CRYOFRACTURE AS A TOOL FOR PREPROCESSING RETRIEVED BURIED AND STORED TRANSURANIC WASTE*

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ABSTRACT

This paper summarizes important features of an experimental demonstration of applying the Cryofracture process to size-reduce retrieved buried and stored transuranic-contaminated wastes. By size reducing retrieved buried and stored waste, treatment technologies such as thermal treatment can be expedited. Additionally, size reduction of the waste can decrease the amount of storage space required by reducing the volume requirements of storage containers. A demonstration program was performed at the Cryofracture facility by Nuclear Remedial Technologies for the Idaho National Engineering Laboratory. Cryofracture is a size-reducing process whereby objects are frozen to liquid nitrogen temperatures and crushed in a large hydraulic press. Materials at cryogenic temperatures have low ductility and are easily size-reduced by fracturing. Six 55-gallon drums and six 2 x 2 x 8 ft boxes containing simulated waste with tracers were subjected to the Cryofracture 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 Cryofracture 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 Cryofracture process was compared to conventional shredders and detailed cost estimates were established for construction of a Cryofracture facility at the Idaho National Engineering Laboratory.

INTRODUCTION

This paper presents a summary of the results of an experimental demonstration program that examined a technique called Cryofracture for size-reducing retrieved buried and stored transuranic waste. Cryofracture is being considered as a pretreatment size-reduction technique for use in processing transuranic-contaminated waste containerized in drums and boxes. The Cryofracture process involves cryogenically cooling the waste in liquid nitrogen, followed by fracturing and shearing these 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 (DOE) weapons complex sites is also contaminated with volatile organics which increases the probability of fire and explosion during conventional shredding processes; the cryogenic operation eliminates this probability.

This report first gives background information on how the Cryofracture process might be used to process retrieved transuranic waste at the Idaho National Engineering Laboratory (INEL). Discussed next are details of the testing program, including the test procedures and a description of the simulated wastes and containers subjected to the Cryofracture process. This is followed by a summary of the results of the Cryofracture testing. Then, a cost estimate for the Cryofracture shredding capability at the INEL is given. Finally, conclusions and recommendations for using the Cryofracture process throughout the DOE complex are presented.

BACKGROUND

Between 1952 and 1970 over 56,000 cubic meters of primarily Rocky Flats Plant (RFP)-generated transuranic waste was stored at the INEL in shallow land filled pits and trenches, which consisted of sludges, cloth, paper, metal, wood, concrete, and asphalt contaminated with micron-sized, oxidized particles of plutonium and americium. Additionally, there is another 56,000 cubic meters of RFP-generated waste stored aboveground at the INEL. Much of the waste from RFP is containerized in 55-gallon drums and 4 x 4 x 7 ft boxes. One of the options for the buried waste is to retrieve, treat, and dispose of the waste in a permanent disposal site. The aboveground stored waste could be treated and similarly disposed.

The Cryofracture 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. The process involves robotically manipulating the materials into 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 1,000 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

* Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Idaho Field Office, Contract DE-AC07-76ID01570.

below its nil-ductility temperature will cause the material to brittle fracture into shrads, analogous to the fracture of a ceramic pot.

THE NEED FOR SIZE REDUCED WASTES IN THE DOE COMPLEX AND THE ADVANTAGES OF CRYOFRACTURE

Candidate transuranic wastes at the INEL that could be processed in a Cryofracture 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. One of the main advantages of the Cryofracture 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.

TESTING PROGRAM

This section summarizes the Cryofracture facility and experimental procedure, and describes the simulated waste that was subjected to the Cryofracture process. The Cryofracture process testing program consisted of size reducing six 55-gallon drums and six 2 x 2 x 8 ft boxes containing simulated wastes.

CRYOFRACTURE FACILITY

Testing was performed by Nuclear Remedial Technologies at the Cryofracture prototype line in the General Atomics Laboratory at San Diego, California. The prototype line consisted of cryogenic baths for total immersion of the waste, a feed tunnel with a pusher adaptor to feed the waste through a 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 1-ton containers containing chemical agents. The bulk tooling could accommodate the 55-gallon drums containing wastes; however, the size of the boxes were reduced to 2 x 2 x 8 ft from the original planned for 4 x 5 x 8 ft (1). Scaling down did not compromise the test results because the stoke of the press via the tooling into the waste was independent of the height. Modifying the facility to accommodate the larger boxes is a simple task; however, budget constraints did not allow that option for this testing program. The operation to move the waste container into the cryogenic bath and then to the press was completed manually using overhead rigging.

SIMULATED WASTE MATERIAL

Simulated waste was placed in six 55-gal drums and six 2 x 2 x 8 ft boxes. The waste consisted of scrap cloth; paper; carbon steel items including I-beams, 6-8 in. valves, steel plates, and 1-in. diameter cables; stainless steel items including tanks and plates; asphalt and concrete chunks up to 2-ft in breadth; wood debris; and a special simulated sludge consisting of vegetable oil, Microcell E, and Oil Dri. Several of the boxes were backfilled with INEL soil to simulate retrieved buried waste. Rare-earth tracers were added to each container at a level equal to about 10 times background by weight.

TEST PROCEDURE

The test articles were cryogenically cooled in a liquid nitrogen (LN2) bath to reduce the temperature of the packaging and contents to -320°F. 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. As a pretest, the soak time to achieve cryogenic temperatures in the containers was determined experimentally. It was determined in these pretest experiments that the thermal soak time for containers without puncturing (to allow LN2 to penetrate the drum) was excessive (up to 17 hours for drums containing metals). Since the cooldown rate for the nonpunctured drum was found to be excessive, all test articles were punctured.

During the cryogenic soak in the LN2, the thermocouples in the test articles were sampled once every 10 seconds. The cryogenically-treated packages were then removed from the LN2 and placed into the ram tunnel. The ram pushed the test article into the press tooling, and the press was cycled to fracture and shear the front end of the test article. The ram and press were then alternated until the entire test article was fractured. Every stage of this procedure was videotaped and still photographed. A video summarizing the entire process for the various INEL waste was assembled.

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.

TEST RESULTS

The cryofracture process successfully size reduced all items that were processed. This included size reduction of many materials that severely challenge conventional shredders, such as large high-pressure valves, structural I-beams, aerosol cans, 1-in. dia. lifting cables, and electrical cables. Additionally, using the shearing action of the bulk tooling, stainless steel items were also size reduced.

The test results are summarized in Table I which presents both cooldown rates and Cryofracture data for six drums and six boxes containing simulated waste. Detailed results from the Cryofracture testing are found in Ref. 2.

As shown in Table I, the time required for punctured drums and boxes to cool to -320°F ranges from 12 minutes to 2.7 hours, and averages about 45 minutes. In general, this variation correlates well with the thermal inertia and void space of the contents being cooled. Cloth, having the least thermal capacity and greatest porosity, cools the fastest, while sludge, having the greatest bulk and least void space, requires the longest time to cool.

As shown in Table I, the cooling rate for a special 4 x 4 x 8 ft box filled with metal debris is about the same as for the downsized boxes. Since holes were drilled into each of these boxes, the cooling rate was limited by the amount of time

TABLE I

Test Results for Cryofracture Demonstration

Contents	Time to Reach -320°F (hr)	Max. Press. Force (tons)	Process Duration (min)	% Weight of Debris <6 in.	% Weight of Debris <3 in.	Largest Piece (in.)	Volume Reduction (%)
Drum-- Cloth	0.20	61	16	80	--	13	37
Drum-- Paper	1.20	753	21	90	--	11	--
Drum-- Sludge (calcium silicate, vegetable oil, Oil Dri)	2.70	382	22	95	--	12	0
Drum-- Metals	0.40	288	14	88	--	10	25
Drum-- Concrete/asphalt	1.30	808	18	100	80	--	39
Drum-- Wood	0.40	78	16	76	--	16	4
Box-- Carbon steel scrap	0.20	606	33	97	--	20	19
Box-- Carbon/stainless steel mix	0.25	247	27	98	--	16	47
Box-- Stainless steel scrap	0.23	427	25	90	--	12	16
Box-- Soil/carbon steel mix (3:1 by volume)	--	818	47	97	76	15	11
Box-- Soil/carbon & stainless mix (3:1 by volume)	0.70	854	47	99	94	12	4
Box-- Soil/stainless mix (3:1 by volume)	1.00	813	52	96	--	15	1
Box-- 4 x 4 x 8 special	0.23	--	--	--	--	--	--

required for the test article to fill with liquid nitrogen, not by the external dimensions of the package.

The maximum press forces measured during Cryofracture of the test articles is also shown in Table I. 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 the case labeled Box-Stainless steel Scrap and the case labeled Box-Soil/Stainless Mix contained stainless steel; however, the box with no soil showed a maximum tonnage of 426 tons, while the case with soil had a maximum tonnage almost twice that. The presence of the soil caused the press to bottom-out against the soil after the contents had fractured. Therefore, 813 tons represents the load of bottoming-out against an incompressible material, whereas 427 tons represents the maximum load required to fracture the box and contents.

The Cryofracture process was found to be an excellent size-reduction technique for all types of waste, including stainless steel items. An example of the effectiveness of the Cryofracture process is shown in Fig. 1 which compares the pretest material and the posttest debris for the case of Box-Carbon Steel Scrap. To determine size distribution following Cryofracture, 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 6-in. screen size ranged from 76 to 100% by weight, and averaged 90% overall (see Table I). The largest piece of debris was 20-in. across. Generally, these 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 items.

To further characterize the waste distribution following Cryofracture, the debris from several test articles was sampled to determine what percentage would pass through a 3-in. screen, as shown on Table I. For the three cases shown, the percentage of objects that would pass through a 3-inch screen by weight was between 76 and 94%.

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

The volume reduction achieved for each test article varied, and was a direct function of the amount of void space in the test article contents prior to Cryofracture. For example, Drum-wood, which was closely packed with wood and had little void space, had only a 4% volume reduction whereas Drum-Concrete/asphalt, 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 (which average a 27% volume reduction), compared to these same boxes back-filled with soil (which average only 5% volume reduction).

No attempt was made to compress the debris prior to volume reduction measurements; but by visual inspection if was clear that these containers could have easily been compacted to achieve more dramatic increases in volume reduction. However, compaction was beyond the scope of this study.

The amount of LN2 consumed during cryogenic cooling of the test articles was estimated during the demonstration. About 10 ft^3 of LN2 was used to cool each drum and about 15 ft^3 was used to cool each box. These values are 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 I, although these times are not indicative of the processing time at an actual Cryofracture facility. Reference 2 contains details of the testing program. Rare-earth tracers were collected on smears and air filters, and positive results were found on most samples. A qualitative and quantitative analysis of this sampling program is presented in Ref. 3.

Before

After

Fig. 1. Box containing carbon steel.

COST ESTIMATE

The cost estimate for a Cryofracture facility shows that a fully-integrated robotic process line for Cryofracture could be constructed at the 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 2,160 tons of waste (drums containing paper) per year for $595/ton of waste.

CONCLUSIONS

The Cryofracture demonstration has successfully confirmed that Cryofracture is an effective size-reduction process for simulated INEL waste forms. It can be recommended as a candidate technique for size reduction of retrieved buried and stored transuranic waste. Specific conclusions include:

1. Freezing time for the drums and boxes with waste is not excessive. By puncturing the containers, the time to reach -320°F varied between 0.2 and 2.7 hr. These freezing times are compatible with an expedient throughput using an assembly line of baths.
2. The Cryofracture process was successful in size reducing a range of expected waste materials including stainless steel tanks and plates. Over 90% of the waste was reduced to objects less than 6 in. and over 80% of the waste was reduced to objects less than 3 in.
3. The Cryofracture process allowed a volume reduction of debris of up to 47%.
4. The estimated costs of a Cryofracture capability at the INEL are not prohibitive. By size reducing retrieved buried and stored waste, many treatment processes are expedited and made more cost effective, including packaging, thermal treatment, and interrogation for transuranic inventory. Conventional shredders have the problems of fire and explosion which preclude their use without elaborate and costly deterrent schemes. In addition, these shredders cannot handle large, bulky objects or tempered steel. These modified conventional shredders would have to undergo an entire range of testing before judgement could be made on their capability.

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