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Radioactive Waste Shredding— Preliminary Evaluation

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Radioactive Waste Shredding—Preliminary Evaluation

EGG-MS-11147

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ABSTRACT

The critical constraints for sizing solid radioactive and mixed wastes for subsequent thermal treatment were identified via a literature review and a survey of shredding equipment vendors. The types and amounts of DOE radioactive wastes that will require treatment to reduce the waste volume, destroy hazardous organics, or immobilize radionuclides and/or hazardous metals were considered. The preliminary steps of waste receipt, inspection, and separation were included because many potential waste treatment technologies have limits on feedstream chemical content, physical composition, and particle size. Most treatment processes and shredding operations require at least some degree of feed material characterization. Preliminary cost estimates show that pretreatment costs per unit of waste can be high and can vary significantly, depending on the processing rate and desired output particle size.

ACKNOWLEDGMENT

This study was sponsored by the DOE Environmental Management Office of Technology Development (EM-50) to provide insight into the costs of radioactive waste preparation prior to treatment using conventional and innovative technologies. The study is part of a larger project entitled *Integrated Thermal Treatment Systems Study*.

SUMMARY

A literature review and a survey of shredding equipment vendors were performed to determine the critical constraints for sizing radioactive wastes for subsequent thermal treatment. Consideration was given to the types and amounts of DOE radioactive wastes that will require treatment to reduce the waste volume, destroy hazardous organics, or immobilize radionuclides and/or hazardous metals. Waste receipt, inspection, and separation were included in the investigation because many waste treatment technologies have limits on feedstream chemical content, physical composition, and particle size. These constraints, coupled with the nature of the wastes, dictate at least some degree of feed material separation.

Results and Conclusions

Low-speed shredders were identified as the best candidates because they can tolerate the widest variation in waste feedstreams, are least costly, and are least prone to operational problems. In the United States, a number of low-speed shredders have already been sold for radioactive waste processing.[a] However, commercial low-speed shredders reduce waste to 1 to 12 in. in size, too large for many proposed radioactive waste treatment technologies. For example, molten salt oxidation may require a maximum feed particle size of around 0.125 in. while supercritical water oxidation may require feed particle sizes in the range of 0.004 in. (100 μm). The literature and vendors agree that the only realistic process for achieving these small particle sizes is a low-speed shredding followed by high-speed sizing. Low-speed shredders can reduce the size of waste items from several feet to 1 to 12 in. The high-speed sizing process (typically hammer milling) can then reduce the size of this material to 0.125 in. or less.

Preparing most radioactive wastes for treatment by such technologies as molten salt oxidation, supercritical water oxidation, molten metal waste destruction, acid digestion, and gasification would probably include (a) initial receipt, inspection, and separation, (b) low-speed shredding, (c) separation (size, density, magnetic), (d) high-speed sizing, and (e) final separation. It is estimated that separating and shredding combustible waste to a size range of 1 to 12 in., at a rate of 1 ton per hour (T/hr), would cost around \$700/ton.[b] Reducing the maximum particle size to around 0.125 in. would more than double the total pretreatment cost, raising it to around \$1,600/ton. The incremental cost is attributed to the hammer mill, its inert gas system, and additional separation equipment. Reducing the particle size to <0.004 in. necessitates additional screening and recycling of waste through the hammer mill, and higher hammer mill operating and maintenance costs. Attaining a 0.004 in. particle size increases the pretreatment costs to around \$2,100/ton.

The processing rate also affects sizing costs. Reducing the processing rate by a factor of ten, from 1 to 0.1 T/hr, increases the pretreatment unit costs by a factor of 4 to 5 (to approximately \$2,700/ton for 1 to 12 in. particles, \$8,100/ton for <0.125 in. particles, and \$10,200/ton for <0.004 in.

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a. Personal Communication, Joyce Beasley, SSI Shredder Systems, to N. R. Soelberg, EG&G Idaho, January 15, 1994.

b. These cost estimates include (a) straight-line, no interest amortization of capital over 20 yr, (b) maintenance, (c) labor, and (d) power requirements; they do not include decommissioning.

particles). The costs increase dramatically for the lower processing rate because (a) most of the equipment is the same, merely run for a shorter time, so similar capital costs are spread over much less waste, and (b) operating time is reduced only by a factor of 3 even though the processing rate is decreased by a factor of 10.

Based on these preliminary cost estimates, waste pretreatment can be a significant portion of the total treatment cost, especially for treatment technologies requiring small particle sizes. The costs for pretreating wastes must be considered when evaluating any proposed waste treatment technology.

Recommendations

While low-speed shredders are readily available, demonstration of an integrated pretreatment system that includes waste receipt, inspection, handling, transport, sorting, and low-speed shredding is recommended. This demonstration should:

- Emphasize waste handling, characterization, and sorting. The degree of waste handling and sorting (and thus associated costs) can vary widely depending on regulatory, administrative, and treatment requirements.

- Consider cryogenic fracturing as an alternative to low-speed shredding because it would minimize the container opening step and provide nitrogen gas for the hammer mill.

- Be a cooperative effort with vendors of sizing and waste handling equipment to benefit from their expertise and reduce equipment costs. Several vendors contacted in this survey were willing to participate, to some degree, in such a demonstration of their equipment; all vendors were willing to demonstrate their equipment if purchase orders were placed. Demonstrations of purchased sizing system(s) for verifying and optimizing performance are performed by the vendors of those systems as part of their service. Final acceptance of the equipment should be contingent upon successful demonstration with surrogate wastes.

Radioactive waste sizing to achieve particle sizes <0.125 in. is less well developed. Areas of greatest uncertainty include (a) safety (fires, radionuclide and hazardous materials containment), (b) ability to handle a wide variety of waste types, and (c) capital and operating costs. Further work is recommended to:

- Develop a low-speed shredder capable of achieving <0.125 in. particle sizes without the safety, maintenance, and availability concerns common to high-speed mills.

- Demonstrate hammer milling to achieve <0.125 in. particle sizes. Emphasis should be on control of fires, radionuclide and hazardous materials containment, worker exposure, maintenance, and ability to process different types of wastes (especially waste materials prone to "fluff," agglomerate, or otherwise cause operational problems).

- Demonstrate reduction to small particle sizes as part of an integrated pretreatment process.

This should be done in cooperation with equipment vendors to help defray costs.

CONTENTS

FIGURES

TABLES

ACRONYMS

hph	horsepower-hour
ITTS	Integrated Thermal Treatment System
T/hr	Ton per hour
TRU	Transuranic

Radioactive Waste Shredding—Preliminary Evaluation

INTRODUCTION

Approximately 156,000,000 kg of low-level, mixed, and TRU-contaminated wastes are stored at DOE facilities nationwide.[1,2,a] These wastes, which include solids, liquids, and sludges, are packaged in a variety of steel drums, steel boxes, wooden boxes, and tanks. To store these wastes safely, permanently, and in the most cost-effective manner, they must be treated to (a) reduce their volume; (b) destroy, remove, or immobilize hazardous organics; and (c) immobilize radionuclides and hazardous metals.

A number of treatment technologies have been or are being evaluated for achieving these goals. Some technologies, such as rotary kiln incineration, plasma hearth melting, and graphite electrode arc melting, are capable of treating large items, including containerized wastes. However, most of the technologies currently under evaluation require that solid wastes be processed to reduce the particle size.[3,4,5,6] Treatment technologies to be evaluated during Fiscal Year 1994 (FY 94) within the Integrated Thermal Treatment System (ITTS)[b] Study at the INEL may include molten salt oxidation, supercritical water oxidation, molten metal waste destruction, entrained gasification, steam reforming, and acid digestion. All of these technologies, except for steam reforming, require relatively small feed particles. For example, molten salt oxidation may require feedstream particle sizes of 0.125 in. or less,[7,8,c] and supercritical water oxidation may require particle sizes <0.004 in.[d] for solid feed material.

This evaluation of size-reduction technologies suitable for waste treatment provides initial technical and cost information. The cost estimates are intended to be approximate; they furnish a general perspective on sizing and pretreatment costs for waste treatment technologies that cannot accommodate large as-received waste materials such as entire drums and boxes. These costs can be refined using more detailed process and equipment specifications. Recommendations are provided for further research, development, and demonstration to verify technical and cost issues related to sizing and pretreating radioactive wastes.

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a. Excluding the aqueous tank waste at the Hanford Site and the aqueous solar pond wastes at the Rocky Flats Plant.

b. Quapp, W. J., and F. Feizollahi, *Work Plan, Integrated Thermal Treatment System Study,* June 1993.

c. Brown, B. W., *Molten Salt Oxidation Process Description and Requirements (Draft),* January 1994.

d. Barnes, C. M. and N. R. Soelberg, *Feasibility of Treating DOE Mixed Waste Using Supercritical Water Oxidation (Draft),* December 1993.

PRELIMINARY DESIGN OF A SIZING AND PRETREATMENT SYSTEM

The preliminary block diagram of major pretreatment operations, shown in Figure 1, is based on input from various sizing equipment vendors and an architectural/engineering firm (Morrison-Knudsen Corporation). Sizing equipment vendors that were contacted included KOMAR Industries,[e] Triple-S Dynamics,[f] Saturn Manufacturing Company,[g] Williams Patent Crusher and Pulverizer Company,[h,i,j] and SSI Shredder Systems.[k] It was assumed that only solid wastes that are compatible with the candidate treatment processes will be shredded, i.e., combustibles. Noncombustible wastes are assumed to be separated from the combustible wastes at the time of retrieval. Not only are noncombustible wastes less amenable to treatment by the candidate technologies, they are also more difficult to shred with the combustible wastes. Typical combustible waste materials include organic sludges, absorbed organics, plastics, wood and wood products, and cloth. Sizes of individual waste items can vary widely; waste dimensions up to 4 × 4 × 4 ft (one-half the size of a 4 × 4 × 8 ft plywood waste box) were used here.

The first step in the pretreatment process is initial receipt, inspection, and separation. It was assumed that waste containers retrieved from storage have already been opened, emptied, and sorted; this step is receiving the wastes in bulk, inspecting the wastes to verify suitability for shredding and subsequent treatment, and separation of unsuitable waste items that were not removed earlier. It is expected that the containers must be opened and the contents sorted, rather than shredding unopened containers with their contents, because the feedstream size and composition requirements of most treatment processes are relatively stringent while the containerized waste is heterogeneous and poorly characterized.[9]

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e. Personal Communication, Mark Brick, KOMAR Industries, Inc. to N. R. Soelberg, EG&G Idaho, October 19, 1993 and October 28, 1993.

f. Personal Communication, Roger Hill, Triple-S Dynamics, to G. A. Reimann, EG&G Idaho, October 19, 1993.

g. Personal Communication, Glen Newton, Saturn Manufacturing Company, to N. R. Soelberg, EG&G Idaho, October 28, 1993 and December 20, 1993.

h. Personal Communication, Rob Williams, Williams Patent Crusher and Pulverizer Company, to N. R. Soelberg, EG&G Idaho, October 29, 1993.

i. Personal Communication, Harold Groves, Williams Patent Crusher and Pulverizer Company, to N. R. Soelberg, EG&G Idaho, December 21, 1993.

j. Personal Communication, Harold Grovers, Williams Patent Crusher and Pulverizer Company, to N. R. Soelberg, EG&G Idaho, January 24, 1994.

k. Personal Communication, Joyce Beasley, SSI Shredder Systems, to N. R. Soelberg, EG&G Idaho, January 15, 1994.

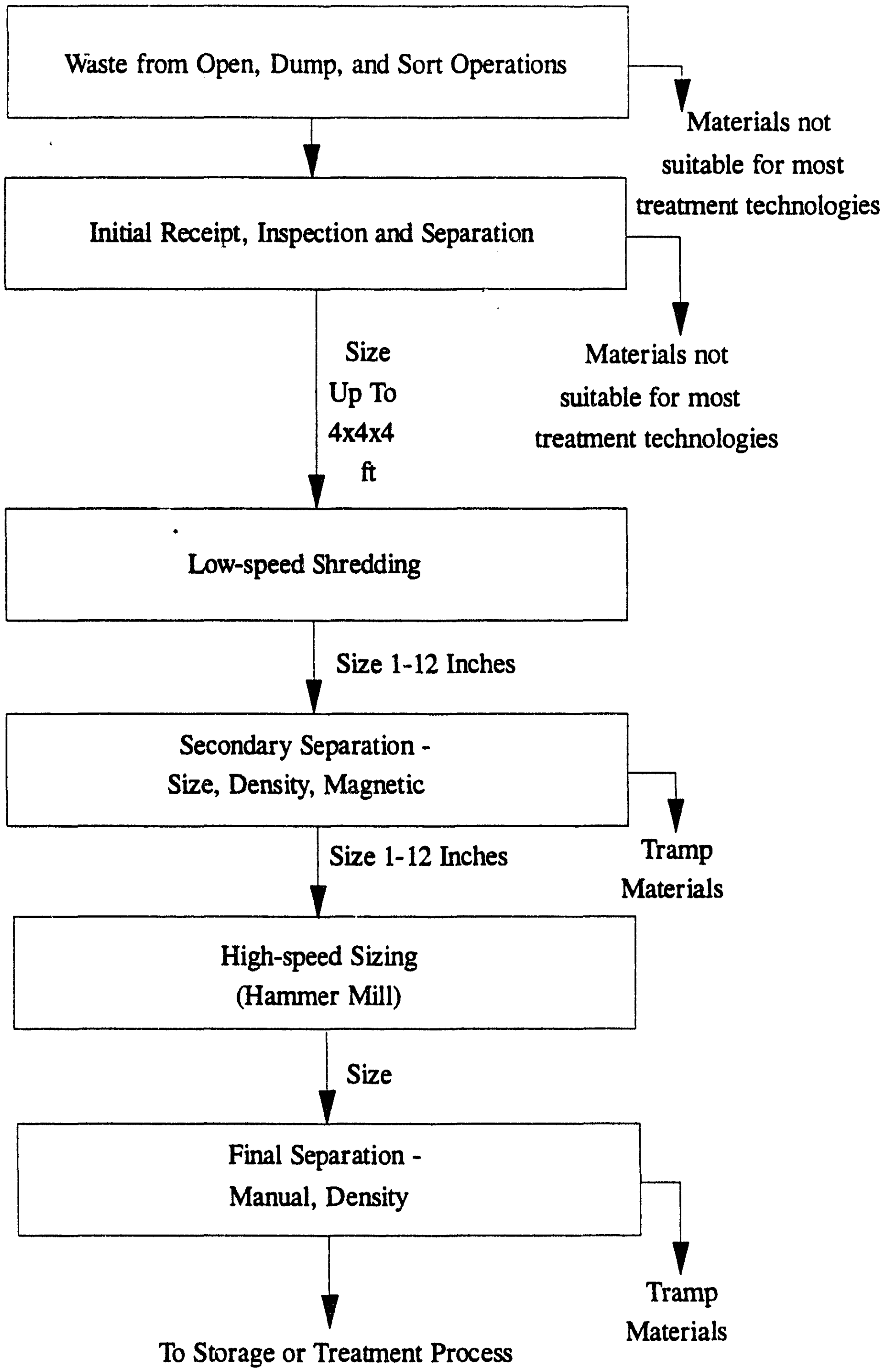

Figure 1. LL/Mixed/TRU waste pretreatment system.

The sorted combustible materials will be shredded to a particle size range of around 1 to 12 in. A shredder was selected for this step because, operating at low speeds, it can handle large items and a wide variety of wastes.[10,11,1] Sizing equipment that operates by fracturing hard, brittle materials, such as crushers, breakers, and many types of mills, is not well suited for sizing the softer, less brittle materials that constitute a large fraction of DOE wastes. Mills, such as hammer mills, are used for combustible wastes such as municipal wastes, but operate at much higher speeds and are prone to dust explosions, have higher capital and maintenance costs, and require more energy than low-speed shredders.

The low-speed shredding step will be followed by a second separation to remove metals and dense inert materials (e.g., bricks) that may damage the equipment in the next step, hammer milling. Hammer milling is necessary to reduce the maximum particle size from around 1 to 12 in. to 0.125 in. or less. Finally, density and magnetic separations may be used to further refine the waste stream for feeding into the treatment process.

All sizing equipment vendors and other sources concurred with the need for two sizing steps in series to achieve the design 0.125 in. maximum particle size. Vendors reported that the low-speed units typically require less power, have lower maintenance costs, are more reliable, and are safer to operate for combustible wastes than hammer mills. However, even multiple low-speed shredders in series are not capable of achieving the particle size necessary for some treatment technologies in a reasonable time. Thus, while the first sizing step should use a low-speed shredder, a high-speed unit was selected for the second sizing step.

High-speed units are susceptible to damage by hard items in the waste stream. Such damage in low-speed units is less common because they can reverse themselves when the torque exceeds preset limits, which allows removal of the potentially damaging item. Damage to high-speed units can best be reduced by rigorous separation of potentially damaging materials (e.g. metals) from the feed stream.

All sizing equipment vendors agreed there is a high potential for fire and explosions in high-speed units, especially when processing combustible materials. Fires in low-speed shredders are less common but can occur when processing highly volatile combustible materials. Inert atmospheres can be economically and effectively used to prevent fires and explosions in low-speed shredders. Inert atmospheres are less common for hammer mills because of the cost of the large volumes of inert gas needed--in high-speed systems for non-radioactive service, there is a cost trade-off between occasional fires and expensive inert gas systems. For this preliminary evaluation, it was assumed that an inert atmosphere is not necessary for the low-speed shredder, but is necessary for the high-speed unit. The costs, and hazards, associated with fires when treating radioactive and mixed wastes are significantly more prohibitive than the costs associated with the inert atmosphere. Nitrogen gas was assumed for the inert gas. While carbon dioxide or dry, relatively inert, offgas from the downstream treatment system may also be used to reduce the risk of fire, these options are not included in this evaluation. Calculations show that the amount of CO_2 that might be recovered from the offgas of the treated wastes would only provide about one-tenth of the inert gas needed for the hammer mill. Other

1. Personal Communication, G. R. Darnell, EG&G Idaho, to N. R. Soelberg, June 1992.

potential problems associated with using offgas for the milling atmosphere include excessive drying of the feed material and corrosion of the equipment.

According to sizing equipment vendors, municipal solid waste combustor facilities frequently use low-speed shredders. Some facilities, such as those using fluidized bed incineration, which requires more uniformly small particle sizes, use hammer mills. Fires are relatively common in these high-speed units if they do not employ systems to mitigate the fire potential.

The vendors also pointed out the high propensity for fines generation in hammer mills, which would necessitate costly control and containment measures f^r radioactive waste.

Cryogenic fracturing of containerized wastes is a potential alternative to the low-speed shredder. While cryogenic fracturing is not capable of achieving the design output particle size (<0.125 in.), it could be a ready source of nitrogen for the inert atmosphere for the hammer mill. Tests have shown that cryogenic fracturing can achieve an output particle size range of around 1 to 12 in.[12] Cryogenic fracturing can safely reduce the particle size of a wide variety of wastes and their wood or steel containers, so the container opening and initial sizing steps may be combined. However, the fractured materials still require inspection and separation, and these operations may be more difficult after containers that hold hazardous and difficult-to-handle materials are fractured. Although cryogenic fracturing has been tested for many types of waste materials, this technology has not yet been proven in full-scale waste treatment operations. While cryogenic fracturing has merit and should be considered when evaluating a detailed pretreatment system, it has been excluded from this evaluation.

KOMAR Industries is presently developing a low-speed "rotary shear finish granulator" that may be suitable for reducing the particle size of combustible DOE wastes to the 0.125-in. range. This device should be investigated when the design matures.

OUTPUT PARTICLE SIZE AND COST

The cost of size reduction depends on many factors, such as initial particle size, type and hardness of the material, desired output particle size range, processing rate, and the expected life of the processing plant. The actual output particle sizes will vary from micron-sized fines to some maximum size limit based on clearances within the sizing equipment and initial aspect ratios (length vs. width vs. height) of the feed material. Items with output sizes and aspect ratios larger than the desired limits are cycled through again or removed from the process.

Assumptions used in these cost estimates include:

- Waste feedstream: low-level, TRU, and/or mixed solid wastes removed from containers such as steel drums and wooden boxes in a prior "open, dump, and sort" step. Solid materials amenable to sizing and thermal treatment must be separated from other materials that are unsuitable for the thermal treatment selected. Acceptable solid wastes will be primarily combustible organics (plastics, wood and wood products, cloth, solidified sludges, etc.) Halogenated materials are also typically acceptable. Moisture contents and inert (noncombustible) contents of up to 20 wt% each should be expected.

- Shredder input particle size range: Fines (such as absorbents, sawdust, etc.) 0.1 in. and smaller, up to 4 x 4 x 4 ft.

- Shredder output particle size ranges: (a) 1 to 12 in. (typical of low-speed shredders), (b) $\leq$0.125 in. on any aspect (the limit for molten salt oxidation), and (c) fines $<$0.004 in. (the limit for supercritical water oxidation).

- Shredder processing rates: 0.1 and 1 T/hr average annual rates. These processing rates are based on a waste retrieval rate of 1 to 5 T/hr, with up to 20% of the retrieved wastes being suitable for treatment. The rate of 1 T/hr was used as the base case for equipment sizing and for estimating operating costs. Costs for processing waste at 0.1 T/hr are estimated by considering how capital and operating costs for the 1 T/hr case may be reduced. However, for the 0.1 and 1 T/hr rates, there is not a significant difference in equipment cost because the equipment size at these low process rates is dictated by the initial size of the feed material, rather than by the processing rate. (The process rates in this evaluation are very low compared to other shredding processes, such as those designed for municipal waste, that have process rates of 50 T/hr or more.)

- Facility lifetime: 20-yr, in agreement with assumptions for the ITTS study.

Estimated Costs for Sizing Waste to 1 to 12 in. Particle Size Range

To size the waste 1 to 12 in., which is suitable for most incineration and arc melting technologies, the hammer mill step and the final separation steps shown in Figure 1 are not necessary. This section addresses the costs through the secondary separation (after low-speed shredding).

Capital Costs for Shredding Waste to 1 to 12 in. Particle Size Range

Costs for shredding waste were estimated from amortized capital costs and annual operating costs. Estimated capital costs for shredding wastes at 0.1 to 1 T/hr average annual rates are shown in Table 1. Including all typical purchase, installation, building, indirect, and other costs, the total capital cost for a system designed to retrieve, separate, and shred wastes to 1 to 12 in. is approximately $10 million for these shredding rates.

Equipment purchase costs for the different unit operations were estimated based on information provided by vendors and previous materials handling estimates. Some of the costs given are averages of widely varying estimates.

The first step, Initial Receipt, Inspection, and Separation, includes a bulk solids dump hopper ($70,000), remote operations using master-slave manipulators ($160,000 each), and other equipment such as size reduction equipment ($360,000). (Size reduction equipment such as rotary and arc cutters may be included here.) Costs for these items were estimated for the proposed INEL Waste Characterization Facility and for the Integrated Thermal Treatment Systems study.[13] For a processing rate of 1 T/hr, at least two master-slave manipulators may be necessary. The total estimated purchase cost used in Table 1 for this step is $750,000.

The Low Speed Shredder step may actually include two shredder units, e.g., the KOMAR single primary screw shredder for initial sizing followed by a KOMAR injector unit to further reducing the material size and to feed waste to the next step. Other shredder manufacturers may specify only one low-speed shredder unit. Estimated low-speed shredder purchase costs range between $120,000 and $275,000. The high value of $275,000 was used as a conservative estimate.

The Secondary Separation step may use both manual and automated separation, as shown in Table 2. There will be significant materials handling equipment for transferring the waste from one unit operation to the next. Without detailed consideration of hoppers, belts, pneumatic systems, or other types of materials handling equipment, the purchase cost for this equipment was assumed to be 10% of the total estimated cost for the other equipment.

The total installed cost ($10 million) is about 7.4 times higher than the total purchase cost ($1.35 million). This is much higher than the installed cost versus purchase cost ratio for most commercial

Table 1. Capital costs ($) for waste sizing to 1-12 in. particle size at 0.1 to 1 T/hr.

Design/Cost Parameter	Receipt, Inspection, and Separation	Low-Speed Shredder	Secondary Separation	Materials Handling Equipment	Total
Equipment:					
Purchase Cost	750,000	275,000	199,000	122,400	1,346,400
Installation at 60%	450,000	165,000	119,400	73,440	807,840
Electrical at 30%	225,000	82,500	59,700	36,720	403,920
Mechanical at 30%	225,000	82,500	59,700	36,720	403,920
Instruments at 55%	412,500	151,250	109,450	67,320	740,520
Subtotal Equipment	**2,062,500**	**756,250**	**547,250**	**336,600**	**3,702,600**
Building	**340,000**	**170,000**	**170,000**	**170,060**	**850,000**
Installed Equipment and Building	**2,402,500**	**926,250**	**717,250**	**506,600**	**4,552,600**
Indirect at 29.1%	**699,128**	**269,539**	**208,720**	**147,421**	**1,324,807**
Total Construction Cost	**3,101,628**	**1,195,789**	**925,970**	**654,021**	**5,877,407**
Other Costs:					
Engineering, 18%	558,293	215,242	166,675	117,724	1,057,933
Proj. Mngmnt, 10%	310,163	119,579	92,597	65,402	587,741
Const. Mngmnt, 17%	527,277	203,284	157,415	111,184	999,159
Contingency, 25%	775,407	298,947	231,492	163,505	1,469,352
Total Capital Cost	**5,272,767**	**2,032,841**	**1,574,149**	**1,111,835**	**9,991,591**

Notes:

1. Equipment purchase cost estimates for retrieval and initial separation, low-speed shredder and secondary separation steps are based on information from shredder vendors.
2. Materials handling costs are estimated at 10% of total purchase cost.
3. Equipment, building, indirect, and other cost factors are from Fred Feizollahi, Morrison-Knudsen Corporation, November 2, 1993.
4. Building square feet estimated from footprint of equipment and costed at $1,700/ft2 for alpha containment.

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Table 2. Secondary separation step.

Separation Method	Purpose	Equipment Purchase Cost ($)
Manual Separation (manipulator)	Remote manipulation of waste items	160,000
Magnetic Drum	Remove ferrous metals	3,000
Eddy Current Vibrating Pan	Remove aluminum, copper and other slightly magnetic materials	30,000
Vibrating Screens	Remove materials not sufficiently size reduced to enter the downstream equipment	3,000
Density Table	Remove heavy, non-ferrous materials, e.g. glass, bricks, and concrete	3,000
Total		199,000

(non-DOE and nonnuclear) industries, which is around 3.1 to 4.3.[14,15,m] This ratio is also higher than the ratio for DOE and other government facilities of around 6×. The principal factor that has made this ratio higher than the typical value is the contingency of 25% of the total construction cost. Without the contingency, the ratio would be 6.3×.

Capital equipment costs for sizing waste to 1 to 12-in. output size at a rate of 10 T/hr are shown in Table 3. This processing rate enables the sizing facility to process waste at an *average* rate of 1 T/hr, while operating for a small portion of the time that a 1 T/hr facility must operate. While selecting the 10 T/hr equipment increases the capital costs, it can significantly reduce the operating costs. Compared to the 1 T/hr case shown in Table 1, capital costs for the Initial Receipt, Inspection and Separation equipment increase due (a) increasing the number of bulk solids dump hoppers from one to two ($70,000 each) and (b) increasing the number of master-slave manipulators from two to four ($160,000 each). The cost for the Low-speed Shredder step increases because (a) the capital cost is 1.7 times larger than the cost of the 1 T/hr shredding equipment, and (b) the footprint is 1.5 times larger. The footprint ratio of 1.5 was also used for the containment building needed for the other process steps.

For the 10 T/hr facility to operate only a fraction of the time, significant waste storage capacity will probably be necessary to enable a more continuous feed to the treatment process. It is assumed that the costs for additional storage capacity are already included in the cost increase for the Materials Handling Equipment, which is 10% of the other costs.

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m. Personal Communication, Fred Feizollahi, Morrison-Knudsen Corporation, to N. R. Soelberg, EG&G Idaho, November 2, 1993.

Table 3. Capital costs ($) for sizing waste to 1-12 in. particle size at 10 T/hr.

Design/Cost Parameter	Receipt, Inspection, and Separation	Low Speed Shredder	Secondary Separation	Waste Holding Areas	Materials Handling Equipment	Total
Equipment:						
Purchase Cost	1,140,000	460,000	338,000		193,800	2,131,800
Installation at 60%	684,000	276,000	202,800		116,280	1,279,080
Electrical at 30%	342,000	138,000	101,400		58,140	639,540
Mechanical at 30%	342,000	138,000	101,400		58,140	639,540
Instruments at 55%	627,000	253,000	185,900		106,590	1,172,490
Subtotal Equip.	**3,135,000**	**1,265,000**	**929,500**		**532,950**	**5,862,450**
Building	**510,000**	**261,800**	**261,800**	**1,020,000**	**261,800**	**2,315,400**
Installed Equip. and Building	**3,645,000**	**1,526,800**	**1,191,300**	**1,020,000**	**794,750**	**8,177,850**
Indirect at 29.1%	**1,060,695**	**444,299**	**346,668**	**296,820**	**231,272**	**2,379,754**
Total Construction Cost	**4,705,695**	**1,971,099**	**1,537,968**	**1,316,820**	**1,026,022**	**10,557,604**
Other Costs:						
Engineering, 18%	847,025	354,798	276,834	237,028	184,684	1,900,369
Proj. Mngmnt, 10%	470,570	197,110	153,797	131,682	102,602	1,055,760
Const. Mngmnt, 17%	799,968	335,087	261,455	223,859	174,424	1,794,793
Contingency, 25%	1,176,424	492,775	384,492	329,205	256,506	2,639,401
Total Capital Cost	**7,999,682**	**3,350,868**	**2,614,546**	**2,238,594**	**1,744,238**	**17,947,927**

Notes:

1. Equipment purchase cost estimates for retrieval and initial separation, low-speed shredder and secondary separation steps are based on information from sizing equipment vendors.
2. Materials handling costs are estimated at 20% of total purchase cost.
3. Equipment, building, indirect, and other cost factors are from Fred Feizollahi, Morrison-Knudsen Corporation, November 2, 1993.
4. Building square feet estimated from footprint of equipment and costed at $1,700/ft2 for alpha containment.

The total installed costs for the 10 T/hr facility, to be operated at an average process rate of 1 T/hr, is $18 million.

Operating Costs for Shredding Waste to 1 to 12 in. Particle Size Range

Estimated operating costs for sizing waste, at a rate of 1 T/hr, to an output particle size of 1 to 12 in. are given in Table 4. The total cost is approximately $2.5 million/yr, or $590/ton. The operating costs were estimated based on the power requirements, labor requirements, and maintenance requirements for the system. The actual time in operation, and thus the throughput, was calculated based on operation 24 hrs per day, 5 days per week, and 240 days per year, times the estimated system availability. (This is the same operating schedule used for the Integrated Thermal Treatment Systems Study.[13]) The estimated equipment availabilities for each process step, given in Table 4, assume reasonable downtime for scheduled and unscheduled maintenance. Power, labor, and maintenance costs for the shredder step were estimated using input from shredder manufacturers. Personnel listed in Table 4 are responsible for multiple operations in the system; automation of much of the equipment is assumed.

Estimated operating costs for shredding waste at a average annual rate of 0.1 T/hr to a particle size range of 1 to 12 in. are listed in Table 5. As noted earlier, the equipment for both process rates is the same. For this reason, it is assumed for Table 5 that there will only be one 8-hr daily shift, for 5 days per week, 240 days per year. It is assumed that, for an integrated treatment facility, the shredding system can stockpile sufficient shredded waste to supply a continuous 24-hr/day treatment process. Since the amount processed per year is assumed to be one-tenth of the amount processed in the 1 T/hr design, with the same availability ratios and 1 daily shift instead of 3, the actual processing rate is 600 lb/hr. The total estimated operating cost is $650,000/yr, or $1,600/ton.

The estimated costs for operating the 10 T/hr system at an annual average rate of 1 T/hr are shown in Table 6. For this estimate, the assumed total operating time for the system is 3 hr/day for 240 days per year. The actual time processing waste is calculated using the total operating time and the availability. The workers for this system will only be needed for one shift per day; it is assumed that they can allocate their time during the other 5 hours of their 8-hr shift to other, non-pretreatment, activities. Other scenarios, such as operating for one 8-hr shift every 3 days, or operating for one 24-hr period every 10 days, are also possible.

Operating power requirements for the 10 T/hr case are increased to reflect the larger equipment needs. Power requirements are a very small part of the total operating costs, and even though the larger equipment has larger power requirements during operating periods, the operating periods are shorter so the increase in power costs is not significant.

Estimated Costs for Sizing Waste to <0.125 in. Particle Size

For sizing waste to the output size range of <0.125 in. (required for molten salt oxidation, for example), the type of system portrayed in Figure 1 is necessary.

Table 4. Operating costs for sizing waste to 1-12 in. particle size at 1 T/hr.

Cost Item	Receipt, Inspection, and Separation	Low-Speed Shredder	Secondary Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	95	73
Operating hrs/year					4,211
Tons per year					4,211
Power, Hp	4	200	3	21	228
Power, $/year	440	21,988	330	2,276	25,034
Power, $/ton	0	5	0	1	6
Operators	2		1	1	4
Rad Con Tech					1
Supervisor					1
Total Personnel					6
Labor Cost:					
$/hr					325
$/year					1,872,000
$/ton					445
Maintenance Cost:					
Annual % of inst. cst	5	10	5	5	
Annual Cost	263,638	203,284	67,844	30,451	565,218
Cost, $/ton	63	48	16	7	134
Total Operating Cost					
$/year					**2,462,251**
$/ton					**585**

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance person, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because an operator may be responsible for multiple operations.
4. Cost parameters, including availability, power, labor requirements and maintenance costs, were obtained from shredder vendors and commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corporation, Jan. 5, 1994, and Carl Libsch, Aptus Incinerator Facility, Jan. 5, 1994).

Table 5. Operating costs for sizing waste to 1-12 in. particle size at 0.1 T/hr.

Cost Item	Receipt, Inspection, and Separation	Low-Speed Shredder	Secondary Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	95	73
Operating hrs/year					1,404
Tons per year					421
Actual rate while operating, lb/hr					600
Power, Hp	4	200	3	21	228
Power, $/year	147	7,329	110	759	8,345
Power, $/ton	0	17	0	2	20
Operators	2		1	1	4
Rad Con Tech					1
Supervisor					1
Total Personnel					6
Labor Cost, $/hr					325
Labor Cost, $/year					456,160
Labor Cost, $/ton					1,083
Maintenance Cost:					
Annual % of inst. cst	2	3	2	2	
Annual Cost, $/yr	87,879	67,761	22,615	10,150	188,406
Cost, $/ton	209	161	54	24	447
Total Operating Cost					
$/year					**652,910**
$/ton					**1,551**

Notes:
1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance person, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because an operator may be responsible for multiple operations.
4. Cost parameters, including availability, power, labor requirements and maintenance costs, were obtained from equipment vendors and commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corporation, Jan. 5, 1994, and Carl Libsch, Aptus Incinerator Facility, Jan. 5, 1994).

Table 6. Operating costs for sizing waste to 1-12 in. particle size with a 10 T/hr system at an average rate of 1 T/hr.

Cost Item	Receipt, Inspection, and Separation	Low-Speed Shredder	Secondary Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	95	73
Operating hrs/year					985
Tons per year					4,211
Power, Hp	8	300	6	62	376
Power, $/year	880	32,985	660	6,817	41,341
Power, $/ton	0	8	0	2	10
Operators	4		1	1	6
Rad Con Tech					1
Supervisor					1
Total Personnel					8
Labor Cost:					
$/hr					425
$/year					418,590
$/ton					99
Maintenance Cost:					
Annual % of inst. cst	5	10	5	5	
Annual Cost	399,984	335,087	112,349	49,902	897,322
Cost, $/ton	95	80	27	12	213
Total Operating cost					
$/year					**1,357,254**
$/ton					**322**

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance person, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because an operator may be responsible for multiple operations.
4. Cost parameters, including availability, power, labor requirements and maintenance costs, were obtained from equipment vendors and commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corporation, Jan. 5, 1994, and Carl Libsch, Aptus Incinerator Facility, Jan. 5, 1994).

Capital Costs for Sizing Waste to <0.125 in. Particle Size

The capital costs for the initial separation, low-speed shredding, and secondary separation steps are the same as those for the system described for sizing waste to 1 to 12 in. Additional capital costs are for the hammer mill, inert atmosphere system, final separation, and associated materials handling equipment. Estimated capital costs for this system to process wastes at a rate of 1 T/hr are shown in Table 7. Including all typical purchase, installation, building, indirect, and other costs, the total capital cost for a system designed to retrieve, separate, and size wastes to an output particle size range of <0.125 in. is approximately $12.6 million.

For an average annual rate of 0.1 T/hr, the estimated capital cost of sizing waste to <0.125 in. is $12.5 million (Table 8). This is slightly lower ($100,000) than the cost for the 1 T/hr case because the cost of the high-speed unit is lower.

The High Speed Mill step may include one hammer mill or two different high-speed units to optimize the input and output sizes and horsepower. Estimated purchase costs for the hammer mill range between $35,000–$70,000 for a processing rate of 1 T/hr. The conservatively high value of $70,000 was used for this estimate in Table 7. For 0.1 T/hr, this cost can be reduced to around $50,000 (see Table 8).

Capital equipment costs for waste sizing to 0.125-in. output size at a rate of 10 T/hr are shown in Table 9. Capital costs are increased as described in Table 3 for the Initial Receipt, Inspection and Separation step and the Low-speed Shredder step. Capital costs for the other steps are increased by a factor of 1.7, while the footprint and building costs are 1.5 times larger.

For the final separation step, it is assumed that manual inspection/separation ($160,000) and density separation ($3,000) are used. The equipment cost for this step is $163,000 for both processing rates.

Operating Costs for Sizing Waste to <0.125 in. Particle Size

Estimated operating costs for sizing waste, at a rate of 1 T/hr, to <0.125 in. particle size are given in Table 10. Because this system is more complex than that for sizing waste to 1 to 12 in., its availability is lower. Estimated operating hours per year for 3 shift/day, 5 day/week, 240 day/yr operation are reduced from around 4,200 to around 2,900. Operating costs are around $3.9 million per year, or $1,400/ton. The decreased annual availability also affects the amortized cost of capital per ton of waste, as discussed in Section 4.4.

Estimated operating costs for sizing waste, at an annual average rate of 0.1 T/hr, to <0.125-in. particle size are shown in Table 11. As in the 1 to 12 in. output case (Table 5), one daily shift (5 days per week, 240 days per year) is assumed. With the same availability ratio as for 1 T/hr, using 1 daily shift instead of 3, and a processing rate of 600 lb/hr while operating, the average annual output is 285 T. The total operating cost is $1.7 million/yr, or $5,900/ton.

Table 7. Capital costs ($) for sizing waste to <0 125 in. particle size at 1 T/hr.

Design/Cost Parameter	Receipt, Inspection, and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equip.	Total
Equipment:								
Purchase Cost	750,000	275,000	199,000	70,000	50,000	163,000	150,700	1,657,700
Installation at 60%	450,000	165,000	119,400	42,000	30,000	97,800	90,420	994,620
Electrical at 30%	225,000	82,500	59,700	21,000	15,000	48,900	45,210	497,310
Mechanical at 30%	225,000	82,500	59,700	21,000	15,000	48,900	45,210	497,310
Instruments at 55%	412,500	151,250	109,450	38,500	27,500	89,650	82,885	911,735
Subtotal Equip.	**2,062,500**	**756,250**	**547,250**	**192,500**	**137,500**	**448,250**	**414,425**	**4,558,675**
Building	**340,000**	**170,000**	**170,000**	**85,000**	**85,000**	**170,000**	**170,000**	**1,190,000**
Installed Equip. and Building	**2,402,500**	**926,250**	**717,250**	**277,500**	**222,500**	**618,250**	**584,425**	**5,748,675**
Indirect at 29.1%	**699,128**	**269,539**	**208,720**	**80,753**	**64,748**	**179,911**	**170,068**	**1,672,864**
Total Const. Cost	**3,101,628**	**1,195,789**	**925,970**	**358,253**	**287,248**	**798,161**	**754,493**	**7,421,539**
Other Costs:								
Engineering, 18%	558,293	215,242	166,675	64,485	51,705	143,669	135,809	1,335,877
Proj. Mngmnt, 10%	310,163	119,579	92,597	35,825	28,725	79,816	75,449	742,154
Const. Mngmnt, 17%	527,277	203,284	157,415	60,903	48,832	135,687	128,264	1,261,662
Contingency, 25%	775,407	298,947	231,492	89,563	71,812	199,540	188,623	1,855,385
Total Capital Cost	**5,272,767**	**2,032,841**	**1,574,149**	**609,029**	**488,321**	**1,356,873**	**1,282,638**	**12,616,617**

Notes:

1. Purchase costs for retrieval and initial separation, low-speed shredder and separation equipment are based on estimates from sizing equipment vendors.
2. Materials handling costs are estimated at 10% of total purchase cost.
3. Equipment, building, indirect, and other cost factors are from Fred Feizollahi, Morrison-Knudsen Corporation, November 2, 1993.
4. Building square feet estimated from footprint of equipment, and costed at $1,700/ft2 for alpha containment.
5. Costs for the nitrogen inerting system are based on estimates from Air Products and an estimated nitrogen demand (including recycle) of 1,500 acfm for a hammer mill, from Williams Patent Crusher and Pulverizer Co.

SHRED1.XLS

Table 8. Capital costs ($) for sizing waste to <0.125 in. particle size at 0.1 T/hr.

Design/Cost Parameter	Receipt, Inspection, and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equip.	Total
Equipment:								
Purchase Cost	750,000	275,000	199,000	50,000	50,000	163,000	148,700	1,635,700
Installation at 60%	450,000	165,000	119,400	30,000	30,000	97,800	89,220	981,420
Electrical at 30%	225,000	82,500	59,700	15,000	15,000	48,900	44,610	490,710
Mechanical at 30%	225,000	82,500	59,700	15,000	15,000	48,900	44,610	490,710
Instruments at 55%	412,500	151,250	109,450	27,500	27,500	89,650	81,785	899,635
Subtotal Equip.	**2,062,500**	**756,250**	**547,250**	**137,500**	**137,500**	**448,250**	**408,925**	**4,498,175**
Building	**340,000**	**170,000**	**170,000**	**85,000**	**85,000**	**170,000**	**170,000**	**1,190,000**
Installed Equip. and Building	**2,402,500**	**926,250**	**717,250**	**222,500**	**222,500**	**618,250**	**578,925**	**5,688,175**
Indirect at 29.1%	**699,128**	**269,539**	**208,720**	**64,748**	**64,748**	**179,911**	**168,467**	**1,655,259**
Total Const. Cost	**3,101,628**	**1,195,789**	**925,970**	**287,248**	**287,248**	**798,161**	**747,392**	**7,343,434**
Other Costs:								
Engineering, 18%	558,293	215,242	166,675	51,705	51,705	143,669	134,531	1,321,818
Proj. Mngmnt, 10%	310,163	119,579	92,597	28,725	28,725	79,816	74,739	734,343
Const. Mngmnt, 17%	527,277	203,284	157,415	48,832	48,832	135,687	127,057	1,248,384
Contingency, 25%	775,407	298,947	231,492	71,812	71,812	199,540	186,848	1,835,858
Total Capital Cost	**5,272,767**	**2,032,841**	**1,574,149**	**488,321**	**488,321**	**1,356,873**	**1,270,567**	**12,483,838**

Notes:

1. Purchase costs for retrieval and intial separation, low-speed shredder and separation equipment are based on estimates from sizing equipment vendors.
2. Materials handling costs are estimated at 10% of total purchase cost.
3. Equipment, building, indirect, and other cost factors are from Fred Feizollahi, Morrison-Knudsen Corporation, November 2, 1993.
4. Building square feet estimated from footprint of equipment, and costed at $1,700/ft2 for alpha containment.
5. Costs for the nitrogen inerting system are based on estimates from Air Products and an estimated nitrogen demand (including recycle) of 1,500 acfm for a hammer mill, from Williams Patent Crusher and Pulverizer Co.

SHRED5.XLS

Table 9. Capital costs ($) for sizing waste to <0.125 in. with a 10 T/hr system at an averate rate of 1 T/hr.

Design/Cost Parameter	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	High Speed Shredder	Nitrogen Inerting System	Final Separation	Materials Handling Equip.	Total
Equipment:								
Purchase Cost	1,140,000	460,000	338,000	119,000	85,000	277,100	241,910	2,661,010
Installation at 60%	684,000	276,000	202,800	71,400	51,000	166,260	145,146	1,596,606
Electrical at 30%	342,000	138,000	101,400	35,700	25,500	83,130	72,573	798,303
Mechanical at 30%	342,000	138,000	101,400	35,700	25,500	83,130	72,573	798,303
Instruments at 55%	627,000	253,000	185,900	65,450	46,750	152,405	133,051	1,463,556
Subtotal Equip.	**3,135,000**	**1,265,000**	**929,500**	**327,250**	**233,750**	**762,025**	**665,253**	**7,317,778**
Building	**510,000**	**261,800**	**261,800**	**127,500**	**127,500**	**261,800**	**261,800**	**1,812,200**
Installed Equip. and Building	**3,645,000**	**1,526,800**	**1,191,300**	**454,750**	**361,250**	**1,023,825**	**927,053**	**9,129,978**
Indirect at 29.1%	**1,060,695**	**444,299**	**346,668**	**132,332**	**105,124**	**297,933**	**269,772**	**2,656,823**
Total Const. Cost	**4,705,695**	**1,971,099**	**1,537,968**	**587,082**	**466,374**	**1,321,758**	**1,196,825**	**11,786,801**
Other Costs:								
Engineering, 18%	847,025	354,798	276,834	105,675	83,947	237,916	215,428	2,121,624
Proj. Mngmnt, 10%	470,570	197,110	153,797	58,708	46,637	132,176	119,682	1,178,680
Const. Mngmnt, 17%	799,968	335,087	261,455	99,804	79,284	224,699	203,460	2,003,756
Contingency, 25%	1,176,424	492,775	384,492	146,771	116,593	330,440	299,206	2,946,700
Total Capital Cost	**7,999,682**	**3,350,868**	**2,614,546**	**998,040**	**792,835**	**2,246,989**	**2,034,602**	**20,037,562**

Notes:

1. Purchase costs for retrieval and initial separation, low-speed shredder and separation equipment are based on estimates from sizing equipment vendors.
2. Materials handling costs are estimated at 10% of total purchase cost.
3. Equipment, building, indirect,and other cost factors are from Fred Feizollahi, Morrison-Knudsen Corporation, November 2, 1993.
4. Building square feet estimated from footprint of equipment, and costed at $1,700/ft2 for alpha containment.
5. Costs for the nitrogen inerting system are based on estimates from Air Products and an estimated nitrogen demand (including recycle) of 1,500 acfm for a hammer mill, from Williams Patent Crusher and Pulverizer Co.

SHRED110.XLS

Table 10. Operating costs for sizing waste to <0.125 in. particle size at 1 T/hr.

Cost Item	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	75	95	95	95	49
Operating hrs/year								2,850
Tons per year								2,850
Power, Hp	4	200	3	225	5	3	44	484
Power, $/year	298	14,883	223	16,744	372	223	3,274	36,018
Power, $/ton	0	5	0	6	0	0	1	13
Operators	2		1	1		1	1	6
Rad Con Tech								1
Supervisor								1
Total Personnel								8
Labor Cost, $/hr								425
Labor Cost, $/year								2,448,000
Labor Cost, $/ton								859
Maintenance Cost:								
Annual % of inst. cst	5	10	5	15		5	5	
Annual Cost	263,638	203,284	78,707	91,354		67,844	30,451	735,279
Cost, $/ton	93	71	28	32		24	11	258
N2 System Fee								
$/year					48,000			48,000
$/ton					17			17
N2 Cost, $/year					598,525			598,525
N2 Cost, $/ton					210			210
Total Operating Cost								
$/year								3,865,822
$/ton								1,356

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance persons, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because of the likelihood of responsibilities of a single operator for multiple operations.
4. Availability, power, labor requirements and maintenance costs were obtained from equipment vendors and from commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corp., January 5, 1994 and Carl Libsch, Aptus Incinerator Facility, January 5, 1994).
5. Nitrogen system costs based on verbal quotes from Air Products and an estimated nitrogen demand (including some recycle) of 1,500 acfm for a hammer mill, based on estimates from Williams Patent Crusher Co.

SHRED3.XLS

Table 11. Operating costs for sizing waste to <0.125 in. particle size at 0.1 T/h.

Cost Item	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	75	95	95	95	49
Operating hrs/year								950
Tons per year								285
Actual rate while operating, lb/hr								600
Power, Hp	4	200	3	110	5	3	33	358
Power, $/year	99	4,961	74	2,729	124	74	806	8,868
Power, $/ton	0	17	0	10	0	0	3	31
Operators	2		1	1		1	1	6
Rad Con Tech								1
Supervisor								1
Total Personnel								8
Labor Cost, $/hr								425
Labor Cost, $/year								1,190,000
Labor Cost, $/ton								4,175
Maintenance Cost:								
Annual % of inst. cst	2	3	2	5		2	2	
Annual Cost, $/yr	87,879	67,761	26,236	30,451	0	22,615	10,150	245,093
Cost, $/ton	308	238	92	107	0	79	36	860
N2 System Fee								
$/year					48,000			48,000
$/ton					168			168
N2 Cost, $/year					199,508			199,508
N2 Cost, $/ton					700			700
Total Operating Cost								
$/year								1,691,470
$/ton								5,935

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance persons, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because of the likelihood of responsibilities of a single operator for multiple operations.
4. Availability, power, labor requirements and maintenance costs were obtained from sizing equipment vendors and from commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corp., January 5, 1994 and Carl Libsch, Aptus Incinerator Facility, January 5, 1994).
5. Nitrogen system costs based on verbal quotes from Air Products and an estimated nitrogen demand (including some recycle) of 1,500 acfm for a hammer mill, based on estimates from Williams Patent Crusher Co.

SHRED7.XLS

The estimated operating costs for sizing waste to <0.125-in. at an annual average rate of 1 T/hr, using a 10 T/hr process operated for a fraction of the time, are shown in Table 12.

Estimated Costs for Sizing Waste to <0.004 in. Particle Size

Achieving extremely small particles, <0.004 in., is very difficult with fibrous materials such as wood, paper, and cloth because these materials tend to "fluff". However, such small particles may be necessary for some treatment technologies, e.g. supercritical water oxidation. Except for fluffing, sizing equipment vendors indicate that the main difference between sizing waste to ~0.125 in. and to <0.004 in. is in the design and operation of the hammer mill. An output screen with smaller apertures limits the output particle size from the mill, but results in a larger inventory of waste material in the mill. This significantly increases the power and maintenance requirements and can also increase the equipment size requirements. The unit operations of the pretreatment system are unchanged.

For hammer mills, a processing rate of 1 T/hr is relatively low. For the processing rates considered, 0.1 and 1 T/hr, capital costs for sizing waste to an output size of <0.004 in. will not change significantly from capital costs estimated for sizing waste to <0.125 in. However, the power requirements, maintenance costs, inert gas costs, and downtime for the hammer mill will increase, and annual availability will decrease. It is assumed that the power requirements will increase to 200 hph/ton. Annual maintenance costs will increase from 15 to 20% of the purchase cost. Annual availability will decrease from 75% to 65%. The nitrogen usage cost per year is assumed to double for the 1 T/hr case, from $870,000/yr to $1.7 million/yr, because of the increase in material recycling. The operating costs for the 1 T/hr case are shown in Table 13, and the operating costs for the 0.1 T/hr rate are shown in Table 14. The estimated operating costs for sizing waste to <0.004 in. at an annual average rate of 1 T/hr , using a 10 T/hr process operated for a fraction of the time, are shown in Table 15.

Combined Capital and Operating Costs

The combined capital and operating costs for sizing DOE combustible wastes to the output sizes of 1 to 12 in., <0.125 in., and <0.004 in. are shown in Table 16 and Figure 2. The capital costs are amortized over 20 years. Capital costs per ton were calculated using the estimated tons per year processed in each scenario. Because the processing rate for each scenario is different, the total amount processed in 20 years for each scenario is also different. In 20 operating years at a process rate of 1 T/hr, over 84,000 tons might be reduced to 1 to 12 in. output size range, but only 49,000 tons to <0.004 in. This is because of fewer available operating hours for the more complex, maintenance-intensive step of sizing waste to <0.004 in. The capital costs range from 12 to 17% of the total cost for the 1 T/hr case, while capital costs account for 26–43% of the total for the 0.1 T/hr case. Operating costs account for the remainder of the costs for each case.

It should be emphasized that these costs are rough estimates; broad assumptions were made based on best input from equipment manufacturers and other sources. To verify that these estimates were reasonable, the approximate costs for shredding at two commercial waste treatment operations were obtained for comparison. The Aptus Incinerator Facility in Tooele County, Utah and the Alberta Special Waste Management Corporation operate rotary kilns for incinerating combustible commercial

Table 12. Operating costs for sizing waste to <0.125 in. with a 10 T/hr system at an average rate of 1 T/hr.

Cost Item	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	75	95	95	95	49
Operating hrs/year								1,455
Tons per year								4,211
Power, Hp	4	200	3	225	5	3	44	484
Power, $/year	440	21,990	330	24,739	550	330	4,838	53,215
Power, $/ton	0	5	0	6	0	0	1	13
Operators	4		1	1		1	1	8
Rad Con Tech								1
Supervisor								1
Total Personnel								10
Labor Cost, $/hr								525
Labor Cost, $/year								763,926
Labor Cost, $/ton								181
Maintenance Cost:								
Annual % of inst. cst	5	10	5	15		5	5	
Annual Cost	263,638	203,284	78,707	91,354		67,844	30,451	735,279
Cost, $/ton	63	48	19	22		16	7	175
N2 System Fee								
$/year					48,000			48,000
$/ton					11			11
N2 Cost, $/year					305,570			305,570
N2 Cost, $/ton					73			73
Total Operating Cost								
$/year								1,905,991
$/ton								453

Notes:
1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance persons, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because of the likelihood of responsibilities of a single operator for multiple operations.
4. Availability, power, labor requirements and maintenance costs were obtained from vendors and from commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corp., January 5, 1994 and Carl Libsch, Aptus Incinerator Facility, January 5, 1994).
5. Nitrogen system costs based on verbal quotes from Air Products and an estimated nitrogen demand (including some recycle) of 1,500 acfm for a hammer mill, based on estimates from Williams Patent Crusher Co.

SHRED310.XLS

Table 13. Operating costs for sizing waste to 0.004 in. particle size at 1 T/hr.

Cost Item	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	65	95	95	95	43
Operating hrs/year								2,470
Tons per year								2,470
Power, Hp	4	200	3	200	5	3	42	457
Power, $/year	258	12,899	193	12,899	322	193	2,677	29,442
Power, $/ton	0	5	0	5	0	0	1	12
Operators	2		1	1		1	1	6
Rad Con Tech								1
Supervisor								1
Total Personnel								8
Labor Cost, $/hr								425
Labor Cost, $/year								2,448,000
Labor Cost, $/ton								991
Maintenance Cost:								
Annual % of inst. cost	5	10	5	20		5	5	
Annual Cost	263,638	203,284	78,707	121,806		67,844	30,451	765,731
Cost, $/ton	107	82	32	49		27	12	310
N2 System Fee								
$/year					48,000			48,000
$/ton					19			19
N2 Cost, $/year					1,197,051			1,197,051
N2 Cost, $/ton					485			485
Total Operating Cost								
$/year								4,488,223
$/ton								1,817

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance persons, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because of the likelihood of responsibilities of a single operator for multiple operations.
4. Availability, power, labor requirements and maintenance costs were obtained from sizing equipment vendors and from commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corp., January 5, 1994 and Carl Libsch, Aptus Incinerator Facility, January 5, 1994).
5. Nitrogen system costs based on verbal quotes from Air Products and an estimated nitrogen demand (including some recycle) of 1,500 acfm for a hammer mill, based on estimates from Williams Patent Crusher Co.

SHRED100.XLS

Table 14. Operating costs for sizing waste to 0.004 in. particle size at 0.1 T/h.

Cost Item	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	65	95	95	95	43
Operating hrs/year								823
Tons per year								247
Actual rate while operating, lb/hr								500
Power, Hp	4	200	3	200	5	3	42	457
Power, $/year	86	4,300	64	4,300	107	64	892	9,814
Power, $/ton	0	17	0	17	0	0	4	40
Operators	2		1	1		1	1	6
Rad Con Tech								1
Supervisor								1
Total Personnel								8
Labor Cost, $/hr								425
Labor Cost, $/year								1,190,000
Labor Cost, $/ton								4,818
Maintenance Cost:								
Annual % of inst. cost	2	3	2	7		2	2	
Annual Cost, $/yr	87,879	67,761	26,236	40,602		22,615	10,150	255,244
Cost, $/ton	356	274	106	164		92	41	1,033
N2 System Fee								
$/year					48,000			48,000
$/ton					194			194
N2 Cost, $/year					399,017			399,017
N2 Cost, $/ton					1,615			1,615
Total Operating Cost								
$/year								1,902,074
$/ton								7,700

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance persons, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because of the likelihood of responsibilities of a single operator for multiple operations.
4. Availability, power, labor requirements and maintenance costs were obtained from sizing equipment vendors and from commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corp., January 5, 1994 and Carl Libsch, Aptus Incinerator Facility, January 5, 1994).
5. Nitrogen system costs based on verbal quotes from Air Products and an estimated nitrogen demand (including some recycle) of 1,500 acfm for a hammer mill, based on estimates from Williams Patent Crusher Co.

SHRED9.XLS

Table 15. Operating costs for sizing waste to 0.004 in. with a 10 T/hr system at an average rate of 1 T/hr.

Cost Item	Receipt, Inspection and Separation	Low-Speed Shredder	Secondary Separation	Hammer Mill	Nitrogen Inerting System	Final Separation	Materials Handling Equipment	Total
Availability, %	90	90	95	65	95	95	95	43
Operating hrs/year								1,679
Tons per year								4,211
Power, Hp	8	300	6	400	10	6	84	814
Power, $/year	880	32,985	660	43,980	1,099	660	9,236	89,499
Power, $/ton	0	8	0	10	0	0	2	21
Operators	4		1	1		1	1	8
Rad Con Tech								1
Supervisor								1
Total Personnel								10
Labor Cost, $/hr								525
Labor Cost, $/year								881,453
Labor Cost, $/ton								209
Maintenance Cost:								
Annual % of inst. cost	5	10	5	20		5	5	
Annual Cost	263,638	203,284	78,707	121,806		67,844	30,451	765,731
Cost, $/ton	63	48	19	29		16	7	182
N2 System Fee								
$/year					48,000			48,000
$/ton					11			11
N2 Cost, $/year					1,197,051			1,197,051
N2 Cost, $/ton					284			284
Total Operating cost								
$/year								2,981,733
$/ton								708

Notes:

1. Energy cost at $0.035/kWh.
2. Labor rates: $50/hr for operators, maintenance persons, and radiation control technician; $75/hr for supervisor.
3. Labor rates for individual operations are not estimated because of the likelihood of responsibilities of a single operator for multiple operations.
4. Availability, power, labor requirements and maintenance costs were obtained from sizing equipment vendors and from commercial waste treatment operations (Mark Polet, Alberta Special Waste Management Corp., January 5, 1994 and Carl Libsch, Aptus Incinerator Facility, January 5, 1994).
5. Nitrogen system costs based on verbal quotes from Air Products and an estimated nitrogen demand (including some recycle) of 1,500 acfm for a hammer mill, based on estimates from Williams Patent Crusher Co.

SHD10010.XLS

Table 16. Total estimated costs for waste sizing.

	Output Particle Size								
	1-12 in.			<0.125 in.			0.004 in.		
Cost Item	0.1 T/h	1 T/hr	10 T/hr Rate, 1 T/h Avg. Throughput	0.1 T/h	1 T/hr	10 T/hr Rate, 1 T/h Avg. Throughput	0.1 T/hr	1 T/hr	10 T/hr Rate, 1 T/h Avg. Throughput
Capital Cost, $	9,991,591	9,991,591	17,947,927	12,483,838	12,616,617	20,037,562	12,483,838	12,616,617	20,037,562
Available Operating hrs/yr	1,404	4,211	576	950	2,850	576	823	2,470	576
Available Operating hrs/20 yrs	28,071	84,214	11,520	19,001	57,002	11,520	16,467	49,402	11,520
Waste Processed, T/20 yrs	8,421	84,214	84,220	5,700	57,002	84,220	4,940	49,402	84,220
Capital Cost, $/ton	1,186	119	213	2,190	221	238	2,527	255	238
Operating Cost, $/ton	1,551	585	322	5,935	1,356	453	7,700	1,817	708
Total Cost, $/ton	2,737	703	535	8,125	1,578	691	10,227	2,072	946

SHREDSUM.XLS

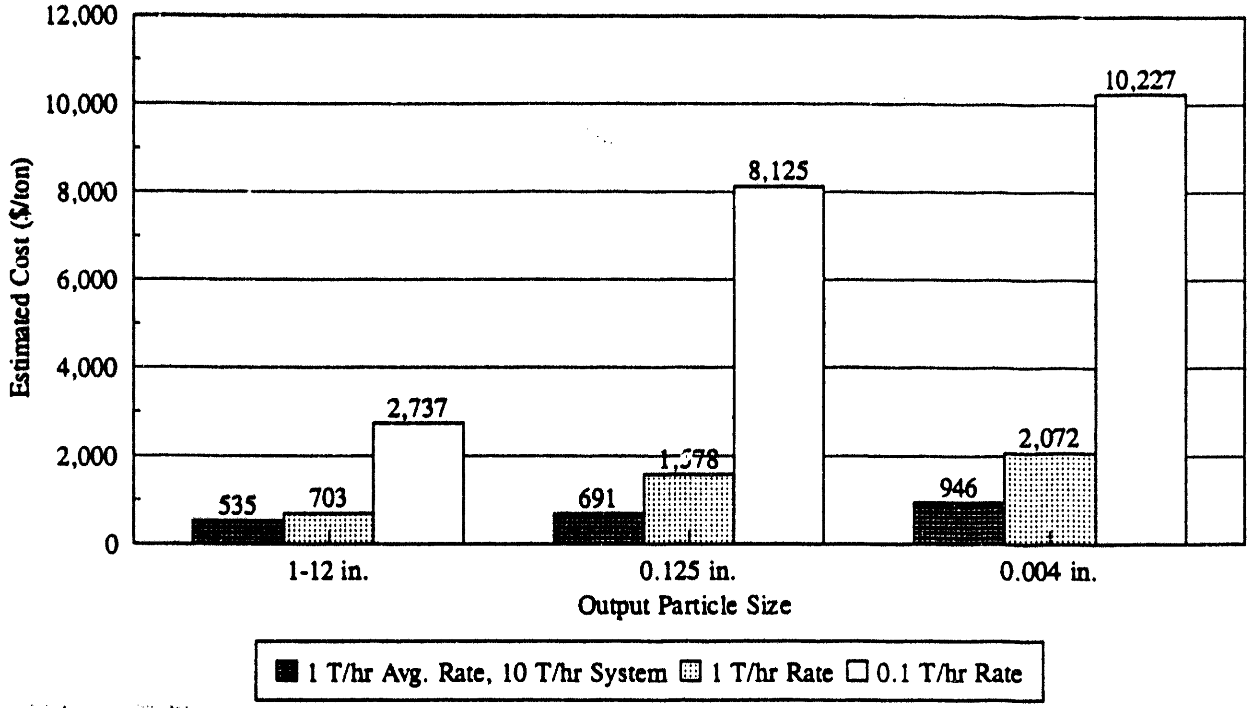

Figure 2. Estimated costs for waste sizing.

wastes. Both facilities use low-speed shredding for sizing waste before incineration. Their output size ranges are similar to the 1 to 12-in. range of this study, although their processing rates can be higher than 1 T/hr. General operations, labor, and maintenance are similar to the assumptions of this study. For these commercial facilities, operating costs for shredding are estimated at $100/ton. Additional estimated costs for more rigorous waste handling and sorting, alpha containment, and other requirements for a DOE facility can significantly increase this cost to near the $700/ton range estimated in this study for sizing waste to an output particle size of 1 to 12 in.

CONCLUSIONS AND RECOMMENDATIONS

A system designed to prepare radioactive wastes for treatment may include (a) initial waste receipt, inspection, and separation, (b) a low-speed shredding step, (c) additional size, density, and magnetic separation steps, (d) a high-speed sizing step, and (e) final size, density, and magnetic separation steps for "polishing" the treatment process feed stream. Waste container retrieval, and initial opening, dumping, and sorting are performed prior to these steps.

The initial receipt, inspection, and separation step accounts for up to one-half of the total capital costs for sizing waste. If this step could be eliminated or minimized, the total sizing costs could be reduced. However, many of the emerging treatment technologies are limited to specific kinds of waste, making waste separation very important.

For wide applicability to DOE wastes, low-speed shredders are the best candidates for size reduction. However, commercially available low-speed shredders are limited to output particle sizes no smaller than about 1 to 12 in., which is too large for some proposed treatment technologies. The only realistic process for achieving smaller particle sizes is a low-speed shredder followed by a hammer mill. Low-speed shredders can reduce the size of waste items from several feet to 1 to 12 in. The hammer mill can then reduce this material to 0.125-in. or less.

Separating and shredding combustible waste to a particle size range of 1 to 12 in., at a rate of 1 T/hr, would cost approximately $700/T. Reducing the particle size to <0.125 in. more than doubles the total cost, raising it to around $1,600/T. The incremental cost is attributed to the added hammer mill, inert atmosphere for the hammer mill, and additional separation equipment. Further size reduction to <0.004 in. increases maintenance and operating costs, as well as maintenance downtime, for the hammer mill. These additional costs for achieving particle sizes of <0.004 in. increase the size reduction costs to around $2,100/T.

The processing rate also affects shredding costs. Reducing the processing rate to 0.1 T/hr increases the total costs by a factor of 4 to 5 (to approximately $2,700/T for 1 to 12 in. particles, $8,100/T for <0.125 in. particles, and $10,200/T for <0.004 in. particles). The costs increase because the capital costs are unchanged (at these process rates equipment size is based primarily on waste feed dimensions, so most of the equipment is the same for both processing rates), so capital cost per ton increases. Also, operating costs per ton increase because operating time is reduced by a factor of 3 but the average process rate decreases by 10.

Disadvantages of hammer mills that are important in radioactive applications include: high maintenance, high downtime, and high levels of dust. Safety issues (fire, explosions, worker exposure during maintenance, etc.) are very important. Purging with inert gas can minimize the fire/explosion hazard, but is very costly. To avoid these difficulties, KOMAR Industries is investigating low-speed equipment that can produce small particles.

In the United States, a number of low-speed shredders have been used for radioactive waste shredding.[n] However, based on prior applications and demonstrations of low-speed radioactive waste shredding, demonstration of an integrated pretreatment facility that includes waste receipt, inspection, handling, transport, sorting, and low-speed shredding is recommended. This demonstration should:

- Emphasize waste handling, characterization, and sorting. The degree of waste handling and sorting (and thus associated costs) can vary widely depending on regulatory, administrative, and treatment requirements.

- Consider cryogenic fracturing as an alternative to low-speed shredding because it would minimize the container opening step and provide nitrogen gas for the hammer mill.

- Be a cooperative effort with vendors of sizing and waste handling equipment to benefit from their expertise and reduce equipment costs. Several vendors contacted in this survey were willing to participate, to some degree, in such a demonstration of their equipment; all vendors were willing to demonstrate their equipment if purchase orders were placed. Specific demonstrations of purchased shredding system(s) should be performed by the vendors of those systems as part of their service. Final acceptance of the equipment should be contingent upon successful demonstration with surrogate and real wastes.

While waste sizing to achieve smaller particle sizes (0.125 in. or smaller) has been demonstrated for many types of wastes, areas of uncertainty remain. These include (a) safety concerns (fires, radionuclide containment, and worker exposure), (b) ability to handle a wide variety of waste types, and (c) capital and operating costs. Further work is recommended to:

- Develop a low-speed shredder capable of achieving <0.125 in. particle sizes, without the safety concerns common to hammer mills.

- Demonstrate hammer milling to achieve <0.125 in. particle sizes. Emphasis should be on control of fires, radionuclide and hazardous materials containment, worker exposure, maintenance, and ability to process different types of wastes (especially waste materials prone to "fluff," agglomerate, or otherwise cause operational problems).

- Demonstrate reduction to small particle sizes as part of an integrated pretreatment process.

This should be done in cooperation with equipment vendors to help defray costs.

Based on the preliminary cost estimates presented here, waste pretreatment can be a very significant portion of the total treatment cost, especially for treatment technologies that require small particle sizes. The costs for pretreating wastes must be considered when evaluating any proposed waste treatment technology.

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