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Cost-Benefits of a Mobile, Trailer-Contained, Vibratory Finishing Decontamination Facility

R. F. Hazelton
M. W. McCoy

July 1982

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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COST-BENEFITS OF A MOBILE, TRAILER-CONTAINED, VIBRATORY FINISHING DECONTAMINATION FACILITY

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

The objective of this study was to determine the cost-benefits of a vibratory finishing process, developed at Pacific Northwest Laboratory (PNL), which has been used successfully to remove a variety of transuranic (TRU) contaminants from surfaces of metallic and nonmetallic wastes. Once TRU contaminants are removed, the metallic and nonmetallic materials can be disposed of as low-level waste (LLW). Otherwise, these materials would be disposed of in geologic repositories.

This study provides an economic evaluation of the vibratory finishing process as a possible method for use in decontaminating and decommissioning retired facilities at Hanford and other sites. Specifically, the economic evaluation focuses on a scoping design for a mobile, trailer-contained facility, which could be used in the field in conjunction with decontamination and decommissioning operations. The costs for the facility are based, in part, on an assumption that no sectioning of contaminated materials is required beyond the optimum for geologic disposal. Optimal sectioning or size reduction of the waste is as yet undefined. The mobile facility would be classified as a low-inventory, nonreactor nuclear facility. Administrative controls would be required to keep its transuranic inventory below specified levels.

The capital cost of the mobile facility is estimated to be about $1.09 million including contingency and working capital. Annual operating costs, including disposal costs, are estimated to be $440,000 for processing about 6340 ft^3/yr of pre-sectioned, TRU-contaminated material. Combining the operating cost and the capital cost, annualized at a discount rate of 10%, the total annual cost estimate is $602,000. The unit cost for vibratory finishing is estimated to be about $11/$ft^3$ of original reference glove box volume (Abrams et al. 1980). All costs are in first quarter 1981 dollars. Although not directly comparable, the unit cost for the vibratory finishing process is very favorable when considered beside typical, substantially higher, unit costs for processing and geologically disposing of TRU-contaminated materials (Brown 1980; Abrams et al. 1980).

The latter process method cost includes costs for size reduction, whereas size reduction or sectioning costs are not included in costs for vibratory finishing.

Sensitivity analyses were made to determine the effect of varying several factors on the total annual and unit costs of vibratory finishing TRU-contaminated materials. Of the varied factors, operating cost had the largest effect on the total annual cost, whereas throughput had the greatest effect on unit cost within the range of variation evaluated. A ±30% change in operating cost altered the total annual cost ±22%. A ±30% change in throughput had little effect on the total annual cost because no modifications requiring expenditure were made to the facility, and labor, the largest element of operating cost, remained constant. However, a 30% increase in throughput lowered the unit cost 20%, and a 30% decrease raised it 38%. Annual savings that might be realized by vibratory finishing TRU-contaminated materials instead of geologic disposal would vary in the same manner as unit costs with changes in throughput.

The costs of vibratory finishing in a fixed facility would be less than those for a mobile facility, principally because the amount of labor could be reduced. A rough estimate for processing the same quantity of material in a fixed vibratory finishing facility, assuming it could be placed in available space in an existing building, indicated that the unit cost would be about $\$6.70/ft^3$ of the original reference glove box volume.

The probable accuracy of this study cost estimate is about ±30%. It is therefore recommended that a detailed cost estimate be prepared if a mobile facility is designed.

ACKNOWLEDGMENTS

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INTRODUCTION

Transuranic (TRU)-contaminated materials generated by nuclear operations are presently placed in interim storage to await availability of a permanent geologic repository. The amount of retrievable TRU-contaminated materials held in interim storage as of 1980 was estimated to be about 61,000 m^3 (2.15 million ft^3); an additional 85,000 m^3 (3.0 million ft^3) was projected to be generated between the years 1980 and 2000 (U.S. DOE 1981). The estimated unit cost, if this waste is placed in interim storage, later retrieved, sorted, packaged, and disposed of in a central geologic repository, is about \$200/ft^3. This cost, the lowest for several processing options evaluated and reported by Brown (1980) and Abrams et al. (1980), is for processing new, stored, and buried transuranic wastes. An economic incentive exists to develop processes to decontaminate TRU-contaminated metallic and nonmetallic materials so that they can be disposed of as low-level waste (LLW) at substantially less cost, perhaps by an order of magnitude.

Vibratory finishing is a promising decontamination process (McCoy, Allen, and Arrowsmith 1980; McCoy, Arrowsmith, and Allen 1980) that has had rapid and successful development at Pacific Northwest Laboratory (PNL). In this process, adapted from one used in the metals finishing industry, contaminants are mechanically and chemically scoured from surfaces of metallic or nonmetallic materials in a vibrating annular tub. PNL studies have demonstrated that vibratory finishing is capable of decontaminating these materials to substantially less than 10 nCi/g, the present maximum limit for disposal of the waste as LLW material. Based on the difference in disposal costs between LLW disposal and geologic disposal, vibratory finishing appears to offer considerable economic benefit.

The purpose of the task discussed in this report was to establish the cost-benefits of a vibratory finishing decontamination facility that can be used in the field in conjunction with decontamination and decommissioning operations to process TRU-contaminated material. The objective was accomplished by estimating capital and operating costs of vibratory finishing and

LLW disposal and then comparing the overall cost with the cost of geologic disposal. All estimates are based on a scoping design facility since no detailed design engineering has been performed. Several alternatives for a mobile vibratory finishing facility with various processing capabilities have been envisioned. One concept, a trailer-contained unit, is evaluated in this report. The estimated costs given throughout this report are in first quarter 1981 dollars. The vibratory finishing facility would be classified as a low-inventory, nonreactor nuclear facility, which requires administrative control to limit its quantity of radionuclides.

This report covers the various aspects of the cost-benefit evaluation, and includes descriptions of the vibratory finishing procedure and the mobile facility. It also gives details on estimated capital costs, operating costs, and resultant annual cost and potential savings. Since each of these costs involves some uncertainty, a sensitivity analysis is provided to show the effect of variation of some cost or processing elements. The appendices contain a discussion of low-inventory, nonreactor facilities and costs for a fixed vibratory finishing facility.

CONCLUSIONS AND RECOMMENDATIONS

The capital cost of the mobile, trailer-contained, vibratory finishing facility is estimated to be about $1.09 million including allowances for contingency and working capital. The yearly operating cost is estimated to be about $440,000 for processing about 6340 ft^3 of pre-sectioned TRU-contaminated waste. With the capital cost annualized, using an 11-year life for the facility and a discount rate of 10%, the total annual cost to operate the facility is estimated to be about $602,000. The unit cost for vibratory finishing pre-sectioned materials in a mobile facility and LLW disposal is about $95/$ft^3$ of reduced volume. This is equivalent to a cost of $11/$ft^3$ of original glove box volume, based upon the reference glove box described by Abrams et al. (1980). All estimated costs are in first quarter 1981 dollars and are based on a scoping design.

The vibratory finishing and LLW disposal costs are based on the assumption that the facility would be classified as a low-inventory, nonreactor nuclear facility and that no additional costs for sectioning mixed TRU-contaminated materials would be incurred over that which could produce a minimum volume of material for geologic disposal. The extent, and consequently the costs, of optimal sectioning or waste size reduction for geologic disposal is as yet undefined. If, after the extent of this sectioning is established, any further sectioning is required before vibratory finishing, the incremental costs will have to be charged to the vibratory finishing operations.

Sensitivity analyses were made to determine the effects of changes in discount rate, throughput, operating cost, capital cost, and facility life upon the total annual cost and the unit cost for processing TRU-contaminated materials. Of the changes evaluated, those for operating cost and throughput had the most significant effects. Changing the operating cost ±30% altered both the total annual cost and unit cost ±22%. Changes in throughput substantially affected the unit cost but had little effect on the total annual cost because the principal elements of this cost, capital and labor, are essentially fixed. An increase in throughput of 30% lowered the unit cost 20%; a 30% decrease raised the unit cost 38%. Annual savings that might be realized by vibratory finishing would vary the same as unit cost with change in throughput. Changes in discount rate, capital cost, and facility life produced smaller changes in the total annual cost and unit cost. An increase in discount rate from 10% of the base case to 20% raised the annual and unit costs by 14%; a $\pm$30% change in capital cost raised or lowered the total annual and unit costs $\pm$8%; cutting the facility life in half increased the annual and unit costs by 15%.

Although a mobile, trailer-contained, vibratory finishing facility has been evaluated in this study, it is but one of several alternatives that have been envisioned. Other alternatives should be evaluated in future studies for cost effectiveness, especially in their use of labor, the major expense for the trailer-contained facility. For example, because of reduced labor requirements, costs for vibratory finishing in a fixed facility would be less than those for the mobile facility. A rough estimate for processing the same quantity of pre-sectioned material in a fixed facility, assuming space in an existing building were available, indicated that the unit cost would be about $58/$ft^3$ as compared with $95/$ft^3$ of reduced volume, or $6.70/$ft^3$ as compared with $11/$ft^3$ of the original glove box volume.

The probable accuracy of this study estimate is about $\pm$30%. Therefore, a detailed cost estimate with a higher accuracy is recommended if a mobile vibratory finishing facility is designed.

VIBRATORY FINISHING PROCESS DESCRIPTION

The vibratory finishing process, adapted from one used in the metals finishing industry for deburring metal parts, combines mechanical scrubbing and chemical action in a vibratory finisher to scour TRU contaminants from surfaces of sectioned-to-size metallic and nonmetallic materials. The principal processing occurs in a vibrating tub that contains metal media of various shapes. These media are capable of entering corners and crevices of the waste. A liquid chemical compound, which both loosens and rinses contaminants from surfaces of the waste, is recirculated from a storage and settling tank to the vibratory tub. A batch of mixed metallic and nonmetallic materials is scoured in the vibrating tub for about 1 hr.

After the metal media is removed by screening, the decontaminated material is rinsed with water, dried, monitored for radiation, and placed into drums for transport to an LLW disposal site. The chemical solution is settled and filtered during recycling, and spent solution is sent from the mobile facility to the nuclear operations site evaporator. Evaporator bottoms and spent filter elements, which together contain the TRU contaminants, are then placed into a drum along with Portland cement for solidification. These materials are mixed in the drum by placing the drum on a roller and allowing the cement paste to solidify. The solidified materials containing the TRU contaminants are then suitable for disposal.

The TRU-contaminated metallic and nonmetallic materials received for vibratory finishing in the mobile facility would be partially decontaminated before sectioning but still contaminated in excess of 10 nCi/g. These materials would be decontaminated by vibratory finishing to less than 10 nCi/g, probably as low as 0.1 nCi/g. Most measurable contamination would be removed; all smearable contamination would be removed (McCoy, Arrowsmith, and Allen 1980).

A block flow diagram for the overall process is shown in Figure 1. A schematic drawing of the principal elements of the system and how they operate

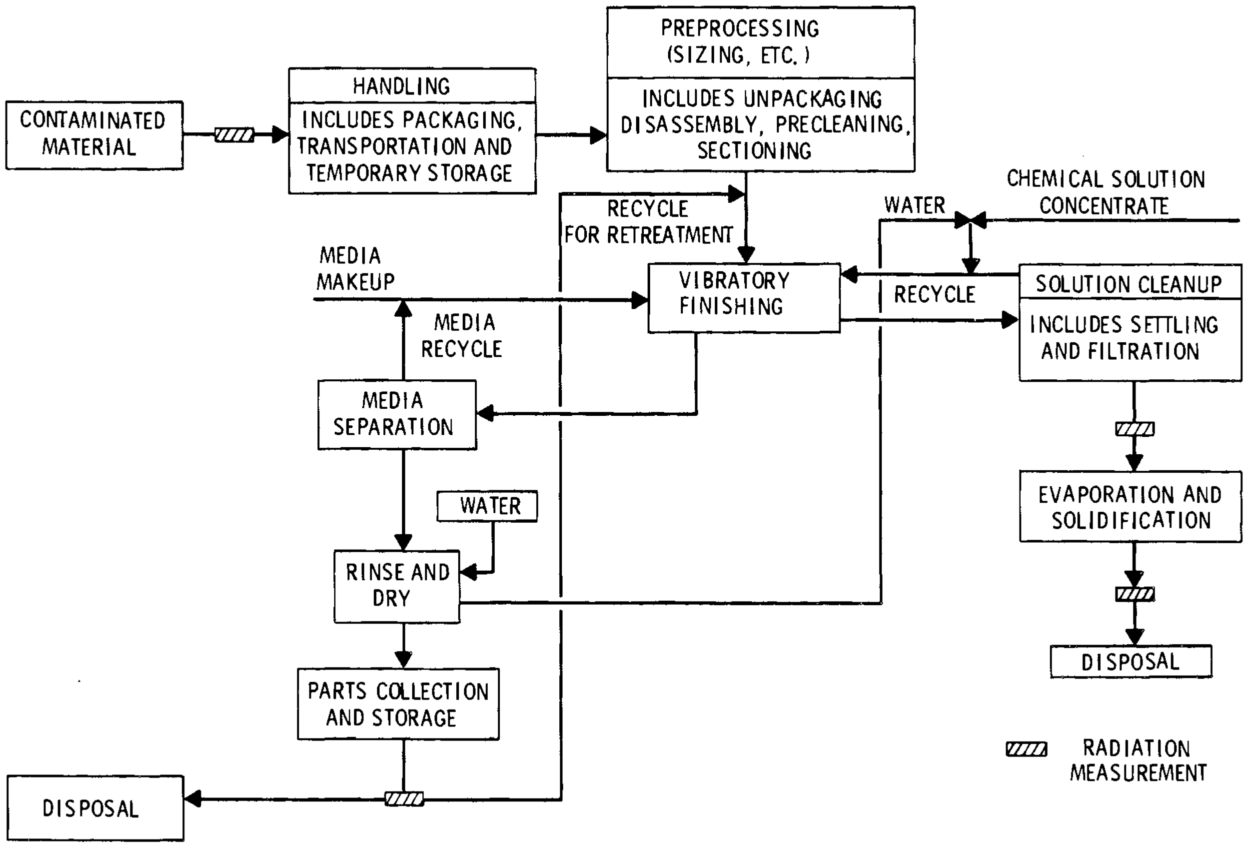

FIGURE 1. Process Flow Diagram for Vibratory Finishing TRU Waste

is presented in Figure 2. A 5.25-ft diameter, 12-ft^3 annular vibratory finisher, which could be used in the facility in a modified version, is shown in Figure 3; the normal frequency of the apparatus is about 1200 vibrations/minute.

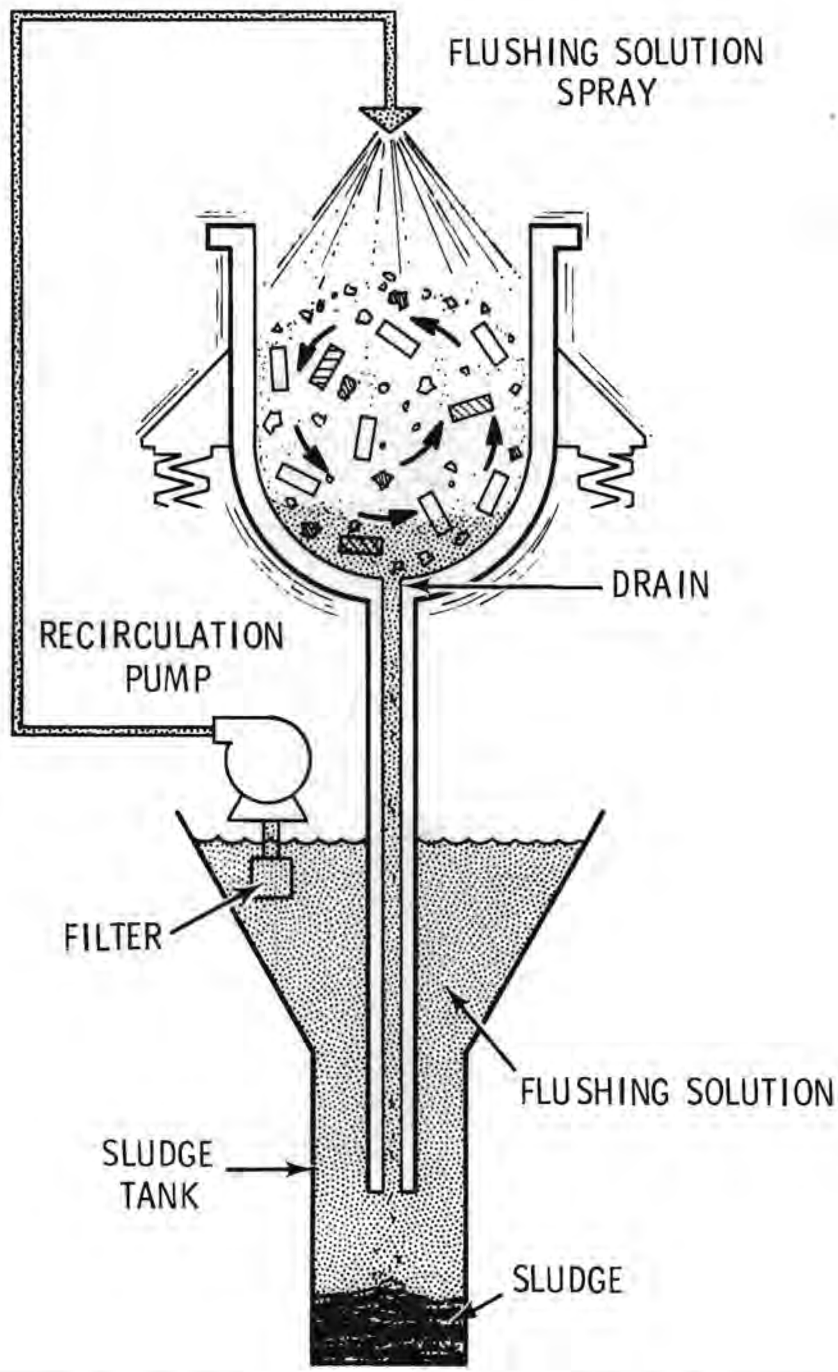

FIGURE 2. Vibratory Finishing Decontamination System

DOE Richland, WA

FIGURE 3. Annular Vibratory Finisher with 12-ft^3 Capacity

FACILITY DESCRIPTION

The mobile vibratory finishing facility would consist of two trailers; one to contain the processing system, the other to contain the support services such as heating, ventilation, and air conditioning (HVAC) and HEPA filtration. The support trailer also would have a change room, a storage area for supplies, and space for an emergency power generator. One possible arrangement for a vibratory finishing process trailer is shown in a plan view in Figure 4 and in a perspective view in Figure 5. Each trailer would be about 10 ft wide and 40 ft long; the height within each trailer would be about 8 ft. The trailers would be lined inside with stainless steel sheeting to permit easy decontamination should an unlikely event occur which dispersed radioactive contaminants within. The trailers would be designed to avoid or minimize contamination and to make cleaning easier. Design techniques that would be used are given by Perrigo (1970).

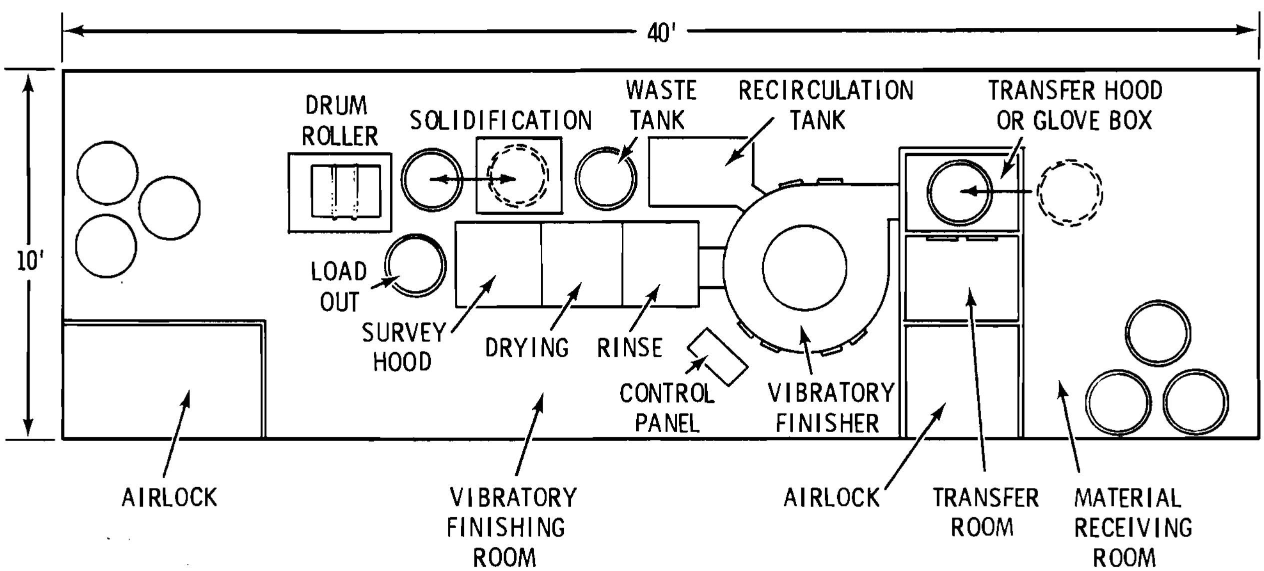

FIGURE 4. Plan View of the Mobile, Trailer-Contained, Vibratory Finishing Facility

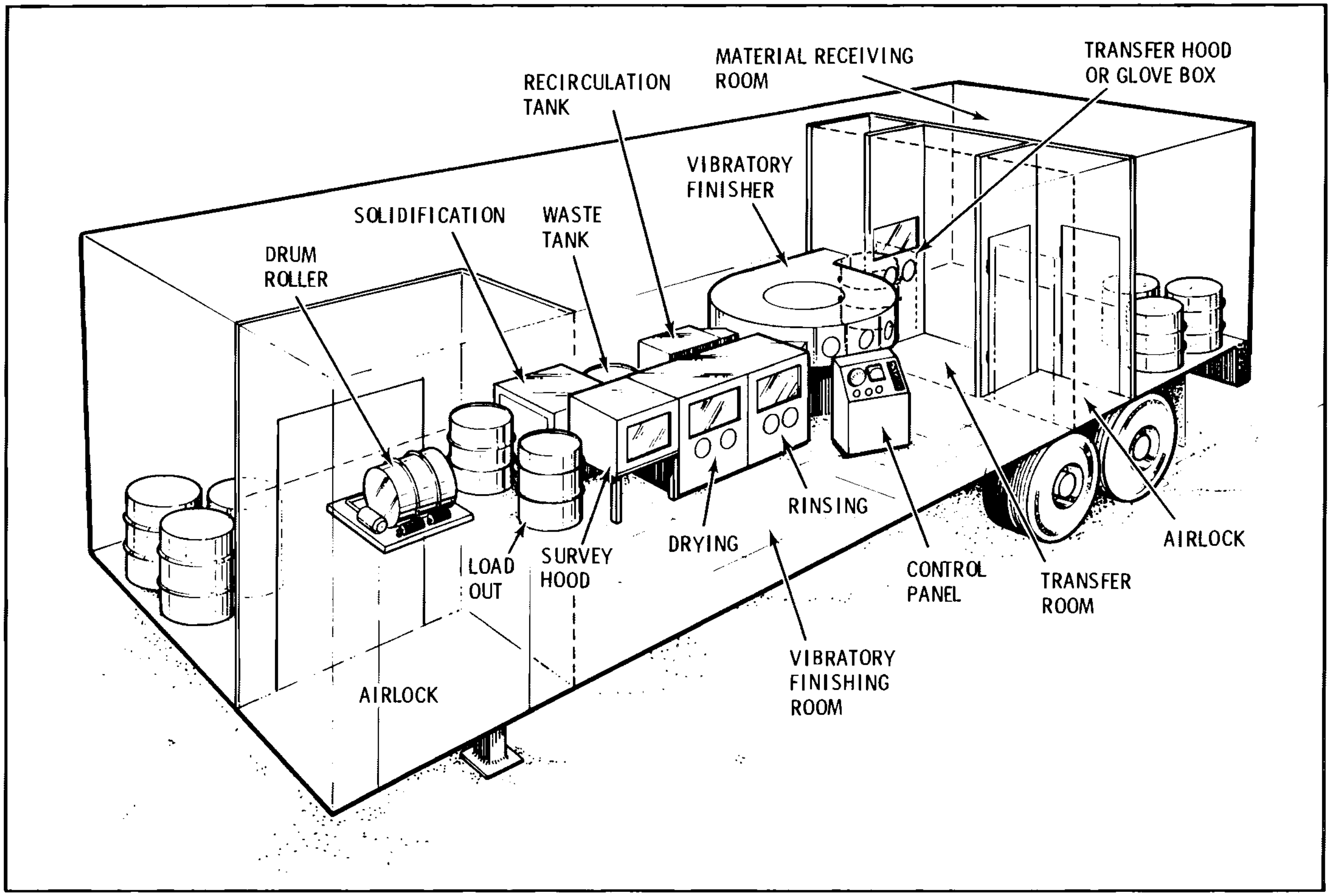

FIGURE 5. Perspective View of the Mobile, Trailer-Contained, Vibratory Finishing Facility

SERVICES

The trailers would be provided with easy hookup to electrical and water services at the site of the decontamination work. All external lighting and other security services would be furnished by the operation site.

Fresh, conditioned air would be supplied by the support trailer. Air would be HEPA filtered before entering and after being exhausted from the process trailer. An entry and an exhaust HEPA filter stage would be installed within the process trailer to prevent external dispersal of any airborne contaminants should slight overpressuring of the trailer and reverse air flow occur. Air would be monitored continuously by automatic radiation instruments. Delivery and exhaust ducts would distribute and collect air at several locations.

Halon® fire protection systems or equivalent also would be provided in each trailer. Few combustibles would be in the facility at one time. The combustibles principally would be plastic bags used to contain sectioned metallic and nonmetallic parts within 55-gal drums.

WORK AREAS OF PROCESS TRAILER

The trailer would have several areas or rooms for material receiving, waste transfer, and vibratory finishing operations. In addition, two airlocks would be provided for personnel to enter or leave the facility. Although at a negative pressure compared to ambient, the airlocks and the material-receiving area would be maintained at a slightly higher pressure than other rooms of the trailer to maintain contamination control integrity.

Material-receiving Room

The material-receiving room would be at the rear of the trailer. It would have a large door to permit receiving and storage of TRU waste in sealed drums. A 2-ton hoist and a small roller conveyor would be furnished for moving drums between storage and the waste transfer room.

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Waste Transfer Room

The radioactive-material waste transfer room would be equipped with a hood having a balanced air system that would allow some air to come from the room and some to come directly from the outside through the HVAC system. The air velocity at the face of the hood would be 150 ft/min. After a sealed drum is conveyed into the transfer room, the two rooms would be isolated from each other before a drum is opened. A drum would be opened by a fully protected operator dressed in radiation zone work clothing, who would transfer TRU waste from the drum to the vibratory finisher tub through an opening in the tub cover. The opening to the vibratory finisher would be closed and the drum resealed once the waste is transferred.

Vibratory Finishing Operations Room

The vibratory finisher, with its controls and support equipment, would be in the largest room of the trailer. The room also would contain the rinse and dry system for the decontaminated waste; a filter; a liquid waste solidification system, including a hydraulic drum roller and lift; and a small conveyor to handle drums filled with either decontaminated, cleaned and dried parts, or solidified materials. The drum roller is provided as a stand-by item since exhausted chemical solution usually would be sent to a liquid waste handling system at the work site for concentration by evaporation and solidification of the evaporator concentrate. A second hoist, like that in the receiving room, would be located in the vibratory finishing room to allow movement and temporary storage of filled LLW drums.

Radiation Monitoring Instrumentation

Radiation monitoring instruments would be placed throughout the facility. Extra instruments would be provided so that a set could be undergoing calibration or maintenance at any time without affecting operations. The instruments would include portable alpha meters, CP beta-gamma survey units, P-11 low-level beta-gamma meters, and neutron survey units.

FACILITY CAPITAL COST ESTIMATE

The estimated capital cost for the entire facility is $1.09 million, as shown in Table 1. This cost is for two trailers, installed process equipment, and working capital. The probable accuracy of the study estimate is in the range of ±30%.

TABLE 1. Capital Cost Summary for Mobile Vibratory Finishing Facility

Cost Basis: First Quarter 1981 Dollars

Trailers (2) 10 ft x 40 ft	$ 500,000
Process Equipment	521,000
Working Capital	73,000
Total Capital Cost	$1,094,000

(Note: The number of significant figures shown is for computational completeness; it is not to imply that accuracy of the estimate is to nearest thousand dollars.)

TRAILER COSTS

A breakdown of the trailer costs is given in Table 2.[a] Two unequipped but custom-built, 10-ft-wide, 40-ft-long, 8-ft-high (internally) trailers would cost $80,000. Stainless steel lining and partitions cost $42,000. Costs of electrical services, the HVAC system (including a heat pump, ducts, and HEPA filters), a Halon® fire protection system (or equivalent), continuous air monitoring apparatus, and miscellaneous equipment are $68,000. Engineering, construction overhead, and contractor profit would be $160,000. Since this is a scoping design estimate, a contingency of 40% was taken, giving a cost of $140,000; total cost for the trailers is $500,000.

(a) Estimate developed by M.E. Olson, PNL Project Management, based upon information provided by Vitro Engineering Corporation. Basic trailer costs obtained from Freuhauf Trailers.

TABLE 2. Capital Cost Estimate for Trailers

Cost Basis: First Quarter 1981 Dollars

Equipment	Cost
Trailer A (10 x 40 x 8 ft)	$ 40,000
Trailer B (10 x 40 x 8 ft)	40,000
Stainless steel liner	
2 trailers	
3600 ft^2 @ $10/$ft^2$	36,000
Stainless steel partitions	
400 ft^2 @ $40/$ft^2$	16,000
Electrical	15,000
HVAC - heat pump, duct work	
HEPA filters	30,000
Fire protection and miscellaneous	23,000
A. Subtotal, Direct Costs	$200,000
Engineering @ 35% A	70,000
B. Subtotal	$270,000
Overhead and Profit @ 35% B	
(rounded to nearest $10K)	90,000
C. Subtotal	$360,000
Contingency @ 40% C	
(rounded to nearest $10K)	140,000
TOTAL	$500,000

PROCESS EQUIPMENT COSTS

Table 3 lists the estimated installed equipment costs, which consist of direct costs for purchasing the equipment and intalling it in the trailer. The purchase costs are based upon:

- actual purchases for PNL vibratory finishing system
- estimates given to PNL for equipment in a preliminary design stage
- prices in a mechanical equipment supply catalog (McMaster and Carr 1979)

TABLE 3. Capital Cost Estimate for Process Equipment

Cost Basis: First Quarter 1981 Dollars

Equipment	Cost
Vibratory finisher	$ 61,000[a]
Vibratory finisher media	5,100
Roller conveyors (2)	800
Hoists (2)	13,000
Filter system	4,200
Rinsing/drying system	36,000
Drum roller	5,600
Waste tank	5,000
Hoods	32,000
Radiation monitoring instrumentation	12,500
Spare parts	19,000
A. Subtotal, Direct Installed Costs, rounded	$194,000
Startup, 12% of direct costs of process equipment and trailer	47,000
B. Subtotal	$241,000
Engineering, 35% of A, Direct Installed Cost, rounded	70,000
C. Subtotal	$311,000
Contractor overhead, supervision, other indirects, and profit; 35% of C	$110,000
D. Subtotal	$421,000
Contingency, 25% of D (rounded)	100,000
TOTAL	$521,000

(a) Direct installed cost of equipment.

- prices in a laboratory equipment catalog (American Scientific Products 1981)
- estimated costs in books on estimating standards (Richardson Engineering Services 1980 and 1981).

The direct costs for installation are based upon factors given by Guthrie (1974) or upon data by Richardson Engineering (1981). Purchased equipment costs were escalated as necessary to first quarter 1981 dollars using Marshall and Swift equipment cost indexes published in each biweekly issue of Chemical Engineering Magazine.

The costs for the vibratory finisher, vibratory finishing media, drum roller, and radiation monitoring equipment are based upon PNL purchases. A circular vibratory finisher similar to that shown in Figure 3 was purchased for about $33,000 in 1979. The cost in Table 3 reflects an estimated modification cost (20%) to give the apparatus glove box capabilities. An installation factor of 1.3 was used. About 11 ft^3 of steel vibratory media, costing $420/$ft^3$ in 1980, would be used. A drum roller, which cost $3900 in early 1980, could be used for solidifying spent liquids with Portland cement. Again, the installation factor used was 1.3.

Estimates were provided to PNL for a filter unit to be used to polish recirculating chemical solution from the vibratory finisher and a rinsing/drying system for decontaminated metallic and nonmetallic materials. Installation factors of 1.4 and 1.5, respectively, were used to give the costs in Table 3. The costs for a 50 to 100 gal liquid neutralization waste tank, used for adjusting the pH of spent vibratory finishing chemical solution, were estimated similarly. This waste tank would be equipped with an agitator, flush system, spray nozzles, and a pH instrument. Because these systems are not yet well defined, the cost estimates are rough.

Roller conveyors would be used at the receiving and discharge ends of the process train. The roller conveyors are 22 in. wide and 5 to 10 ft long with a 2-in. roller spacing, and are capable of carrying 300 lb per roller. The two conveyors would cost about $400 (McMaster-Carr catalog). Installation would double this figure.

Hoods would be used for transferring the contaminated materials into the vibratory finisher, for surveying decontaminated material after rinsing and drying, and for processing spent liquids. Laboratory equipment catalog prices for stainless steel perchloric acid hoods, equipped with wash-down features, were used for this pre-design estimate. A 1.4 installation factor was used.

Two hoists of 2-ton capacity each would be placed at either end of the process trailer to move heavy drums and other material. By means of the Richardson Engineering (1981) standards, an installed cost of $13,000 was estimated.

An allowance of 5% of direct costs for the trailer and process equipment, or $19,000 is provided in the estimate for spare parts that would be needed for equipment repair or replacement. Also, during startup, equipment may have to be altered or replaced. To cover these startup costs, $47,000 or 15% of direct costs is provided.

Engineering and contractor costs, including overhead and profit, are estimated to be about $180,000. The same percentages of direct costs as those used for the trailer cost estimates were used. A contingency of 25% was used for the process equipment instead of 40% because more is known about the equipment that will be used than about the trailer configuration. The estimated total capital cost for installing the process equipment is about $521,000.

EXCLUSIONS

Costs of the following are excluded from this estimate:

- Site development - depends on circumstances ranging from the availability of a work area to the need for a concrete pad and utility lines.
- Emergency backup power - provided by nuclear plant.
- Electrical and water services - provided by nuclear plant.
- Outside lighting - provided by nuclear plant.

- Security, accountability, and criticality safety controls - provided by operators within a security zone; all drums of contaminated metallic and nonmetallic materials are already partially decontaminated before sectioning and pre-screened for fissile material content before placement into drums.

WORKING CAPITAL

Working capital consists of cash kept on hand for monthly payments of operating expenses. Peters and Timmerhaus (1968) state that most chemical plants use an initial working capital amounting to 10 to 20% of the total capital investment. Others (e.g., Lyda 1972) break down working capital into amounts for raw materials and supplies, finished product inventories, accounts receivable less accounts payable, wages, etc. for periods ranging from 15 to 45 days. For this study, an allowance equivalent to 2 months operating costs ($73,000) was taken. This allowance falls between the 10% fraction of capital and that obtainable using the periodic requirements of the individual working capital components. Values of finished product inventories and accounts receivable would not be of concern for a DOE project.

FACILITY OPERATING COST ESTIMATE

The annual operating costs for the trailer-contained, vibratory finishing facility are estimated to be about $440,000 (first quarter 1981 dollars). A breakdown of costs is given in Table 4 for processing 259,000 lb of waste annually. The operating costs are based upon several assumptions, including the amount of TRU-contaminated metallic and nonmetallic materials processed.

TABLE 4. Operating Cost Estimate

Cost Basis: First Quarter 1981 Dollars

Base Case

Material processed: 862 300-lb drums/yr
259,000 lb/yr
6340 ft^3/yr - 179 m^3/yr (reduced volume)

Operation time: 44 wk/yr

	Cost
Labor	$213,000
Maintenance and repairs	60,000
Process Materials	
Chemical concentrate	600
Metal vibratory finisher media	5,100
Filter cartridges	2,000
Portland Type 2 cement	300
Drums (55-gal)	17,500
Protective clothing and laundry	4,500
Operating supplies	10,000
Utilities	
Water	negligible
Electricity	3,300
LLW disposal	24,000
TRU geologic disposal	12,000
Subtotal (rounded)	$352,000
Contingency, 25%	88,000
Total Operating Cost	$440,000

PRIMARY ASSUMPTIONS

The primary assumptions used in preparing the operating cost estimate are:

- Facility will process contaminated material 44 weeks per year. The remaining weeks of the year will encompass downtime for repair, holidays, and moving the trailers from one site to another.
- Operation: 1 shift per day, 5 days per week
- Contaminated metallic and nonmetallic waste processed
  - 30 ft^2 of waste per batch for 12 ft^3 vibratory finisher.
  - 5 batches processed per day, allowing 1/4 hr for feeding the vibratory finisher, 1 hr for operation, and 1/4 hr for cleaned material discharge.
  - average thickness of material: 3/16 in.
  - material all stainless steel with density of 0.29 $lb/in.^3$
  - 300 lb of waste per 55-gal drum.
- Vibratory finishing compound
  - rate of diluted solution recycled to unit: 20 gph.
  - diluted solution: 0.5 - 1% concentrate; remainder, demineralized water.
  - waste solution: 8 gph of the dilute solution, which would be sent to the liquid waste handling system of the visited facility for concentration by evaporation and solidification of the evaporator bottoms.
- Filter cartridges: two 2 x 10-in. filter cartridges used for every 6 hr of operation. When exhausted, these cartridges would be placed into a drum along with evaporated liquid waste residue for solidification. A drum would be used for solidification of 23 gal of dilute solution. A drum ready for disposal would weigh about 600 lb.

- Labor: 2 nuclear technicians, full time; 1 radiation monitor, 1/2 time; 1 supervisor, 1/4 time.
- Sectioning: assumed at no cost for preparation of material for vibratory finishing since equivalent sectioning may be done to reduce volume of material sent to geologic disposal.

MIXED METALLIC AND NONMETALLIC WASTE PROCESSED ANNUALLY

The weight of mixed waste processed in each batch, using the above assumptions, is 235 lb; this waste is chiefly sectioned stainless steel parts. This amount is based upon experience gained at PNL in operating a vibratory finisher. Since area, weight, and shipping volume for a material are indirectly related, the following annual amount is an approximation. With 235 lb per batch, 5 batches per day, 5 days per week, and 44 weeks per year for operation (at 1 shift per day), a total of 259,000 lb would be processed annually. The number of 55-gal drums containing 300 lb of waste each (a typical weight at PNL) would be 862 each year. The material is assumed to be carefully packed into drums to give a packed density of about 40 lb/ft^3 based on the metal weight and the drum volume. The volume of the drums is equivalent to 6340 ft^3 (reduced volume) of waste per year, or the volume of waste that would have to be disposed of.[a]

LABOR COSTS

Two nuclear technicians would conduct the operations of the vibratory finishing facility on a full-time basis. Although not needed for the

(a) The volume of a given weight of metal waste is variable as it depends upon the shape, random arrangement, and other factors for individual pieces within a waste collection. Waste volume can be affected by rearrangement, sectioning, melting, or other processing. This has been illustrated by Copeland and Heestand (1980). In their study, they took a random sample (218 kg) of mixed metal scrap, containing 40% aluminum, 35% steel, and lesser percents of other metals from a scrap bin and reduced this volume from 1.60 m^3 (56.5 ft^3) to 0.395 m^3 (14 ft^3) by mechanical sectioning, then to 0.0497 m^3 (1.75 ft^3) by melting into ingots and slag. Apparent bulk densities calculated from their data are, respectively, 136 kg/m^3, 552 kg/m^3, and 4160 kg/m^3 (8.50 lb/ft^3, 34.4 lb/ft^3, and 260 lb/ft^3).

operations, the second technician is required for safety within the isolated facility. A fixed, unisolated facility would not have this requirement since the operation may be integrated with others. The labor cost rate including fringe benefits and overhead is assumed to be $34/hr for each technician. This rate is an approximation for that of the labor grade that might be used at the Hanford Site. A radiation monitor would survey operations frequently; a supervisor, who would have other assignments, would check work a few times a day. These labor costs are $34/hr and $50/hr, respectively. Considering the manpower assumptions and assuming 5% additional cost for overtime, the annual cost for labor would be $213,000.

MAINTENANCE AND REPAIR

An allowance of 6% of process equipment trailer costs is assumed for maintenance and repairs. The annual cost would be about $60,000.

EXPENDED MATERIALS COSTS

The chemical concentrate used in the dilute chemical solution costs about $6.80/gal. The vibratory finisher will operate about 5 hr/day; the rest of a shift would be used for loading or unloading the machine. The dilute solution having 1% concentrate is expended at a rate of 8 gph. At that rate, the annual cost of concentrate would be about $600/yr.

Only a small amount of vibratory finishing media, a hardened steel, is anticipated to be lost due to wear or carried out with decontaminated material. Because the steel media is self-cleaning, no permanent radionuclide contamination is foreseen and replacement of the media for this cause should be infrequent. Replacement would be based upon an otherwise uncorrectable decrease in the system's decontamination efficiency. An annual allowance of $5100, which is equivalent to the cost of media to fill the vibratory finisher, is provided.

Two filter elements would be used daily and disposed of by solidification along with spent chemical solution. The annual cost is estimated at $2000 with each element priced at $5.30.

About 8800 gal of spent chemical solution is produced yearly by processing 6340 ft^3 of TRU-contaminated material. The waste liquid would be sent to the waste liquid handling system of the visited nuclear facility, and would be concentrated 20:1 by evaporation and solidified in 55-gal drums. The solidified waste containing the TRU contaminants would be disposed of in a geologic repository. Spent filter elements would be solidified and disposed of along with the concentrated liquid. Electricity required for evaporation would be about 23,000 kWh annually. Twenty-two 55-gal DOT-17H drums and 80 94-lb sacks of Portland Type 2 cement are required for solidification. The annual costs for drums and cement are about $400 and $300, respectively. The solidified waste also would be geologically disposed of; the unit cost of $2600/$m^3$ (Brown 1980) gives an annual disposal cost of $12,000. The costs for electricity and drums are included in the totals for these items in Table 4. The cement and geologic disposal costs are listed individually.

Assuming the same number of drums would be used for waste metal as those received, 862 drums would be used annually at a cost of about $17,100. The total drum cost, including that for solidification would be $17,500.

PROTECTIVE CLOTHING AND LAUNDRY COSTS

Hanford Site laundry costs for radiation worker coveralls and other protective clothing are about $0.47 per lb, or about $1.10 per change. The annual cost for laundry, based upon about four changes of clothes per worker per day, would be about $4500.

OPERATING SUPPLIES

The cost of operating supplies is assumed to be about 1% of capital cost, excluding working capital, or about $10,000.

UTILITIES COST

Demineralized water is used for rinsing processed waste and chemical solution makeup. The annual use is estimated to be about 10,000 gal. Since process water costs about $3.00/1000 gal, the total water cost is negligible.

The following amounts of electricity are estimated as being used annually in the facility:

	kWh/yr
HVAC and HEPA filtration	105,700
Lighting	5,600
Vibratory finishing	7,700
Rinse-dry system	13,000
Evaporation	23,000
Drum roller-solidification	1,100
TOTAL	156,100

Since this is an order-of-magnitude estimate it is assumed that 160,000 kWh are used annually. The total electricity cost at about $0.02 per kWh would be $3200 annually.

LLW DISPOSAL COSTS

At the Hanford Site, the cost to dispose of LLW in drums was about $2.75 to $3.75/ft^3 in mid-1980. With this cost adjusted to the first quarter 1981, the annual cost to dispose of 862 drums of decontaminated metallic and non-metallic materials would be $24,000. Other wastes such as rags would be disposed of, but the amount is comparatively small so their disposal cost is excluded.

CONTINGENCY

A contingency allowance of 25% of the subtotal of operating costs is provided to cover unknown costs that may arise.

EXCLUSIONS

A number of possible cost items are excluded from the estimate as they may be highly variable and unpredictable and chargeable to other accounts. These are:

- Taxes and insurance - These costs are not applicable for a government-owned facility. For a private facility these costs could amount to about 2% of total capital.
- Security, accountability, and criticality control operations - These functions will be provided by the nuclear site generating the waste to be processed.
- Forklift operations external to the facility and other costs of delivery and removal of wastes from the facility.
- Facility decontamination costs should an improbable accident occur that dispersed radionuclides throughout the facility.
- Costs to move trailers from site to site and set up at new sites.
- Environmental impact statements - All liquids, HEPA filters, and other materials possibly containing radionuclides would be removed from the facility and the facility would be cleaned and released before transit.
- Transit security - Security would not be needed on the highway because the facility would be prepared to meet low specific activity (LSA) requirements, a DOT shipping category. A Radiation Shipment Report (RSR) would be used for transit at the Hanford Site.

ANNUAL COSTS, UNIT COSTS, AND POTENTIAL SAVINGS

Annual costs, including capital and operating costs, of vibratory finishing followed by LLW disposal can be determined using the technique given by Grant, Ireson, and Leavenworth (1976). They give the following equation to calculate annual cost for capital investment, or capital recovery:

$$CR = (P - L)(A/P)_{i*,\ n} + Li*$$

where CR is annual cost of capital recovery; P is the first cost of a structure; n is the facility's useful life; L is prospective net salvage value at the end of n years, A is an end-of-period payment or receipt; $(A/P)_{i*,\ n}$ is the capital recovery factor obtained from compound interest tables; and i* is the discount rate or minimum attractive rate of return.

In this calculation, L was used to include recoverable working capital and salvage value, which was estimated at 5% of initial fixed capital cost, or $51,000. The IRS allows 11 years (n) to depreciate a chemical or process-type facility so this number was used as facility life. Discount rates, i*, of 5, 10, 15, and 20% were used. Capital recovery factors were obtained from tables in Grant et al. (1976). The annual costs of capital recovery, facility operating cost, total annual costs and costs per unit volume are given in Table 5.

Using a 10% discount rate for the base case, which will be used in the following discussion on sensitivity, the annual capital cost is $162,000 for a facility life of 11 years. This cost, coupled with the annual $440,000 operating costs, gives a total annual cost of $602,000. With about 6340 ft^3 of sectioned metallic and nonmetallic material processed each year, the total annual cost for vibratory finishing and LLW disposal is equivalent to a unit cost of $95/$ft^3$ of reduced volume. This is equivalent to a cost of $11/$ft^3$ of the original glove box volume.[a]

(a) The ratio of original volume to sectioned or reduced volume is based on a reference glove box, which is a 4 x 4 x 8-ft unit with a storage volume of 128 ft^3. The metallic surface area is about 120 ft^2 and the corresponding solid volume is about 0.88 ft^3. The unit has plastic side and top panels (Abrams et al. 1980).

TABLE 5. Cost and Effects of Varying Discount Rate

Cost basis:	First quarter 1981 dollars
Material Processed:	6340 ft^3/yr (reduced volume)
Operation Time:	40 wk/yr, 1 shift/day

	Discount Rate			
	5%	10% (Base Case)	15%	20%
Annual Operating Cost	$440,000	$440,000	$440,000	$440,000
Annual Capital Cost	123,000	162,000	204,000	249,000
Total Annual Cost	$563,000	$602,000	$644,000	$689,000
Unit Cost, $/$ft^3$, Reduced Volume	89	95	102	109
% Change in Total Annual Cost	-6	-	7	14
% Change in Unit Cost	-6	-	7	14

This unit cost, which excludes costs for sectioning or size reduction, indicates that there may be potential for substantial savings by vibratory finishing TRU-contaminated materials and disposing of the materials as LLW. The unit cost for geologic disposal has been estimated to be about $200/$ft^3$ of original volume (Abrams et al. 1980). However, a clear comparison cannot be made directly because the unit cost for geologic disposal includes costs for some size reduction, whereas the unit cost for vibratory finishing does not. As stated earlier, it was assumed for this evaluation that the vibratory finishing facility would receive pre-sectioned material.

SENSITIVITY ANALYSES

A sensitivity analysis is a means of evaluating the effects of uncertainty on investment by determining how the profitability varies as the parameters are varied that affect economic evaluation results (Stermole 1980). For further discussions of sensitivity, see Stermole (1980) or Grant, Ireson, and Leavenworth (1976).

Sensitivity analyses were made in this evaluation to determine the effects of varying discount rate, throughput, operating cost, capital cost, and facility life upon total annual cost and upon unit cost for vibratory finishing TRU-contaminated materials. In addition, a rough sensitivity analysis was made to determine the effect of having the vibratory finishing system located in the available space of an existing building rather than in a mobile facility.

As shown in Table 5, lowering the discount rate to 5% from the base case of 10% decreases both the annual cost and unit costs by 6%; raising the discount rate to 15% and 20%, respectively, increases the annual and unit costs by 7% and 14%. Changes in throughput of ±30% have no substantial effect upon total annual cost, as shown in Table 6. However, the unit cost ($\$/ft^3$) is affected markedly, ranging from a decrease of 20% for an increase in throughput of 30% to an increase of about 38% for a decrease in throughput of 30%. The reason for these effects is that the annual capital cost is constant regardless of throughput, and operating costs for this range of variance are nearly constant. The bulk of operating cost is for labor, which would be the same in each case, assuming that only one work shift is used; only the costs for processing materials and waste disposal vary with throughput.

A variance in operating cost of ±30% directly increases or reduces the annual cost ±22%, when the annual capital cost is held constant. A variance in annual capital cost, being but 27% of the base case total annual cost, has less of an effect; the annual cost varies ±8% with changes in capital costs of ±30%. The unit costs vary by the same percentages with changes in operating and capital costs. These effects are shown in Tables 7 and 8.

TABLE 6. Effects of Varying Throughput of TRU-contaminated Materials (Same bases as Table 5)

	Change in Throughput				
	+30%	+15%	Base Case	-15%	-30%
Throughput, ft^3/yr	8,240	7,290	6,340	5,390	4,440
Annual Operating Cost	$461,000	$450,000	$440,000	$430,000	$419,000
Annual Capital Cost	162,000	162,000	162,000	162,000	162,000
Total Annual Cost	$623,000	$612,000	$602,000	$592,000	$581,000
Unit Cost, $\$/ft^3$ Reduced Volume	76	84	95	110	131
% Change in Total Annual Cost	3	2	-	-2	-3
% Change in Unit Cost	-20	-12	-	16	38

TABLE 7. Effects of Varying Operating Cost (Same bases as Table 5)

	Change in Operating Cost				
	+30%	+15%	Base Case	-15%	-30%
Annual Operating Cost	$572,000	$506,000	$440,000	$374,000	$308,000
Annual Capital Cost	162,000	162,000	162,000	162,000	162,000
Total Annual Cost	$734,000	$668,000	$602,000	$536,000	$470,000
Unit Cost, $\$/ft^3$ Reduced Volume	116	105	95	85	74
% Change in Total Annual Cost	22	11	-	-11	-22
% Change in Unit Cost	22	11	-	-11	-22

TABLE 8. Effects of Varying Capital Cost (Same bases as Table 5)

	Change in Capital Cost				
	+30%	+15%	Base Case	-15%	-30%
Annual Operating Cost	$440,000	$440,000	$440,000	$440,000	$440,000
Annual Capital Cost	211,000	186,000	162,000	138,000	113,000
Total Annual Cost	$651,000	$626,000	$602,000	$578,000	$553,000
Unit Cost, $/ft^3$ Reduced Volume	103	99	95	91	87
% Change in Total Annual Cost	8	4	-	-4	-8
% Change in Unit Cost	8	4	-	-4	-8

A facility life of 11 years has been used for this study but could decrease with advances in technology or for other reasons. Therefore, the effect of cutting the life of the facility in half is shown in Table 9. Both the total annual cost and the unit cost for vibratory finishing would increase by 15% due to a 54% increase in annual capital cost caused by the decrease in facility life. Although actual unit costs for a comparative geologic disposal process have not been determined, possible savings by vibratory finishing would be affected similarly.

Rough costs for vibratory finishing in a fixed facility are developed in Appendix B. Assuming that the same amount of TRU-contaminated materials would be processed as that for the mobile facility, the unit cost using the fixed facility would be $58/ft^3 of reduced volume ($6.70/ft^3 of the original reference glove box volume) as compared with $95/ft^3 ($11/ft^3 of the original glove box volume). The fixed facility costs are not optimized. Most of the unit cost reduction results from reducing labor costs.

TABLE 9. Effects of Varying Facility Life (Same bases as Table 5)

	Facility Life	
	5-1/2 Years	11 Years (Base Case)
Annual Operating Cost	$440,000	$440,000
Annual Capital Cost	250,000	162,000
Total Annual Cost	$690,000	$602,000
Unit Cost, $/ft^3, Reduced Volume	109	95
% Change in Total Annual Cost	15	-
% Change in Unit Cost	15	-

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APPENDIX A

LOW-INVENTORY, NONREACTOR NUCLEAR FACILITIES

APPENDIX A

LOW-INVENTORY, NONREACTOR NUCLEAR FACILITIES

According to Backman et al. (1981):[(a)]

> Many PNL-managed facilities contain low inventories of dispersible radioactive materials that are a necessary part of the programs conducted therein. The impact of an accident in these facilities would not be large to persons on the outside. A "low" inventory has been arbitrarily specified as the inventory of radioactive material that would be small enough to limit the consequences of a release to a maximum annual dose of 500 mrem to the critical organ of any individual located outside a facility should an accident occur within. The value of 500 mrem was selected as it is only 10% of the allowable radiation worker annual radiation dose limit to any critical organ. Also, the annual dose to an individual at the site boundary would be less than 50 mrem and, therefore, less than 10% of the allowable maximum annual dose to a member of the public.

The inventories of radioactive materials involved in a release without exceeding the abovementioned dose are contained in Table A.1. If more than one radionuclide is present at a work site, the amount of radioactive material may not exceed a quantity calculated using a formula given in the referenced document, wherein the sum of ratios of the individual quantities to the allowable quantity is equal to or less than 1. If the inventories of radionuclides were to be uncontrolled, the mobile facility might have to meet plutonium facility design requirements as given in Part II Buildings and Facilities Design, Section B - Plutonium Facilities, Facilities General Design Criteria, ERDA Appendix 6301. This document gives tornado and other wind and storm design requirements, seismic design requirements, and other requirements

(a) Backman, G. E., B. J. McMurray, N. P. Nisick and C. R. Richey. 1981. General Safety Assessment Document for PNL-Managed Nonreactor Nuclear Facilities. PNL-3280, Pacific Northwest Laboratory, Richland, Washington.

TABLE A.1. Limits on Curie Inventory Quantities for Radionuclides in Low-Inventory Facilities[(a)]

Radionuclide	Inventory, curies	Inventory, grams
^{3}H	2,100	2.2×10^{-1}
^{60}Co	850	7.5×10^{-1}
^{85}Cr	170,000	4.3×10^{2}
^{89}Sr	2,100	7.3×10^{-2}
^{90}Sr	550	3.8
^{99}Tc	6,500	3.8×10^{5}
^{106}Ru	480	1.4×10^{-1}
^{129}I	0.24	1.5×10^{3}
^{131}I	1.1	8.9×10^{-6}
^{137}Cs	7,500	7.6×10
^{144}Ce	550	1.7×10^{-1}
^{226}Ra	3.2	3.3
^{235}U	7.5	3.5×10^{6} [(b)]
^{238}U	8.0	2.4×10^{7}
^{237}Np	1.8	2.6×10^{3}
^{238}Pu	1.5	8.9×10^{-2}
^{239}Pu	1.7	2.8×10
^{240}Pu	1.7	7.5
^{241}Pu	850	7.5
^{241}Am	1.5	4.6×10^{-1}
^{243}Cm	1.5	3.6×10^{-2}
^{244}Cm	1.5	1.8×10^{-1}

(a) Backman, G. E., et al. 1981.
(b) Although a facility may have less than threshold quantities of ^{235}U in the form of enriched uranium, it is classified as a Principal Nonreactor Nuclear Facility if the amount of enriched material exceeds 45% of a minimum critical mass, i.e., a Fissionable Material Facility.

to assure that the design of the facility will protect the public and operating personnel from hazards associated with normal plutonium operations or design basis accident (DBA) conditions.

At this stage of evaluating a mobile, trailer-contained, vibratory finishing decontamination facility, it appears impractical for the facility to meet requirements other than those of low-inventory nonreactor nuclear facilities; i.e., the radionuclides must be controlled to below the quantities given in Table A.1.

An example of TRU-contaminated material that may be processed in a mobile vibratory finishing facility is the metal scrap stored at the Idaho National Engineering Laboratory (Abrams et al. 1980). This stored metal scrap, with a density of 26 lb/ft^3, has a ^{239}Pu content of 0.090 g/ft^3. If this scrap were sectioned (and no decontamination assumed) and placed into 55-gal drums so that a drum would contain 300 lb of the waste, the drum would then contain about 1 g ^{239}Pu. If the equivalent of the TRU contaminants from 10 drums of waste were in the vibratory finishing facility, about 10 g of ^{239}Pu would be present, whereas the control level in Table A.1 is 28 g for a low-inventory facility. Thus, administrative controls of curie inventories apparently can be reasonably achieved without overburdening operations of the facility.

APPENDIX B

COSTS FOR A FIXED VIBRATORY FINISHING FACILITY

APPENDIX B

COSTS FOR A FIXED VIBRATORY FINISHING FACILITY

Both the capital and operating costs for a fixed facility for vibratory finishing of TRU-contaminanted metallic and nonmetalic materials can differ depending on whether a new building is required or unoccupied space in an existing low-inventory nonreactor nuclear facility can be used. Rough estimates, intended to illustrate possible fixed facility costs, are given below.

FIXED FACILITY CAPITAL COST ESTIMATES

A cursory look has been taken of a facility in which existing unoccupied space is used. It is assumed for this case that the space would be adjacent to other working areas and that utilities and services, such as HVAC, would be available. No capital cost for a building would be required; the only capital requirement would be that for process equipment and installation and for working capital. A contingency of 40% is used as there are many unknowns in this case. Capital costs for this facility based upon those in Table 3 are below.

Process Equipment	$421,000
Contingency @ 40%	168,000
Fixed Capital Cost	$589,000
Working Capital	
(2 month Operating Cost)	45,000
Total Capital Cost	$634,000

FIXED FACILITY OPERATING COST ESTIMATE

In the mobile facility, two workers are required to be in the unit; this is not an operating need, but a safety requirement. The supervisor and a radiation monitor would have to spend more time with the isolated mobile facility than with a fixed facility adjacent to other work areas, primarily because of travel between locations. Consequently, the amount of labor required for a fixed facility would be half that needed for a mobile facility. This is reflected in estimated operating costs given in Table B.1.

Maintenance and repair costs for a fixed facility would also be less than those for a mobile facility since there would be no additional, or at least very minimal, building maintenance costs. Costs for utilities, LLW disposal, and TRU geologic disposal would be identical for both the mobile and fixed facilities.

Process materials costs would be the same for the mobile or fixed facility, except for protective clothing and laundry, which are directly associated with the number of workers involved and their need to periodically leave the facility. Since the fixed facility would have full services, the single worker assigned full time to vibratory finishing would have less need to change clothing, as also would the supervisor and radiation monitor. The latter costs

TABLE B.1. Fixed Facility Operating Cost

Labor	$106,000
Maintenance and Repair	35,000
Process Materials	
Chemical concentrate	600
Metal vibratory finisher media	5,100
Filter cartridges	2,000
Portland cement	300
Drums (55-gal)	17,500
Protective clothing-laundry	800
Operating supplies	10,000
Utilities	
Water	negligible
Electricity	3,300
LLW Disposal	24,000
TRU Geologic Disposal	12,000
Subtotal (rounded)	$217,000
Contingency (25%)	54,000
Total Operating Cost	$271,000

prorated for all operations in the building. It was assumed that the equivalent of 2-3/4 changes of clothing per day could be charged to the vibratory finishing operation.

Based upon the above assumptions, the total operating cost for vibratory finishing in a fixed facility would be about $271,000.

ANNUAL COSTS

The same equation as in the body of the report was used to determine capital recovery or annual capital costs. The values for the equation are P = $634,000, L = $74,000 ($29,000 as salvage value at 5% of initial fixed capital cost and $45,000 as working capital recovered as end of facility life), i* = 10% (discount rate), n = 11 yr (facility life), and the capital recovery factor $(A/P)_{i*,n}$ = 0.15396. The annual capital cost was calculated to be $94,000.

The estimated total annual cost and unit cost for vibratory finishing TRU-contaminated metallic and nonmetallic materials are below:

Annual Operating Cost	$271,000
Annual Capital Cost	94,000
Total Annual Cost	$365,000
Unit Cost,	
$/ft³ (reduced volume)	58
$/ft³ (original volume[a])	6.70

The total annual cost and unit cost for a fixed facility are about 60% of similar costs for the mobile facility. This is due to substantially less capital investment and labor cost.

(a) Based on the reference glove box described by Abrams et al. (1980).

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