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INFORMAL REPORT

Executive Summary of the Cryofracture Demonstration Program

**Guy Loomis
Denise Osborne
Mike Ancho**

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**EXECUTIVE SUMMARY OF THE
CRYOFRACTURE DEMONSTRATION PROGRAM**

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Published September 1991

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September 1991

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ABSTRACT

This report provides an executive summary of the CryofractureSM demonstration program performed at Nuclear Remedial Technologies Corporation under contract to EG&G Idaho, Inc., for the Department of Energy (DOE). CryofractureSM is a size-reducing process whereby objects are frozen to liquid nitrogen temperatures and crushed in a large hydraulic press. Material at the cryogenic temperatures have low ductility and are easily size reduced by fracturing. The main application being investigated for the DOE is for retrieved buried and stored transuranic (TRU) waste. Six 55-gallon drums and six 2 ft x 2 ft x 8 ft boxes containing simulated waste with tracers were subjected to the CryofractureSM process. Data was obtained on (a) cool-down time, (b) yield strength of the containers, (c) size distribution of the waste before and after the CryofractureSM process, (d) volume reduction of the waste, and (e) sampling of air and surface dusts for spread of tracers to evaluate potential contamination spread. The CryofractureSM process was compared to conventional shredders and detailed cost estimates were established for construction of a CryofractureSM facility at the Idaho National Engineering Laboratory. Although cost estimates for conventional shredding are higher for CryofractureSM, the potential for fire and explosion during conventional shredding would incur additional costs to preclude these events. These additional costs are unknown and would require considerable research and development.

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EXECUTIVE SUMMARY OF THE CRYOFRACTURE DEMONSTRATION PROGRAM

INTRODUCTION

This report provides an executive summary of the results of a demonstration program that examined a technique called CryofractureSM for size-reducing retrieved buried and stored transuranic (TRU) waste. This demonstration program was performed by Nuclear Remedial Technologies Corporation (NRT) for EG&G Idaho, Inc., under contract to the Department of Energy Field Office, Idaho (DOE-ID). CryofractureSM is being considered as a pretreatment size-reduction technique for use in processing transuranic-contaminated waste contained in drums and boxes. The CryofractureSM process involves cryogenically cooling the waste in liquid nitrogen, followed by fracturing and shearing the embrittled packages in a hydraulic press.

Size reducing transuranic waste is desirable for a variety of reasons including (a) volume reduction for interim storage, (b) homogenization of waste for facilitating assay for transuranic content, and (c) increasing the surface area for thermal processing. The transuranic waste associated with Department of Energy weapons complex sites is also contaminated with volatile organics which increases the probability of fire and explosion during conventional shredding processes; the cryogenic operations eliminate this probability.

This report gives background information on the CryofractureSM process and also how the process might be used at the Idaho National Engineering Laboratory (INEL). This is followed by a summary of the results of the CryofractureSM testing. Next, a comparison of conventional shredders for the CryofractureSM shredding process is given. Finally, a detailed cost estimate for an integrated CryofractureSM processing plant at the INEL is given with conclusions and recommendations.

BACKGROUND ON THE CRYOFRACTURE PROCESS

The CryofractureSM process was developed by General Atomics for the U.S. Army for demilitarization of chemical and biological munitions. The process was developed to render inert and destroy chemical weapons. It was selected as an alternative technology to the Army's reverse disassembly demilitarization technology which was time consuming and dangerous to operators. Chemical weapons such as 105-mm and 155-mm projectiles, land mines in 30-gallon drums, and rockets are handled robotically and then immersed in a bath containing liquid nitrogen (LN₂) until all elements of the weapon or package reach cryogenic temperature (-320°F). The material is then crushed in a large 1000-ton Williams-White hydraulic press. Most materials (a notable exception is stainless steel) when cryogenically cooled reach nil-ductility temperature and lose their capability to absorb energy via plastic deformation. An adequate force applied to a material below its nil-ductility temperature will cause the material to brittle fracture into shards, analogous to the fracture of a ceramic pot.

One of the main advantages of the CryofractureSM process is that it can render inert and desensitize explosives and pyrophorics. Another advantage is that the cooling process can solidify sludges and liquids, and recondense most vapors.

Candidate transuranic wastes at the INEL that could be processed in a CryofractureSM facility include both aboveground stored boxes and drums and buried waste. By size reducing this waste, further processing steps such as thermal treatment (aboveground glassification) is expedited by increasing the surface area for combustion. Another reason to size reduce the waste is to achieve a volume reduction for repackaging. This could result in a cost savings for planned interim storage options. Finally, by size reducing the completely heterogeneous transuranic wastes stored and buried at the INEL a more homogeneous waste stream allows an expedited assay for plutonium/americium content and possibly more efficient separation schemes.

RESULTS OF THE TESTING PROGRAM

This section summarizes the results from the testing and analysis program conducted by NRT. Additionally, this section describes the CryofractureSM facility, test procedures, and simulated waste. The testing program involved a cooperative effort between EG&G Idaho and NRT. EG&G Idaho provided programmatic requirements, waste form containers, comparison analysis to conventional shredders, and a complete sampling program during the CryofractureSM testing. NRT provided the CryofractureSM facility waste fabrication, testing and analysis, and a detailed cost estimate for a potential CryofractureSM facility at INEL.

CRYOFRACTURE FACILITY

Testing was performed at the CryofractureSM prototype line in San Diego, California. The prototype line (see Figure 1) consisted of cryogenic baths for total immersion of the waste, a feed tunnel with a pusher adaptor to feed the waste through the press, the press (Williams-White 1000 Ton) with a special cutting blade to simultaneously fracture and cut the waste, and a hopper to focus the fractured and sheared waste into a container. The tooling in the press for this demonstration is called the bulk tooling system which was designed to process one-ton containers containing chemical agents. Original plans called for a tooling modification for this test program. However, after preliminary scoping tests with similar INEL simulated wastes and containers, it was decided that the bulk tooling was not only adequate but also desirable because it could also size reduce stainless steel items. The bulk tooling could accommodate the 55-gallon drums containing wastes; however the size of the boxes was reduced to 2 x 2 x 8 ft from the original 4 x 5 x 8 ft. Scaling down did not compromise the test results because the stroke of the press via the tooling into the waste was independent of the height. The one component that was included in the line, but not used during this demonstration, was the robotically-controlled (PRABB robot) handling tool to remove the munitions from the cryogenic bath of liquid nitrogen to the pusher/feeder mechanism. This operation was completed manually using overhead

Figure 1. Schematic representation of bulk processing system.

rigging. This line was designed and developed by General Atomics, an affiliate of NRT under contract for the Army for the demilitarization of chemical munitions.

TEST PROCEDURE

The test articles were cryogenically cooled in a liquid nitrogen (LN_2) bath to reduce the temperature of the packaging and contents to $-320^{\circ}F$ (verified by internal thermocouples within each waste container). During the cryogenic soak in the LN_2 , the thermocouples in the test articles were sampled once every 10 seconds. After cooling the waste in a cryogenic bath to nominally $-320^{\circ}F$, the waste was manually maneuvered with rigging into the pusher feed system. The feed ram advanced the test article through the feed tunnel and into the press tooling. The press was then lowered to fracture the front end of the test article. Following fracture, the press was raised and the test article was again advanced and the press lowered. With each press stroke, two shear cuts were made and an additional section of the test item was fractured. These steps were repeated until the entire test article was processed. The debris created during CryofractureSM passed through a chute directly below the press into a hopper for collection. Every stage of this procedure was videotaped and still photographed. A video summarizing the entire process for the various INEL waste was assembled and is available from either NRT Corporation, San Diego, California, or EG&G Idaho, Inc., Idaho Falls, Idaho.

After test-article processing was completed, the test article debris was retrieved and temporarily packaged. The size distribution was measured by sifting the debris through wire screens. The volume reduction effectiveness was quantified by placing the fractured waste into containers of known volume.

DESCRIPTION OF SIMULATED WASTE FORMS AND CONTAINERS

Descriptions of the test articles used in the CryofractureSM demonstration are summarized in Table 1. Table 1 shows the type of waste simulated, the type of waste container used, and the total weight of each test article.

The drums were 55-gallon DOT type 17C drums provided by EG&G Idaho, each containing a polyethylene liner with lid. The plywood waste boxes tested were 2 x 2 x 8 ft, of the same materials, thicknesses, design, and construction as the 4 x 4 x 8 ft boxes used at the INEL, but downsized in width and height to fit into the existing tooling in the CryofractureSM equipment at NRT. Since the materials of construction and the simulated waste contents were left at full scale, downsizing the boxes did not change the outcome of the results of this demonstration.

Tracers were added to each test article to simulate TRU contamination within the test articles. To avoid cross-contamination, the tracers were loaded into the test articles at a location separate from the CryofractureSM test area. The type and quantity of tracer in each test article is also shown in Table 1.

Thermocouples were located in each test article to record its temperature profile versus time. The drums contained three thermocouples and the boxes contained six thermocouples. The locations of these thermocouples are shown in Figure 2. As shown in Figure 2a, three Type-T thermocouples were placed by the manufacturer into an 8-ft long, 1/4-in. diameter stainless steel sheath to form a multicouple. The sheath was then packed with magnesium oxide for insulation. These multicouples were then installed in the test articles as shown in Figures 2b and 2c.

The test plan for this CryofractureSM demonstration program¹ required that, as an initial test, a drum filled with metallic wastes and a drum filled with cloth wastes be immersed in liquid nitrogen to determine the soak time required to reach -320°F. These results were to then determine

Table 1. Test articles for CryofractureSM demonstration

Test Article No.	Test Seq. No.	Wt. (lbs)	Drum	Box	Contents	Punctured	Tracer Type	Qty (g)
CD ^a -1	6	97	X		Cloth	yes	Dysprosium oxide	15
CD-2	4	173	X		Paper	yes	Dysprosium oxide	15
CD-3	3	371	X		Sludge (Microcell E, vegetable oil, Oil Dri)	yes	Terbium oxide	10
CD-4	2	359	X		Metals	yes	Neodymium oxide	100
CD-5	1	419	X		Concrete/asphalt	yes	Ytterbium oxide	15
CD-6	5	126	X		Wood	yes	Neodymium oxide	100
CD-7	9	1090		X	Carbon steel scrap	yes	Neodymium oxide	200
CD-8	7	705		X	Carbon/stainless steel mix	yes	Terbium oxide	20
CD-9	8	448		X	Stainless steel scrap	yes	Ytterbium oxide	15
CD-10	11	1633		X	Soil/carbon steel mix (3:1 by volume)	yes	Ytterbium oxide	50
CD-11	10	1462		X	Soil/carbon&stainless mix (3:1 by volume)	yes	Terbium oxide	50
CD-12	12	1280		X	Soil/stainless mix (3:1 by volume)	yes	Neodymium oxide	400

a. CD = Cryofracture Demonstration

Figure 2a. Type-T multicouple.

Figure 2b. Multicouple installation in 2 x 2 x 8 ft box.

Figure 2c. Multicouple installation in 55-gallon drum.

whether the test articles would be punctured to hasten cooling by allowing LN₂ inside the package during soaking. Since the cooldown rate for the nonpunctured drum was found to be excessive (17 hrs), all test articles were punctured. In drums CD-4 and CD-5, four equally spaced 11/16-inch diameter holes were drilled into the circumference of the drums at mid-height. In the remaining drums, only three holes were drilled, all at mid-height, and spaced 45 degrees apart on the drum circumference. In the boxes, six 1-in diameter holes were drilled, two on each of the long sides and two on the lid.

Photographs were taken of each test article before and after assembly to document the configuration of its contents. An extensive photographic record is provided in References 2 and 3.

TEST RESULTS AND OBSERVATIONS

General Results

The CryofractureSM process successfully size reduced all items that were processed. This included size reduction of many materials that severely challenged conventional shredders, such as large high-pressure valves, structural I-beams, aerosol cans, 1-in. diameter lifting cables, and electrical cables.

The test results are summarized in Tables 2 and 3. Table 2 presents results for initial screening tests to determine cooling rates for unpunctured containers and punctured containers and Table 3 presents both cooldown rates and CryofractureSM data for CD-1 through CD-12. These results were extracted from the thermocouple and press data provided in Reference 2.

As shown in Table 2, the amount of time for a nonpunctured drum (CD-A) filled with metal to cool was over 17 hours. As a result, per the test plan (see Reference 1), all test articles were punctured to hasten cooling. As shown in Table 3, the time required for punctured drums and boxes to cool to -320°F ranged from 12 minutes to 2.7 hours, and averaged about 45 minutes. In general, this variation correlated well with the thermal inertia and void space of the contents being cooled. Cloth, having the least thermal capacity and greatest porosity, cooled the fastest while sludge, having the greatest

Table 2. Test results for Cryogenic cooling screening tests

Test Article No.	Wt. (lbs)	Container	Contents	Time to Reach -320°F (hr)
CD-A	500	55-gallon drum with liner (unpunctured)	Metals	17.45
CD-B	93	55-gallon drum with liner (punctured)	Cloth	1.75
CD-C	5100	4 x 4 x 8 ft plywood box (punctured)	Metals and soil	0.23

Table 3. Test results for CryofractureSM demonstration

Test Article No.	Wt. (lbs)	Container		Time to Reach -320°F (hr)	Max Press Force (tons)	Process Duration (min)	Volume Reduction (%)	% Weight of Debris <6"	Largest Piece (in.)
		Drum	Box						
CD-1	97	X		0.20	61	16	37	80%	13
CD-2	173	X		1.20	753	21	--	90%	11
CD-3	371	X		2.70	382	22	0	95%	12
CD-4	359	X		0.40	288	14	25	88%	10
CD-5	419	X		1.30	808	18	39	100%	--
CD-6	126	X		0.40	78	16	4	76%	16
CD-7	1090		X	0.20	606	33	19	97%	20
CD-8	705		X	0.25	247	27	47	98%	16
CD-9	447		X	0.23	427	25	16	90%	12
CD-10	1633		X		818	47	11	97%	15
CD-11	1462		X	0.70	854	47	4	99%	12
CD-12	1280		X	1.00	813	52	1	96%	15

bulk and least void space, required the longest time to cool. During cryogenic cooling of the test articles, the thermocouple data indicating that -320°F had been reached was verified by visually checking the baths to see that LN₂ was no longer boiling around the test articles. (The reason boiling is important is because of the convection heat transfer that takes place.) When the test article and the LN₂ were 400°F apart, very violent boiling took place when the test article was placed into the LN₂. But as heat was transferred from the test article, the boiling lessened until the waste container reached the same temperature as the LN₂, at which time the boiling came to a complete stop. In all cases involving drums, boiling ceased within 15 minutes after the thermocouples read -320°F.

As shown in Table 2, the cooling rate for a 4 x 4 x 8 ft box is about the same as for the downsized boxes used in CD-7 through CD-12. Since holes were drilled into each of these boxes, the cooling rate was limited by the amount of time required for the test article to fill with liquid nitrogen, not by the external dimensions of the package.

The maximum press forces measured during CryofractureSM of the test articles are shown in Table 3. These forces range from 60 tons to 854 tons, and average about 511 tons. However, these tonnages are misleading for determining the maximum force required to process test articles that contain soil, concrete, and asphalt because these materials build-up under the press tooling and cause it to "bottom-out." For example, both CD-9 and CD-10 were filled with carbon steel; but CD-9 showed a maximum tonnage of 426 tons while CD-10 (which was back-filled with soil) had a maximum tonnage twice that. In the case of CD-10, the presence of the soil caused the press to bottom-out against the soil after the contents had fractured. Therefore, 800 tons represents the load of bottoming-out against an incompressible material, whereas 400 tons represents the maximum load required to fracture the box and contents.

POST-TEST DEBRIS CHARACTERIZATION

Examples of the test article debris following CryofractureSM are shown in Figures 3 through 6. These photographs show processed boxes and drums containing metals, concrete, asphalt, paper, and cloth. In general, the drums CryofracturedSM on the initial compression in the press, but showed ductile deformation once they began to warm. The contents within the drums remained cold and continued to brittle fracture. Further size reduction of the drum exterior was then caused by the shearing due to the press tooling. The boxes all splintered during CryofractureSM, as shown by the debris in the photographs.

Sludge CryofracturedSM easily when it was frozen, but it became sticky once it began to warm. However, warming did not interfere with size reduction and would not have jeopardized a CryofractureSM processing plant. Once the tooling is optimized, the increase in the processing throughput rate will mitigate the problem by processing sludge packages completely before they warm.

The volume reduction measurements listed in Table 3 were determined by filling containers of known volume with test article debris. The percent of volume reduction is the volume of debris after CryofractureSM divided by the initial volume of the test article.

The volume reduction achieved for each test article varies, and is a direct function of the amount of void space in the test article contents prior to CryofractureSM. For example, CD-4, which was closely packed with wood and had little void space, had only a 4% volume reduction, whereas CD-5, which was filled with large pieces of concrete and asphalt and had voids due to the geometry of the pieces, showed a 39% volume reduction. A similar trend was shown for boxes filled with only metal (CD-7 through CD-9, which average a 27% volume reduction), compared to these same boxes back-filled with soil (CD-10 through CD-12, which averaged only 5% volume reduction).

No attempt was made to compress the debris prior to volume reduction measurements. But by visual inspection it was clear that these containers

Figure 3a. Box containing carbon steel [before (CD-7)].

Figure 3b. Box containing carbon steel [after (CD-7)].

Figure 4a. Box containing carbon and stainless steel [before (CD-8)].

Figure 4b. Box containing carbon and stainless steel [after (CD-8)].

Figure 5a. Drum containing paper [before (CD-2)].

Figure 5b. Drum containing paper [after (CD-2)].

Figure 6a. Drum containing mixed metals [before (CD-4)].

Figure 6b. Drum containing mixed metals [after (CD-4)].

could have easily been compacted to achieve more dramatic increases in volume reduction. However, compaction was beyond the scope of this study.

To determine size distribution following CryofractureSM, the test article debris was dumped onto a 6-in. screen. The 6-in. screen was then sifted, and all materials that did not fall through were weighed and the dimensions of the largest piece documented.

The amount of debris less than the 6-in. screen size ranged from 76% to 100% by weight, and averaged 90% overall. The largest piece of debris was 20-in. across. Generally, the larger pieces were caused by limitations of the pusher adaptor on the feed ram, which had not been designed to confine the waste container, and allowed some large pieces to bypass the press. In addition, manually transferring test articles by crane, and the relatively slow processing of the test articles through the feed system, allowed some packages to warm significantly prior to processing. Enhancements in the press tooling and feed system would reduce the size of these pieces. To further characterize the waste distribution following CryofractureSM, the debris from several test articles was sampled to determine what percentage would pass through a 3-in. screen. The results are shown in Table 4.

Table 4. Size reduction characterization

CD#	% Weight < 3 in.	% Weight < 6 in.
CD-5	80	100
CD-10	76	97
CD-11	94	99

The amount of LN₂ consumed during cryogenic cooling of the test articles was estimated during the demonstration. About 10 ft³ of LN₂ was used to cool each drum and about 15 ft³ was used to cool each box. These values were consistent with conservative LN₂ consumption estimates made during previous chemical demilitarization testing which showed that 1 lb of material at room temperature required 1 lb of LN₂ to cool to -320°F.

The amount of time required to process each test article in this demonstration is shown in Table 3, although these times are not indicative of the processing time at an actual CryofractureSM facility. Rare-earth tracers were collected on smears and on air filters and positive results were found on most samples. A qualitative and quantitative analysis of this sampling program is presented in Reference 3.

DISCUSSION OF CONVENTIONAL SHREDDERS

In 1983 an evaluation of shredders was performed for a waste processing facility at the INEL.⁴ The concept for this facility was to shred waste and waste containers at the same time to achieve a significant volume reduction. The report concluded high-speed shredders were unacceptable for the application because of dust generation, maintenance costs, capital cost, and large horse power requirements. The report focused on low-speed shredders.

Reference 4 evaluated four different shredders, SHREDPAX, SATURN, TRIPLE/S DYNAMICS, and BLOWER APPLICATION COMPANY. Tests performed showed that a SHREDPAX 80 hp shredder performed the best on the drums and waste boxes tested. With this justification, two SHREDPAX shredders were purchased and used in the Process Experimental Pilot Plant (PREPP) facility. An additional company, Komar has developed a completely new low-speed shredder design that uses an auger screw to force the material to be shredded between breaker bars. The auger/shredder design pulls material into it, eliminating the need for a pushing apparatus. The Komar shredders can also be purchased with air-tight doors over the hopper which would significantly aid in the containment of dust. A Komar single auger/shredder was chosen for the secondary shredder at the PREPP facility.

A possible negative aspect of the shredders is the cleaning of the internal hopper area and shredding teeth. This could be done with a vacuum system, but the effect of cleaning on production will be determined by the level of cleanliness. Because the shredder will only be used for containers it will likely never build up significant radiation levels, but it could build up dust. The nonradiation-based decision as to when to clean the hopper area could effect the overall processing time.

Komar demonstrated the capability of shredding a TX-4 overpack, a 4 x 4 x 8 ft plywood waste box, a 55-gallon drum with 90-mil liner, and an 83 gallon overpack drum. A TX-4 was chosen over a sand box or a M-III bin because it was determined to be the most rugged and thus likely the hardest to shred.

The plywood box was the first item processed by the 150 hp dual auger shredder. The shredder was effective. However, a 2 x 4 ft wooden brace from the shredded box remained suspended on the side of the hopper walls due to steel plate welded on the walls. These steel plates were designed to direct railroad tie waste into the augers. This problem would not occur on a waste handling unit, because the hopper walls would be vertical. Next, the empty drums were placed into the shredder. The augers easily shredded the drums. The machine processed both the drums and the plywood box in under 15 min. The doors of the shredder were opened and the material was allowed to fall out of the shredder. The largest piece left was from the 55-gal drum with poly liner and was only 17 in. long. Wood was shredded to approximately a 5-in. size. Next, the TX-4 (with top removed) was put in the shredder. The TX-4 overpack was made of 14-gauge sheet metal with 3\16 in., 2 x 2 in. angle iron for corner support. The augers immediately grabbed the box and deformed it considerably, but because of the low horse power, were not able to immediately shred the material. It required about 25 min for the machine to ball up the material and slowly take off smaller pieces of metal. After 25 min the pieces were small enough that they could fit into a 55-gal drum. After the box was processed, the lid was put in the shredder. The lid of the TX-4 was constructed of 14-gauge sheet with 1 x 2 in. solid bar stock as structure around the outside. Once the lid was placed so that the augers could grab it, the processing took between 10 and 15 min. to produce pieces that fit into a 55-gal drum.

Komar recommended a 400 hp dual auger machine for use on containers like the TX-4. This added horse power would allow the machine to shear the material rather than balling up the metal. The results produce smaller pieces in a faster time with less stress on the machine.

Komar claims to have developed machines for many applications in the hazardous waste field including machines that shred waste, mix it with cement and water, and extrude the mixture to a designated container. In addition, nitrogen sealed systems, explosion proof systems and systems designed for Zone 3 seismic requirements have been built.

The Komar engineers continue to develop their machines and systems to be of modular design so that replacement of parts is easier. This modular design

will also allow the hydraulic components to be moved outside of the containment cell, making access for repairs and maintenance easier. Komar also has the technical expertise to custom design their machines to meet specific customer requirements.

A cost estimate using the Komar shredder as the main tool (see Table 5) resulted in a capital cost of \$2.4 M, excluding building and facilities (see Reference 3). Assumptions used for this cost estimate are identical to a detailed cost estimate performed for the Cryofracture facility in the next section. Operating costs for the conventional Komar shredder range between \$25 per 55-gal drum with paper to \$101 per 4 x 4 x 8 ft box with metal. The building working volume for the conventional shredder is estimated at 65 ft wide by 90 ft long by 40 ft high by 10 ft below grade. For the Komar shredder system, 2160 tons of drums (containing paper) per year could be processed for \$506/ton and 43,200 tons of boxes (containing metal) per year could be processed for \$25/ton.

Table 5. Conventional shredder capital cost

System	Cost (K)
Input receiving and storage	84,000
Input interlock and conveyors	34,000
Pretreatment	807,000
Shredder	830,000
System product documentation	25,000
Output transfer and interlock	35,000
Output storage and transfer	44,000
System controls and data management	222,000
Closed circuit TVs	15,000
Radiation monitoring	48,000
System reentry	18,000
TOTAL	2,162,000
plus 10% spare parts	216,500
GRAND TOTAL	2,378,500

COST ESTIMATE FOR AN INEL CRYOFRACTURE FACILITY

This section presents a cost estimate for a full-scale operational CryofractureSM capability at the INEL. The previously discussed cost estimate for the conventional shredder uses the same cost basis as is used in this section covering the CryofractureSM facility.

The costs in this report include (a) the estimated capital costs of process equipment (excluding the costs of a building to house the equipment and excluding the cost of installing the equipment in the building) and (b) the estimated annual costs of operating and maintaining the facility (excluding normal building operation and utilities costs such as heating, ventilation, air conditioning, lighting, communications, etc.). Unit costs—in terms of estimated costs per drum, per box, per ton, and per cubic meter—are derived for each type of waste treated in the plant.

ASSUMPTIONS

The basis for this cost estimate are as follows:

- Plant operation is conducted at one shift/day, five days/week, less 10 holidays per year, equal to 250 working days/year, or 2,000 hours/year
- Scheduled plant maintenance is accomplished on weekends or overnight during scheduled plant down time and does not affect scheduled operating hours
- Plant availability is based upon 10% unscheduled downtime per year, yielding 90% uptime, equivalent to 225 operating days or 1,800 operating hours per year.

Plant capacity during uptime is set at 24 drums/hour and six boxes per hour, based upon the capacity of the CryofractureSM press and/or the shredder. This is consistent with reasonable capacities for other unit operations in the downsizing process.

COST ESTIMATE

Equipment Cost Estimate

Table 6 shows the estimated capital cost of applicable equipment in the Plant. As previously discussed, the cost of the building, utilities, and equipment delivery and installation is not included in these costs.

Operating Cost Estimate

Table 7 shows the estimated annual manpower costs for the Plant operation and maintenance. These costs were provided by EG&G Idaho as representative of fully loaded labor rates at INEL.

CONCLUSIONS

The following basic conclusions can be drawn from the results of this cost estimate:

- The cost of equipment required to carry out the CryofractureSM process is estimated to be about \$3.6 million (excluding building and installation costs)
- The building working volume required to carry out CryofractureSM is estimated at 65 wide x 130 long x 40 high x 10 ft below grade.
- Based on single-shift operation, the annual operating cost (personnel, materials, and spares) is estimated to range from \$1,285,000 (55-gal drums with paper only) to \$4,963,000 (4 x 4 x 8 ft boxes with metal only). On a cost-per-container basis, this equates to \$30 per drum and \$460 per box.
- Based on single-shift operation, at 90% plant availability, the maximum throughput is 24 55-gallon drums per hour (43,200 drums/yr) or six 4 x 4 x 8 ft boxes per hour, (10,800 boxes/yr)

Table 6. Capital cost for Cryofracture

System	Cost (K)
Input receiving and storage	84,000
Input interlock and conveyors	34,000
Pretreatment	1,377,000
Cryofracture press and feed ram	1,430,000
Product documentation	25,000
Output transfer and interlock	35,000
Output storage and transfer	44,000
Controls, data management	222,000
Closed circuit TVs	15,000
Radiation monitoring	48,000
Reentry operations	<u>18,000</u>
TOTAL	3,255,000
plus 10% spare parts	<u>326,500</u>
GRAND TOTAL Equipment Cost	3,581,500

Table 7. Cryofracture plant annual manpower costs

Staff Member	Labor Rate ^a	Hours/Year	Annual Cost \$
Operations			
1. Plant Superintendent	65	2,000	130,000
2. Receiving Operator	65	2,000	130,000
3. Receiving Technician	50	2,000	100,000
4. Receiving Technician	50	2,000	100,000
5. Control Room Foreman	65	2,000	130,000
6. Control Room Assistant	50	2,000	100,000
7. Shipping Operator	65	2,000	130,000
8. Shipping Technician	50	2,000	100,000
Total Operations			920,000
Maintenance			
1. Maintenance Mechanics	50	600	30,000
2. Maintenance Electrician	50	600	30,000
3. Maintenance Technician	50	600	30,000
4. Health Physicist	65	200	13,000
Total Maintenance			103,000
GRAND TOTAL MANPOWER			1,023,000

a. Fully loaded hourly rate prevailing at INEL.

- CryofractureSM head-end treatment of mixed-waste drums and boxes can be accomplished at reasonable costs, even with single-shift operation, probably allowing cost reductions in subsequent operations on the exposed, volume-reduced fractured material.
- CryofractureSM is most cost-effective on the high-density wastes (metals) and more costly on low-density packages (paper or cloth).
- The annual tonnage throughput of any of the mixed wastes is a direct function of the speed at which the cryopress can fracture a single unit (estimated to be 2.5 minutes per drum and 10 minutes per box in this report). Higher speeds on the press, however, may result in throughput limits elsewhere in the plant, such as in the robot or crane transfer operations.
- The cost of LN₂ is very significant and is directly related to the assumed LN₂ requirement per ton of mixed-waste throughput.
- Full automation with minimum human re-entry is a requirement for an effective CryofractureSM plant. However, the functional operations in the plant appear amenable to such automation.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The CryofractureSM demonstration has successfully confirmed that CryofractureSM is an effective size reduction process for simulated INEL waste forms. The following objectives of the test plan (see Reference 1) were accomplished:

- CryofractureSM of 12 test articles, six 55-gal drums and six boxes, with contents representing a variety of stored and buried waste forms
- Effective size reduction, reducing the volume by up to 47% and shredding the debris so that, on average 90% by weight passes through a 6-in. mesh
- Processing of materials which severely challenge conventional shredders, such as heavy structural pieces, cable, cloth, and aerosol cans.

The cost estimate for a CryofractureSM capability at the INEL shows that a fully-integrated robotics process line for CryofractureSM could be constructed at INEL for \$3.6 million. The plant could process up to 43,200 tons of waste (boxes of metal) per year, for \$115/ton of waste. A Cryofracture facility could also process 2160 tons of waste (drums containing paper) per year for \$595/ton of waste.

A conventional shredding capability could be constructed at the INEL for \$2.4 million. Additionally, the Komar system could process 43,200 tons of waste (boxes with metal) for \$25/ton. For the Komar shredder the 2160 tons of waste (drums containing paper) per year could be processed for \$506/ton. The conventional Komar shredder costs are cheaper for both equipment and operating costs primarily because of the liquid nitrogen costs. However, even though the KOMAR shredder cost estimate (using the same basis) is cheaper, the potential for fire and explosions due to potential pyrophorics and explosives makes this option a high-risk operation. Additionally, with a throughput of

24 drums per hour and/or 6 boxes per hour, the Cryofracture facility should process difficult waste faster than the conventional shredder. Unanticipated down time will be much higher for the conventional shredder because of the difficulty of shredding large objects. Although no provision was made in the cost estimate for the Komar system to mitigate the potential for explosion or fire, additional costs would have to be incurred to accomplish this. As an example, the waste may be soaked in LN₂ which would make the overall costs almost identical between Cryofracture and conventional shredding.

RECOMMENDATIONS

It is recommended that the CryofractureSM process be pursued as a means of size reducing INEL stored and buried waste forms. The CryofractureSM process is simple and rugged, can process a broad range of materials, and is well suited for fully robotics-automated design.

The facility and equipment used during this CryofractureSM demonstration was designed and developed for the processing of chemical agent munitions. Although the results were successful, optimization of the test equipment to adapt to INEL waste forms would significantly speed up the CryofractureSM processing rate. The next step in pursuing CryofractureSM for processing wastes at INEL is to perform an integrated demonstration at the NRT facility using a 100% robotics system and to prepare a conceptual design of a full-scale CryofractureSM production facility, including all the necessary features required to process the projected volumetric and tonnage throughput rates. This conceptual design would include:

- Facility, equipment, and automation requirements for the CryofractureSM plant
- A systems-integration study to show how CryofractureSM fits into INEL's overall waste management scheme
- Demonstration of decontamination, sorting, and classification systems using cryogenics, such as cryo-blasting (using either high pressure LN₂ jets or CO pellets for decontamination of the press, tooling, and handling systems), and float separation (where light-

weight combustibles float upon and metals sink in a LN_2 bath). The advantage of these systems is that materials can be decontaminated and sorted without creating additional waste streams.

REFERENCES

1. Denise Osborne et al., Test Plan for CryofractureSM Demonstration, Sampling, and Analysis, EGG-WTD-9780, July 1991.
2. Denise Osborne and Walter Scheib, Test Report for Cryofracture Demonstration, NRT 3001-5 Rev.1, September 1991.
3. Mike Winberg, Mike Ancho, Denise Osborne, Walter Scheib, Cryofracture Demonstration Program, EGG-WTD-9915, October 1991.
4. G. Ross Darnell and Wesley C. Aldrich, Low-Speed Shredder and Waste Shreddability Tests, EGG-2226, April 1983.

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