anticipated for the process time for these steps. A simpler FSS will reduce the time, but there will be more munitions. Incorporation of semi-automated man-assist mechanisms, like those currently in use at the Pine Bluff EDS operation, will reduce stress on the operators.

Vessel Loading and Closure – The simplified vessel closure system is expected to save about 25 minutes. It will also be much easier for the operators.

Leak test – The Grayloc seal has proven to be highly reliable with the leak rate rarely exceeding 10^{-3} std cc/sec. Given that the vessel on the HTEDS is in a fume hood, even the largest leaks observed in EDS operations should be acceptable. A gross problem with the seal such as a pinched wire or a missing seal ring is detected by monitoring the clamp displacement. Therefore, we propose to eliminate the leak test in the HTEDS, saving about 25 minutes.

Detonation and re-entry – The detonation is unchanged. However, following the detonation, the transfer of reagents can be started remotely without waiting for three cycles of the Minicams before the operators re-enter the VCS.

Treatment – The processes of transferring the reagent, heating and agitating the vessel, collecting samples, and draining the vessel take about five hours. In the HTEDS these steps will be somewhat faster, but more importantly, they will be done in a separate vessel so they are not on the critical path. The critical time instead is how long it takes to wash the contents of the detonation containment vessel into the treatment vessel. The system performance estimate below conservatively allows one hour for this.

Hot water rinse – The various steps associated with the hot water rinse take almost five hours plus the vessel must cool overnight. In HTEDS this step is done only at the end of the campaign, thereby saving the entire five hours during routine operation. When the rinse is done, the time is reduced to about an hour by using steam.

Helium flush and gas sample – Like the hot water rinse, these steps are not required routinely for the HTEDS because the operation is done in the fume hood. This saves about 30 minutes.

Vessel opening – The improved vessel closure design along with the loading tray and the reduced amount of scrap will reduce the time taken to open and then unload the vessel by about an hour.

Prepare vessel for next operation – The time required to rinse the vessel, clean the sealing surfaces, apply lubricant, and install a new gasket is expected to remain about the same.

EXPECTED PERFORMANCE

Figure 4 shows the process time line for HTEDS. The EDS P2 process takes two days with a very long first day (~13 hour). The HTEDS, with its two detonation containment vessels, a separate treatment vessel, and simplified processes can complete five batches in one 10-hour day with the system ready to resume operation the next day at the same rate. Furthermore, the detonation containment vessel can handle twice as many munitions in one batch as the EDS P2. Altogether, this results in a 20-fold increase in system throughput. In other words, the HTEDS can process sixty 4.2-inch mortars in one day compared to six in two days in the EDS P2. A single crew can handle the operation of the entire system including both detonation containment vessels. Their primary task is preparing and loading the munitions into the vessel. Much of the remainder of the process is handled remotely from the control room.

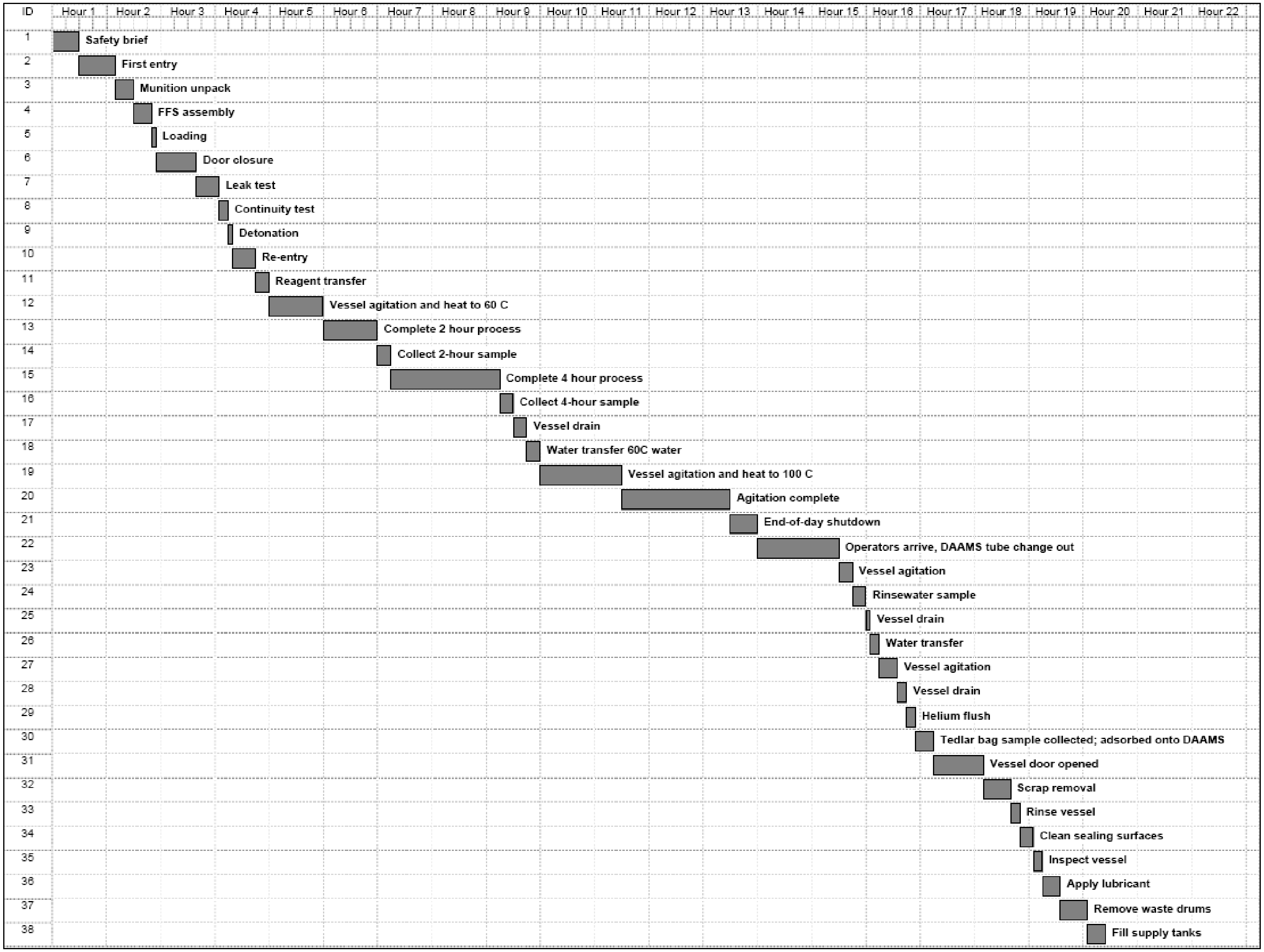

Figure 3. Process Time for Current EDS Systems

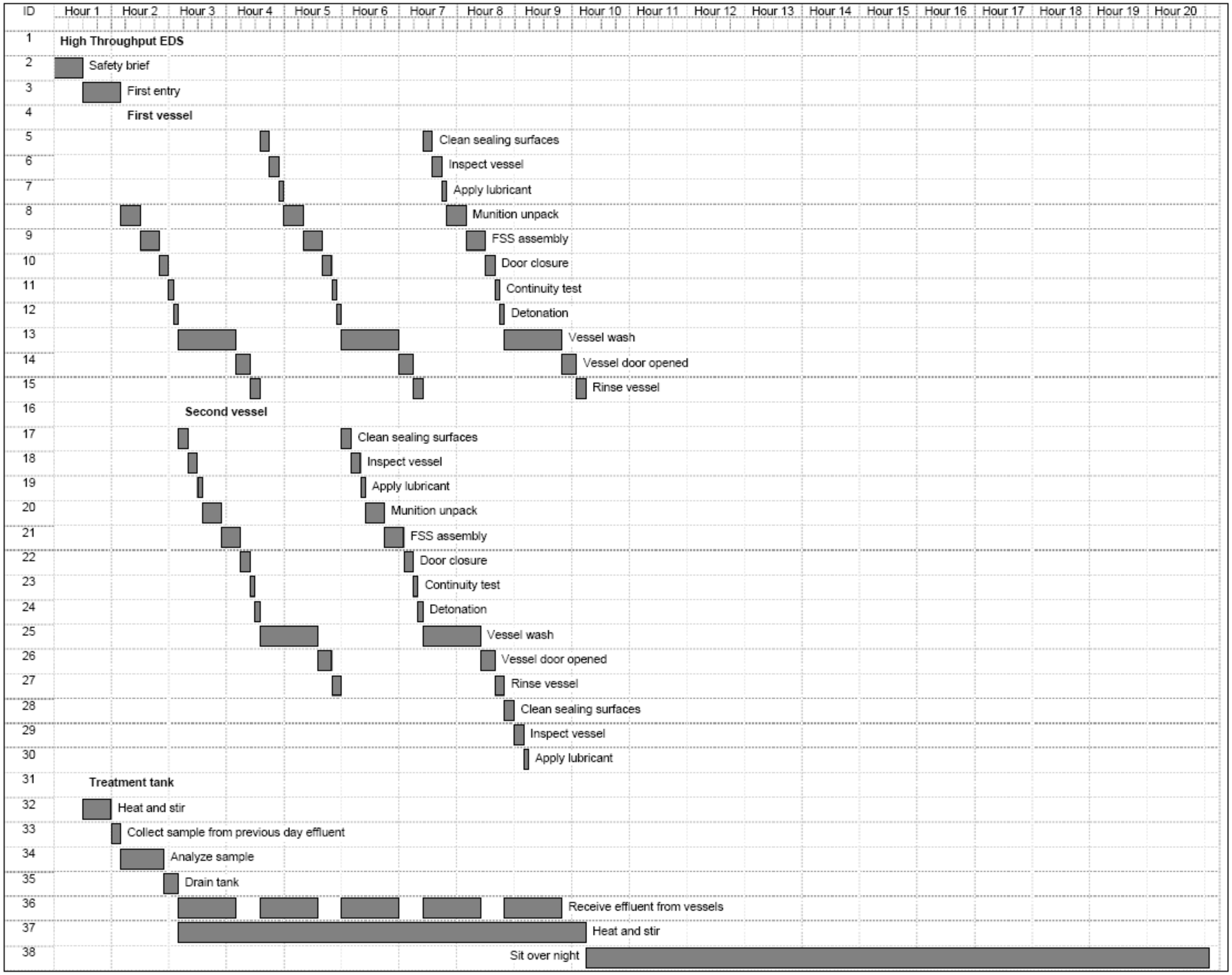

Figure 4. Expected Process Time for High Throughput EDS

CONCLUSIONS

We believe it is feasible to develop a new, High-Throughput Explosive Destruction System with a 20-fold increase in capacity relative to the EDS P2 systems. Since the system builds on the experience and proven record of the EDS, the initial system can be developed, fabricated, and ready to begin qualification testing in 18 to 24 months. The changes are evolutionary. They create minimal technical risk and maintain the characteristics that have made EDS successful such a total containment; proven, controlled, non-incineration treatment chemistry; the flexibility and reliability of shaped charges to open the munitions; and the proven design of the detonation containment vessel and seal. Development of the system will have significant benefits for ongoing non-stockpile operations and will provide a valuable tool for other potential applications such as large burial sites and international chemical weapon disposal.