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An Evaluation of Supercompaction of Drums Containing Solid Low-Level Waste from Oak Ridge National Laboratory

J. M. Kennerly
A. L. Rivera
R. W. Morrow
L. C. Williams

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ORNL/TM-10652

Chemical Technology Division
Waste Management Technology Center

AN EVALUATION OF SUPERCOMPACTION OF DRUMS CONTAINING SOLID LOW-LEVEL WASTE FROM OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

The activities and results described in this report are part of the Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program to evaluate candidate technologies, including volume reduction, which are likely to be incorporated into low-level radioactive waste (LLW) management facilities planned for the 1990s. A significant cost-effective reduction in the space required for disposal of solid LLW is being investigated as a key element in implementing a strategy for managing LLW at Department of Energy facilities.

Supercompaction and grouting technologies were demonstrated with solid LLW from Oak Ridge National Laboratory at the Solid Waste Storage Area 5 (SWSA 5) between March 9 and 27, 1987. The subcontractor, US Ecology of Louisville, Kentucky, used its mobile supercompaction system operating at 2200 tons of compressive force to volume reduce 300 55-gal drums of solid LLW. The supercompaction of these drums resulted in a disposal capacity savings of about 85% of the original disposal capacity needs. The packaging of the compacted drums into 47 overpacks decreased the disposal capacity savings by about 19%. The net disposal capacity savings from the demonstration project is about 66% of the original, uncompacted waste volume.

Based on the approximately $95K in direct costs, the supercompaction of the 2304 ft^3 of waste processed cost about \$41/ft^3 of uncompacted waste. Once the supercompaction unit was set up and operating, the incremental cost for the supercompaction services was only about \$4/ft^3. The economic assessment for this project revealed that the cost-effectiveness of on-site demonstrations is very sensitive to the on-site support (non-vendor-related) costs. The minimum disposal costs for cost-effectiveness in this demonstration project was calculated to be about \$18/ft^3 for no on-site support costs and about \$180/ft^3 when the on-site support costs represented about 90% of the total demonstration project cost.

The most significant conclusions and recommendations from the demonstration are related to equipment improvements, costs, characteristics of drums, and media coverage.

1. EXECUTIVE SUMMARY

The Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program, being carried out by Oak Ridge National Laboratory (ORNL) for the U.S. Department of Energy, Oak Ridge Operations (DOE/ORO), is investigating candidate technologies for managing low-level radioactive wastes (LLW). Cost-effective volume reduction of solid LLW to achieve a significant reduction in the space required for disposing of this type of waste is a key element in implementing the strategy for managing LLW at DOE facilities. The activities and results described in this report are part of the overall LLWDDD Program to evaluate candidate technologies, including volume reduction, which are likely to be incorporated into LLW management facilities planned for the 1990s.

A demonstration of supercompaction and grouting of 300 55-gal drums of solid LLW from ORNL was successfully completed between March 9 and 27, 1987, at the ORNL Solid Waste Storage Area 5 (SWSA-5). All drums had been examined by real-time radiography (RTR) prior to being processed so that those drums containing free liquids could be identified and eliminated. The subcontractor, US Ecology of Louisville, Kentucky, used its mobile supercompaction system operating at 2200 tons of compressive force. During the demonstration, the 300 drums were reduced in volume by a factor of approximately 6.7:1; following grouting of the supercompacted drums into forty-seven 125-gal overpacks, the overall volume reduction was approximately 2.9:1.

During the crushing of the drums, it was found that absorbed liquids undetected by the RTR examinations were released and collected from 94 of the 300 drums in amounts varying from a fraction of a pint up to 3 gal. A total of about 60 gal of fugitive liquids was collected during the processing. However, contamination of the supercompaction unit was insignificant, and decontamination to meet U.S. Department of Transportation (DOT) standards was carried out at the conclusion of the processing to the satisfaction of Martin Marietta Energy Systems and US Ecology.

Following a 2-d period (March 10 and 11) of orientation and whole-body counting of US Ecology personnel and surveying of the supercompactor to establish a baseline contamination level, setup activities were conducted at the job site from March 12 to 16. During setup, US Ecology assembled their processing unit on one trailer and carried out some preliminary decontamination in and around the hydraulic press unit to meet ORNL "green tag" levels for tranferrable radiation as specified by Energy Systems in the Statement of Work. As received, the press unit had failed to meet ORNL specifications for transferrable and fixed radiation contamination.

ORNL Plant and Equipment personnel then constructed a temporary containment enclosure of wood, plastic sheeting, and plywood around the exit side of the press to serve as a "contaminated" (C-zone) operating area. An air-lock enclosure at the entrance to the C-zone work area was also provided. Other setup activities included the placement and interface of a large mobile diesel generator unit adjacent to the job site. This unit was brought from Y-12 to generate the 480-V, 3-phase, 220-A power required.

Compacting of LLW drums actually began on March 17 and continued through March 23, 1987. The number of drums processed per day varied from 27 to 75, reflecting the influence of the delay introduced by the cleanup required after liquids squeezed out of drums contaminated the press equipment. Grouting of the overpacks was completed on March 25, and decontamination to meet DOT standards was carried out on March 26. The supercompaction unit was demobilized from the job site on March 27, and the temporary enclosure was taken down.

The direct costs incurred included a payment to US Ecology of approximately $41.5K and an overhead charge of about $12.5K. Site support and miscellaneous charges associated with the demonstration activities are estimated at about $40K; these charges include construction, rigging, materials, health physics services, and other costs. Waste Management Operations and LLWDDD labor costs, procurement services, disposal cost for the overpacks, and certain other charges are not included. Of the $41.5K in direct charges by US Ecology,

\$13K was for mobilization to and demobilization from the site, \$8.7K was for the actual supercompaction and grouting of the drums, and approximately \$19.8K was for the overpack and reinforcing cage used to produce the final waste form around the stack of compacted drums.

Based on the approximately \$95K in direct costs, the supercompaction of the 2304 ft^3 of waste processed cost about \$41/ft^3 of uncompacted waste. If Energy Systems had opted only to supercompact the drums, omitting the grouting operation by the vendor, the cost would have been approximately \$32/ft^3 of uncompacted waste. Based on the on-site vendor charges for the supercompaction services once the unit was set up and operating, the incremental cost for the supercompaction was only about \$4/ft^3. Thus, to minimize the cost for the on-site supercompaction services, two cost-determining factors must be considered: (1) maximization of the number of drums processed and (2) minimization of the on-site, non-vendor-related support costs.

The non-vendor-related on-site support costs could be significantly reduced by the use of a permanent facility where a supercompaction unit could be set up and operated. For comparison purposes, placement of the supercompacted drums into a concrete vault of the type proposed for the ORNL above-grade tumulus disposal unit, followed by grouting of the void spaces surrounding the waste, is estimated to cost about \$4/ft^3 of uncompacted volume. In contrast, the overpacking and grouting performed by US Ecology cost approximately \$9/ft^3 of uncompacted volume.

A systems analysis study was conducted to evaluate the results of this demonstration project with respect to the applicability of this technology as an element of the solid LLW management system. The supercompaction of 300 drums resulted in a disposal capacity savings of about 85% of the original disposal capacity needs. The packaging of 300 compacted drums into 47 overpacks decreased the disposal capacity savings by about 19%. The net disposal capacity savings from the demonstration project is about 66% of the original uncompacted waste volume.

About 40% of the 300 drums had uncompacted densities of 10 to 15 lb/ft^3. All uncompacted drums had densities less than 55 lb/ft^3. The compacted densities ranged from 30 to 270 lb/ft^3. About 66% of compacted drums had densities between 75 and 140 lb/ft^3. A volume reduction factor lower than 10 was obtained from drums whose uncompacted density was greater than 12 lb/ft^3. For drums with an uncompacted density lower than 12 lb/ft^3, a volume reduction factor of 10 to 30 was obtained.

A differential cost analysis was performed on those elements of the waste management system that were not common to current practices and to this demonstration project as alternative scenarios. It was found that the cost-effectiveness of using supercompaction/grouting service contracts for the management of solid LLW at ORNL can be increased by

1. increasing the scale of the operation,
2. increasing the number of drums per overpack, and
3. decreasing the non-vendor-related project support costs.

The economic assessment for this project revealed that the cost-effectiveness of on-site demonstrations is very sensitive to the on-site support (non-vendor) costs. The minimum disposal cost required for cost-effectiveness in this demonstration project was calculated to be about $18/$ft^3$ for no on-site support costs and about $180/$ft^3$ when the on-site support costs represented about 90% of the total demonstration project cost.

The means for final disposal of the overpacks has not been decided upon, although a hill-cut unit, a greater confinement disposal silo, and placement on the tumulus are being considered.

No accidents, injuries, environmental releases, radiation releases, or worker exposures occurred as a result of the demonstration. Favorable publicity was generated by three local television news releases and in local newspaper coverage. In addition, the demonstration was witnessed on two occasions by representatives of the Tennessee Department of Health and Environment.

Photographs and a videotape of the demonstration were made and US Ecology supplied information regarding their processing experience. Other supporting information that was required for the demonstration included environmental, health, safety, and quality assurance documentation.

The most significant conclusions and recommendations from the demonstration, which were related to equipment improvements, costs, characteristics of the drums, and media coverage, are as follows:

1. An improved system is needed for collecting fugitive liquids released during the compaction process. This improvement would significantly reduce delays in the operation to clean up liquids released to the drum press area.
2. A vendor-supplied radiation containment enclosure on the outlet side of the supercompaction unit would facilitate setup and would reduce site support costs.
3. Because the RTR system cannot detect absorbed liquids on such items as mop heads and absorbent materials, these wastes should be segregated from the dry materials at the point of generation and should be clearly identified.
4. Favorable media coverage resulted from the demonstration, crediting DOE/ORO and Energy Systems for their efforts to improve radioactive waste management practices. Careful planning of the media event after achieving successful operation greatly increases the likelihood of a favorable impression of the technology being demonstrated.

2. INTRODUCTION

2.1 COORDINATION OF WASTE MANAGEMENT DEMONSTRATION ACTIVITIES

The Oak Ridge Model has been established to provide oversight and direction for identifying and implementing acceptable solutions to waste management problems through interaction among the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), state regulators, the private sector, and academic institutions. The Oak Ridge Model is the means that DOE's Oak Ridge Operations (DOE/ORO) will use to carry out a corporate approach to solving waste management problems that exist at its facilities.

Operating as the technology demonstration arm of the Oak Ridge Model, the Waste Management Technology Center (WMTC) was established as a service organization to address the overall waste management demonstration within DOE/ORO. In order to accomplish this task, the WMTC will be conducting, coordinating, or participating in a variety of activities directly related to defining acceptable solutions to DOE/ORO waste management problems. There will be a greater focus on the actual demonstrations of available technology using DOE/ORO waste materials. These demonstrations are expected to be conducted primarily by qualified companies within the private sector who will be selected for participation through a Request for Proposal (RFP) process to be conducted by the Purchasing Division of Martin Marietta Energy Systems, Inc. During the performance of these demonstrations, the WMTC will be accumulating information needed to define an overall waste management strategy for DOE/ORO facilities.

Ultimately, the information generated by the waste management demonstrations to be conducted over the next several years will be used to identify and provide treatment, storage, and disposal facilities and/or services for DOE/ORO which will be acceptable to the regulatory agencies, the public, and DOE.

2.2 DEMONSTRATION OF IMPROVED SOLID WASTE DISPOSAL PRACTICES

DOE/ORO facilities have large quantities of high-volume, low-activity, solid low-level wastes (LLW) being generated at seven sites

[Oak Ridge National Laboratory (ORNL), Oak Ridge Gaseous Diffusion Plant (ORGDP), and the Y-12 Plant, Oak Ridge, Tennessee; Portsmouth Gaseous Diffusion Plant, Piketon, Ohio; Paducah Gaseous Diffusion Plant, Paducah, Kentucky; RMI Extrusion Plant, Ashtabula, Ohio; and the Westinghouse Feed Materials Production Center, Fernald, Ohio]. Shallow-land burial is the primary means of disposal for this solid LLW. Because available space for this method of disposal is being used up rapidly, volume reduction for solid wastes is being pursued vigorously as the most promising means readily available for extending the life of existing facilities and for reducing the scope of future facilities.

Supercompaction is an effective mechanical volume reduction process that is distinguished from ordinary compaction by the force delivered by the press (>1000 tons of compressive force). Commonly used by the nulcear power industry to reduce the volume of waste prior to storage and disposal, supercompaction has been recognized as being capable of volume reducing wastes formerly considered to be noncompactible. Materials in this category include structurally rigid items, such as pipes, valves, motors, certain construction materials, etc.

Demonstration of supercompaction capabilities available from the private sector is a key element in the implementation of the Low-Level Waste Disposal Development and Demonstration (LLWDDD) strategy. The planned volume reduction demonstration program includes supercompaction of a variety of DOE/ORO wastes and a comparison of processing on-site (at a DOE/ORO facility) and off-site (at a private sector facility). There are certain risks and cost factors associated with on-site vs off-site processing which the demonstration program will address and evaluate.

The demonstration described in this report was among the first in which a private sector company, selected by a competitive bidding process, was contracted to demonstrate available waste management technology applicable to DOE/ORO solid LLW. As a result of the demonstration, Energy Systems, serving as the operating contractor for five of the DOE/ORO facilities, intends to use the information gained from this demonstration, and from future demonstrations involving other enhanced waste forms, to ultimately define a waste disposal process for LLW which will be acceptable to the regulatory agencies and to DOE/ORO.

In this demonstration, conducted by US Ecology of Louisville, Kentucky, 300 55-gal drums containing solid LLW were crushed at Solid Waste Storage Area 5 (SWSA 5) on the Oak Ridge Reservation. The crushed drums were then placed in overpack containers and encapsulated by injecting the containers with grout/cement to fill all voids and produce a stable waste form. All activities during the demonstration were subject to the requirements detailed in the statement of work (SOW), which was part of the RFP.[1] This document contained provisions for ensuring the protection of workers and the environment, as well as the overall interests of Energy Systems and DOE/ORO.

2.3 OBJECTIVES OF THIS DEMONSTRATION

To produce an enhanced waste form having greater integrity and resistance to permeation by groundwater, the LLWDDD Program, managed by the WMTC, is considering the encapsulation of volume-reduced wastes in high-density grout within suitable containers prior to disposal. The resulting waste forms will be used to evaluate the potential of this technique for achieving greater waste stability and isolation. In carrying out this demonstration, the WMTC intended to obtain cost and performance information related to supercompaction of solid LLW drums and subsequent grout/cement encapsulation of the compacted drums in suitable overpacks.

In order to obtain cost and performance information related to volume reduction and encapsulation of the 300 55-gal drums processed during this demonstration, the following specific objectives were specified in the SOW:

1. obtain compaction factors for the individual drums,
2. obtain subcontractor and internal (Energy Systems) support costs for the on-site supercompaction and encapsulation service,
3. evaluate the effectiveness of the real-time radiography (RTR) unit used by ORNL to identify drums containing free liquids,

4. assess the problems associated with fugitive liquids and the volume of liquid liberated from the supercompacted drums,
5. assess operating problems associated with this technology, and
6. evaluate health physics and industrial hygiene data.

In general, the presence of undetected liquids in containers of contaminated solid waste that will eventually undergo compaction is undesirable. The RTR system used by ORNL, a continuous X-ray technique installed at the Waste Examination and Assay Facility, has been developed for examining and certifying that free liquids are absent from containers of waste. This system is shown in Fig. 2.1. An important objective of this demonstration was to evaluate the effectiveness of the RTR technique by observing the amount of liquids released during the compaction process. During the demonstration, the volume of liquid released from individual drums was recorded by US Ecology. Although the handling of fugitive liquids proved to be somewhat of an operational problem, all liquids were contained, collected, and returned to Energy Systems.

ORNL PHOTO 8615-85

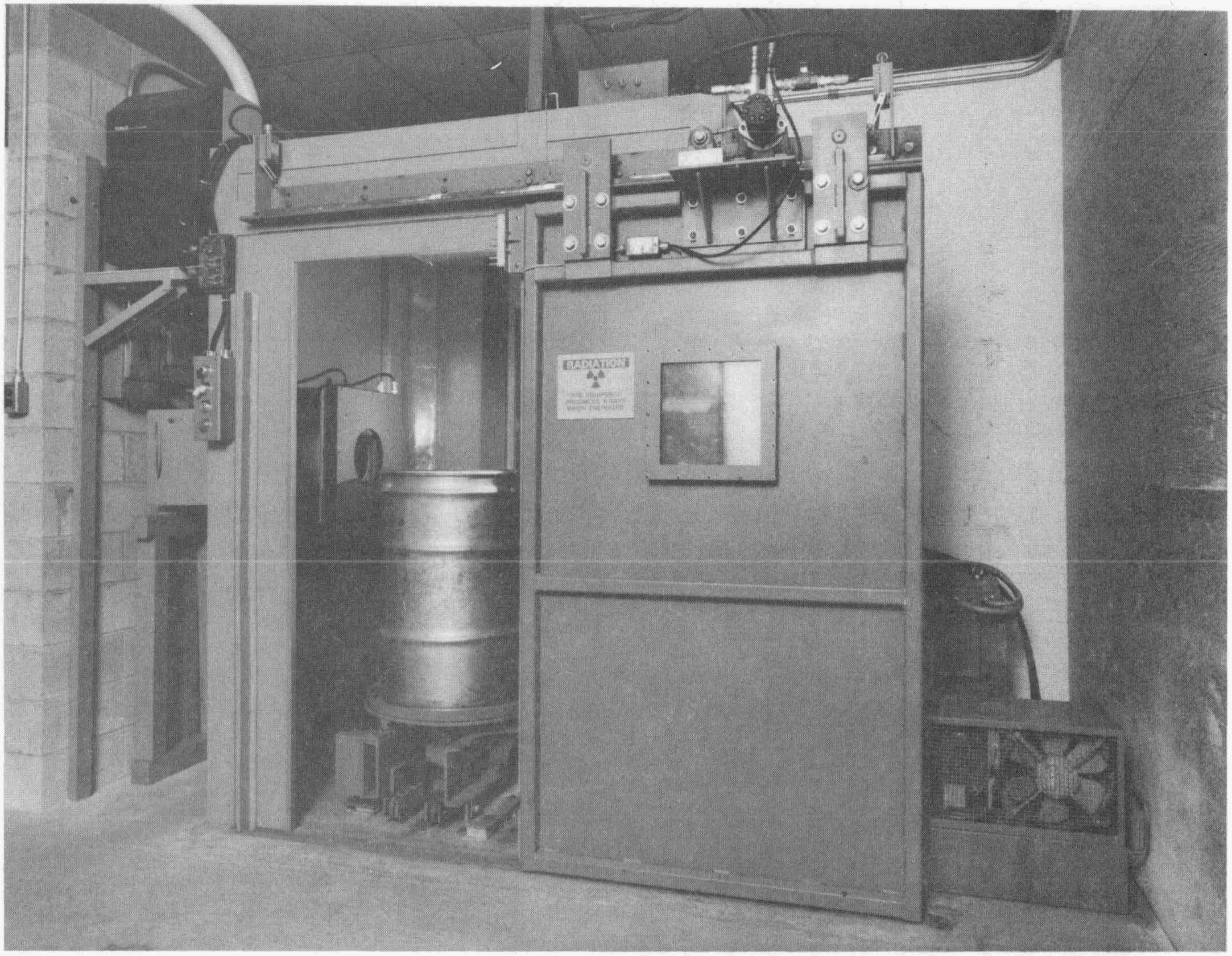

Fig. 2.1. Real-time radiography (RTR) unit.

3. DESCRIPTION OF ACTIVITIES

3.1 SCOPE OF WORK

US Ecology furnished on-site supercompaction capabilities at ORNL's SWSA-5 to compact 300 55-gal drums containing solid LLW. Energy Systems personnel provided site support for the demonstration, including the construction of a temporary enclosure on the outlet side of the supercompactor to contain any fugitive radioactivity that could have been generated during the course of the activities. In addition, other support provided by Energy Systems included the staging of 300 drums near the inlet of the drum press; the provision and operation of a mobile generator to supply the 480-V, 3-phase, 220-A power required; and the provision of on-site personnel (health physics, operations interface, project manager, and craft support). The supercompaction unit as set up at SWSA-5 is shown in Fig. 3.1.

The 300 55-gal drums of waste processed were characterized by ORNL prior to the demonstration and were provided to US Ecology at the SWSA-5 work site. The low-level, radioactively contaminated wastes contained in the drums can be described as bulk solids containing low concentrations of fission products. The external gamma radiation levels for all drums was limited to 200 mrem/h as determined by existing ORNL procedures. However, to limit the potential for a significant release of radiation in fugitive liquids pressed out of the waste during the compaction process, the decision was made during the demonstration to process only drums having an external radiation level of no more than 50 mrem/h. The transuranic content of the waste was limited to 100 nCi/g. The waste materials in the drums included clothing, shoe covers, rags, protective equipment, paper, plastic, wood, building materials, a wide variety of metal objects (including pipe and valves), and decontamination and cleanup materials. All drums had been examined by the RTR technique to detect liquids before delivery to US Ecology, and a videotape of the examination was kept as a record. Many of the drums, which were not of the type approved by the U.S. Department of Transportation (DOT) as suitable for shipment over the public highways, were ideal for an on-site demonstration.

ORNL PHOTO 2488-87

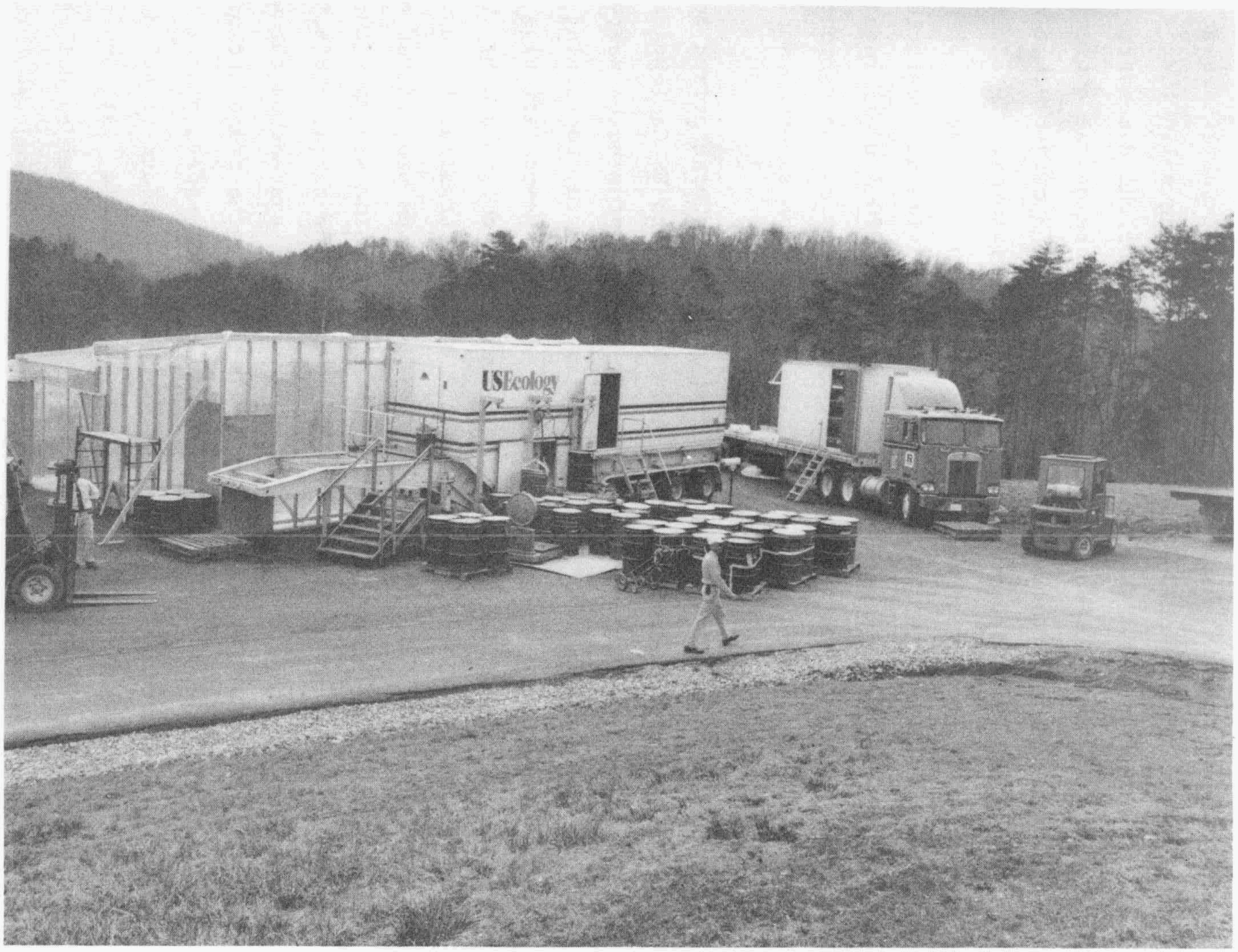

Fig. 3.1. Supercompaction unit set up at SWSA-5 site.

During the supercompaction, US Ecology placed the supercompacted drums (pucks) in 125-gal steel overpacks fitted with a reinforcing steel cage around the stack of pucks. Following the compaction operations, US Ecology filled the annular space around the stack of pucks in the 47 overpacks with a cement grout specified to have a minimum unconfined compressive strength of 2000 psi. The cement grout was supplied by a local firm and was delivered in standard trucks fitted with rotating tilt mixers. A nominal thickness of 3 in. of grout was placed between the stack of pucks and the wall of the overpack during the generation of the final waste form.

Energy Systems provided US Ecology personnel with an initial orientation in which ORNL health, safety, and environmental protection requirements were described. As an added precaution, Energy Systems carried out whole-body radiation counting surveys for all US Ecology personnel upon their arrival and before their departure. In addition, Energy Systems established a "baseline" radiation survey of the US Ecology equipment upon its arrival and before demonstration activities were allowed to begin. These surveys were repeated after the final decontamination procedures were carried out, prior to releasing the equipment for transport over public highways under DOT requirements, as summarized in a letter[2] from R. L. Jeffers of the ORNL Radiation and Safety Surveys Department. As a result of the initial, baseline survey, US Ecology was required to carry out a moderate amount of decontamination before beginning the supercompaction operations. During this decontamination, it was verified to Energy Systems that the ORNL "green tag" threshold radiation level for transferrable radiation was not being exceeded.

Considerable internal documentation is required by Energy Systems for on-site demonstrations in which a subcontractor performs work on DOE/ORO facilities with DOE/ORO wastes. The purpose of the documentation is to protect the interests of Energy Systems and DOE/ORO in activities carried out by a subcontractor. As a result of this demonstration and others conducted under similar circumstances, this documentation, designed to protect the interests of all involved, has proven to be invaluable. For this on-site demonstration, the following documentation was provided:

1. Statement of work for supercompaction and grouting of RTR Drums,[1] including an appendix detailing the Energy Systems administrative requirements regarding environmental, health, safety, and transportation protection with which the subcontractor is required to comply.
2. Documents for both the supercompaction and grouting activities to satisfy National Environmental Policy Act requirements for environmental activities and address the environmental protection of the site during the demonstration.
3. Safety assessment documentation for all demonstration activities, to determine the adequacy of US Ecology's and Energy Systems' safety systems associated with the demonstration activities. No further documentation (such as a final safety analysis report or an operational safety requirements document) was found to be required.
4. Quality assurance documentation covering Energy Systems' support for the demonstration.

A summary of processing data and experience was supplied by US Ecology in late July 1987 that provided details of the on-site demonstration results for the supercompaction of the 300 RTR-examined drums and the forty-seven 125-gal grouted overpack waste forms produced. Much of the information contained in this report is based on the data and descriptions supplied by US Ecology in their summary.

3.2 EQUIPMENT DESCRIPTION AND SPECIFICATIONS

The US Ecology supercompactor consisted of a 2200-ton vertical hydraulic press built onto a 49-ft double-drop trailer equipped with two fixed axles and two steerable axles. Because of the high payload, the trailer was designed with four axles and added length so that it could be transported through any state with overload permits. The tractor and compactor trailer weighed a total of 115,000 lb, creating axle weights of <18,000 lb. An artist's rendering of the supercompaction unit is shown in Fig. 3.2.

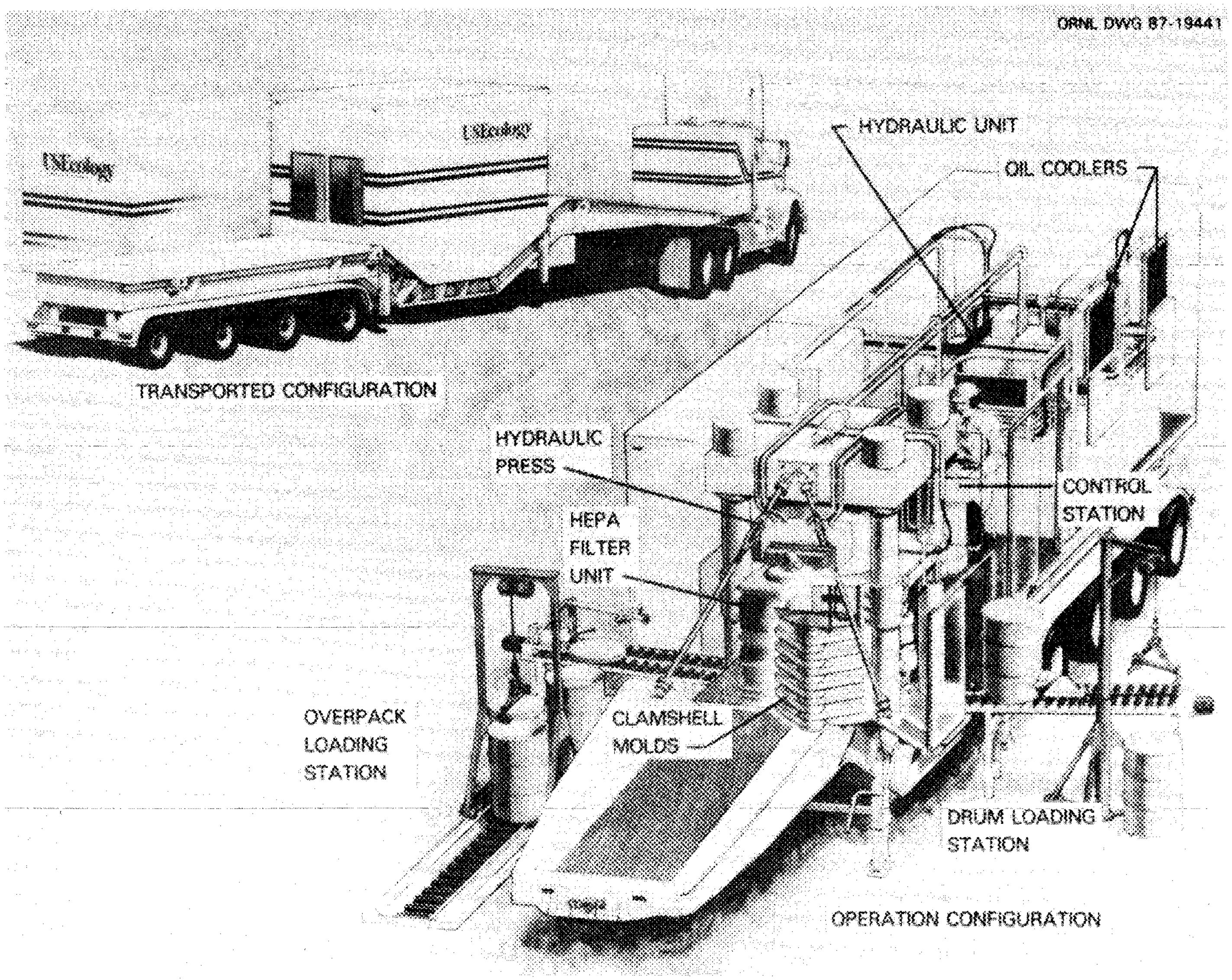

Fig. 3.2. US Ecology's supercompaction equipment.

The hydralic power unit and control room module were constructed so that they could be detached and shipped on a separate standard flat-bed trailer. When the supercompaction system arrived at ORNL, four jack stands were used to raise the hydraulic unit above the flat-bed trailer. The flat-bed trailer was then pulled from underneath the hydraulic power unit, and the compaction press trailer was positioned underneath the power unit. The power unit was then lowered onto the compaction trailer and attached with four standard cargo container locks. The assembled compactor unit was then ready for final assembly, which consisted of electrical power hookup, conveyor attachment, and hydraulic connections.

The vertical hydraulic press installed in the procesing trailer was manufactured by Hansa Projekt Company of the Federal Republic of Germany. Drums to be compacted were fed into the inlet side of the trailer by means of a conveyor to the press platform. A "clamshell" mold, hinged for easy opening and closing, closed and locked around the drum.

A hydraulically activated piston, having the same diameter as the drum, pressed the drum within the confines of the mold until a preset resistance (about 2200 tons for this demonstration) was met, stopping the stroke of the piston. The piston was then retracted, the clamshell mold was unlocked and opened, and the puck was withdrawn from the platform via a conveyor to the outlet side of the trailer. Doors were provided at both the inlet and outlet openings of the trailer; these doors were closed during compaction operations. A flow of air through the compaction area was provided during compaction by an induced-draft fan discharging through a HEPA filter and a carbon bed. All operations were observed and controlled from the control booth, from which the operator could see the movement of drums into and out of the compaction area through glass windows.

3.3 OPERATION OF THE SUPERCOMPACTOR

The supercompactor was operated by a four-person crew consisting of an operator, a drum loader, a compacted drum handler, and a person to manage the required documentation. Operation of the compactor was done completely within the compactor control room, from which the operator initiated the sequences and the microprocessor controlled the chain of events. The computer system constantly monitored many interlocks, hydraulic temperatures and pressures, and the air filtration and conveyor systems. The operator viewed the press operation through the press-room windows and monitored the compaction input and output via the closed-circuit television system. Emergency stop buttons, located in six strategic locations throughout the unit, were provided to shut down all electrical hydraulic power. The hydraulic system was powered by two 72-hp electric motors, each of which was connected to two hydraulic pumps. An additional 10-hp motor and pump supplied all the system hydraulics other than that to the main piston. In addition to the standard hydraulic hardware, the system included automatic oil coolers and heaters, filter monitors, and oil spill warning lights.

Environmental controls on the compaction system included an air emission control system consisting of a HEPA filter and a carbon bed. The HEPA filter cartridge was tested by Energy Systems personnel and was determined to have a removal efficiency of 99.93% at 0.3 μ. Roll-up air-lock doors were closed during the entire compaction operation, sealing off the press compartment entirely. During the time when the press compartment was sealed, the air filtration system was drawing air from a ring just above the clamshell mold at a flow rate of about 260 ft^3/min, thereby creating a negative pressure within the press compartment to prevent the outflow of fugitive emissions. Air withdrawn from inside the press compartment was passed through HEPA and charcoal filters and then exhausted to the atmosphere. A differential pressure sensor across the filter cartridges was provided to signal the operator when cartridges needed to be replaced to maintain optimum flow and efficiency.

3.4 DESCRIPTION OF THE SUPERCOMPACTION PROCESS

Energy Systems personnel staged the 55-gal drums near the inlet side of the compactor. From that point, US Ecology personnel took the drums, deformed the locking ring to minimize the diameter, and loaded the drums onto the input conveyor, as shown in Fig. 3.3. As each drum was made ready for input, the drum identification number and weight were recorded. After the drum was loaded onto the input conveyor, the control room operator initiated transport of the drum into the press, where the drum was automatically centered within the clamshell mold. As the input conveyor automatically retracted, an audible signal sounded and an indicator on the operator's control panel signaled completion of the first step.

The second step involved securing the press compartment and the clamshells. Roll-up doors on the inlet and outlet sides of the press compartment closed, and the air emission control system automatically started, creating a negative pressure within the compartment. The clamshell closing and locking procedure was then initiated. The clamshells rotated shut to completely enclose the drum within the mold. A dovetailed latch block was positioned to lock onto a matching dovetail built into the clamshells. Upon completion of these functions, the operator was then signaled that all interlocks were completed, and the compression cycle was begun.

During the compression cycle, the hydraulic ram crushed the drum with increasing force until a force of 2200 tons was measured by the system. At that point the hydraulic pressure was reduced, the clamshells were unlocked and opened, and the piston was retracted.

After all these steps were completed and the interlocks were satisfied, the air-lock doors were raised. The outlet conveyor started, and the puck was automatically retrieved from within the press. The compacted puck was then moved onto the storage conveyor to await overpacking. Each overpack had the capacity to store up to three pucks. Figure 3.4 illustrates a typical puck that has been withdrawn from the press. Three 125-gal overpacks were staged near the outlet conveyor, allowing the operator to choose the overpack which resulted in the best utilization of overpack capacity, thereby minimizing overpack cost and disposal volume. From the outlet conveyor, the operator lifted the puck with a vacuum hoist, transporting it along the monorail crane, and lowering it into one of the three overpacks.

ORNL PHOTO 2983-87

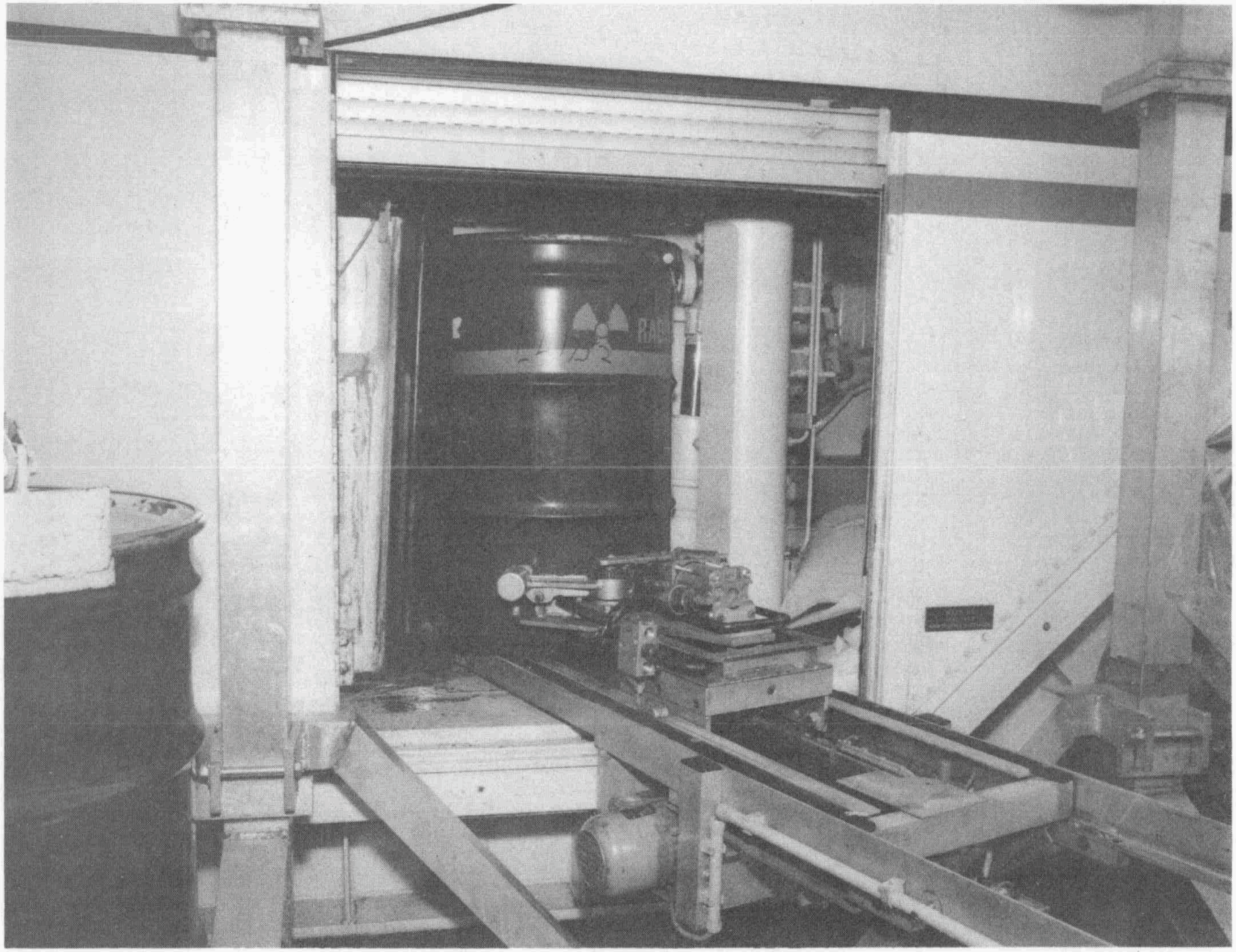

Fig. 3.3. Uncompacted drum in the press prior to closure of the clamshell mold.

ORNL PHOTO 2484-87

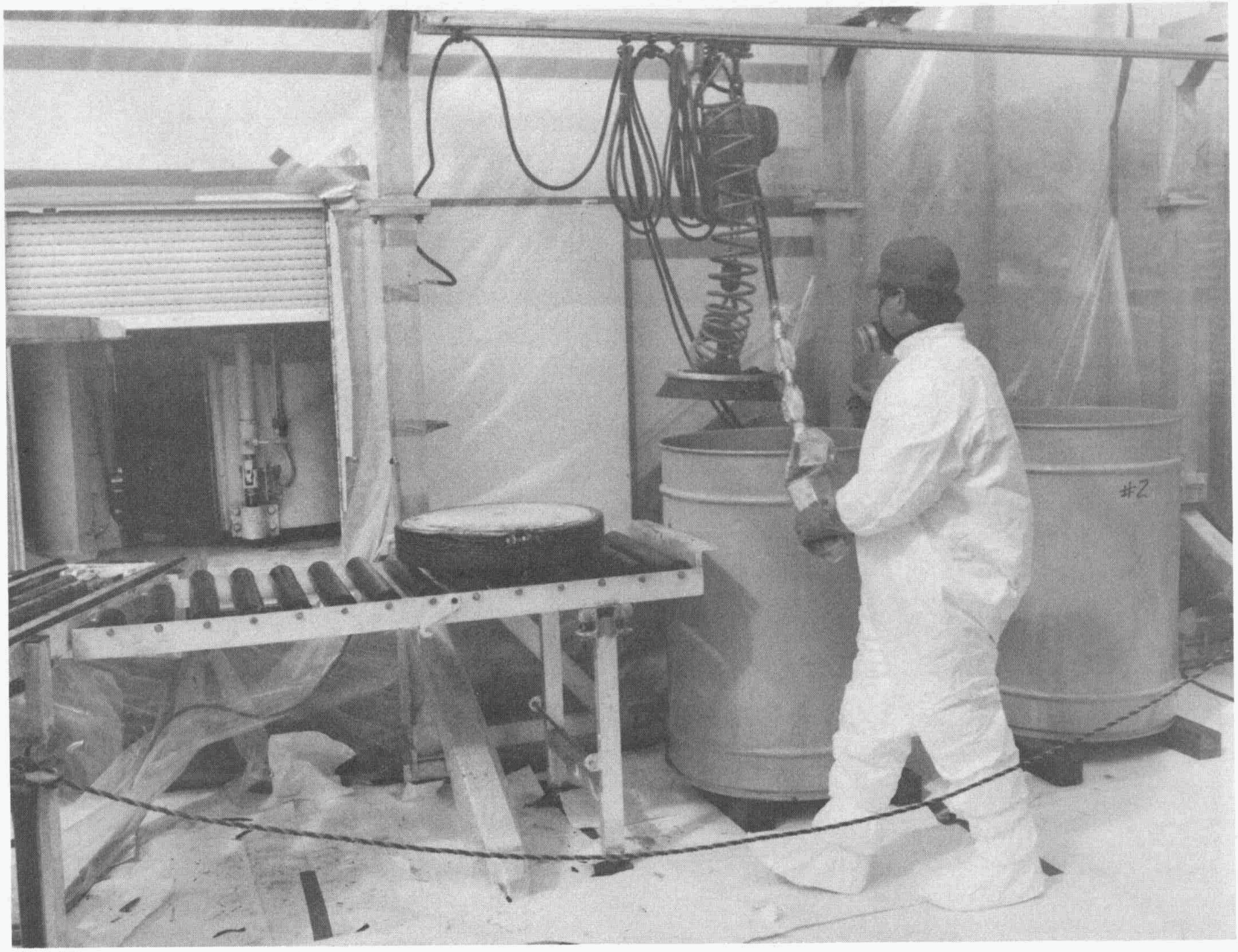

Fig. 3.4. Typical compacted drum (puck).

About one-third of the drums supercompacted released some amount of liquid during the pressing. Although the press area was equipped to contain a small amount of runoff in a containment vessel, volumes of liquid of about 1 quart or more presented unexpected cleanup problems. Liquids released tended to flow out into the area surrounding the clamshell and required removal before compaction could resume, thus causing a significant delay in operations. Energy Systems provided US Ecology a special portable vacuum system to facilitate removal of liquid releases. In addition to the cleanup of liquids in the press area, it was necessary to place blotter paper on the floor of the enclosure to absorb fugitive liquids which continued to drip out of the pucks on the conveyor.

US Ecology and Energy Systems personnel working within the radiation contamination control enclosure were required to wear protective clothing and fitted respirators equipped with combination cartridges. The clothing included disposable Tyvex suits and shoe covers. Continuous alpha and beta/gamma radiation monitors were used inside the enclosure to detect any release of radioactivity.

3.5 DESCRIPTION OF THE OVERPACKING AND GROUTING OPERATION

To comply with the Energy Systems requirement that the compacted drums be surrounded by a nominal 3 in. of reinforced concrete in the final waste form, US Ecology opted to construct the waste form by using a precast bottom concrete billet containing the preformed steel reinforcing bars that would surround the stack of pucks. The 3-in.-thick billet containing the reinforcing bars was placed in the overpack prior to the staging of the overpack near the outlet conveyor. A typical overpack containing the billet with reinforcing steel is shown in Fig. 3.5. The layout of the reinforcing steel within the waste form is shown in Fig. 3.6. As each compacted drum was placed in the overpack, it was centered within the steel reinforcement. Succeeding compacted drums were handled in this same manner. If any drums had unlevel tops or bottoms, a precast concrete spacer was used to keep the pucks centered within the overpack.

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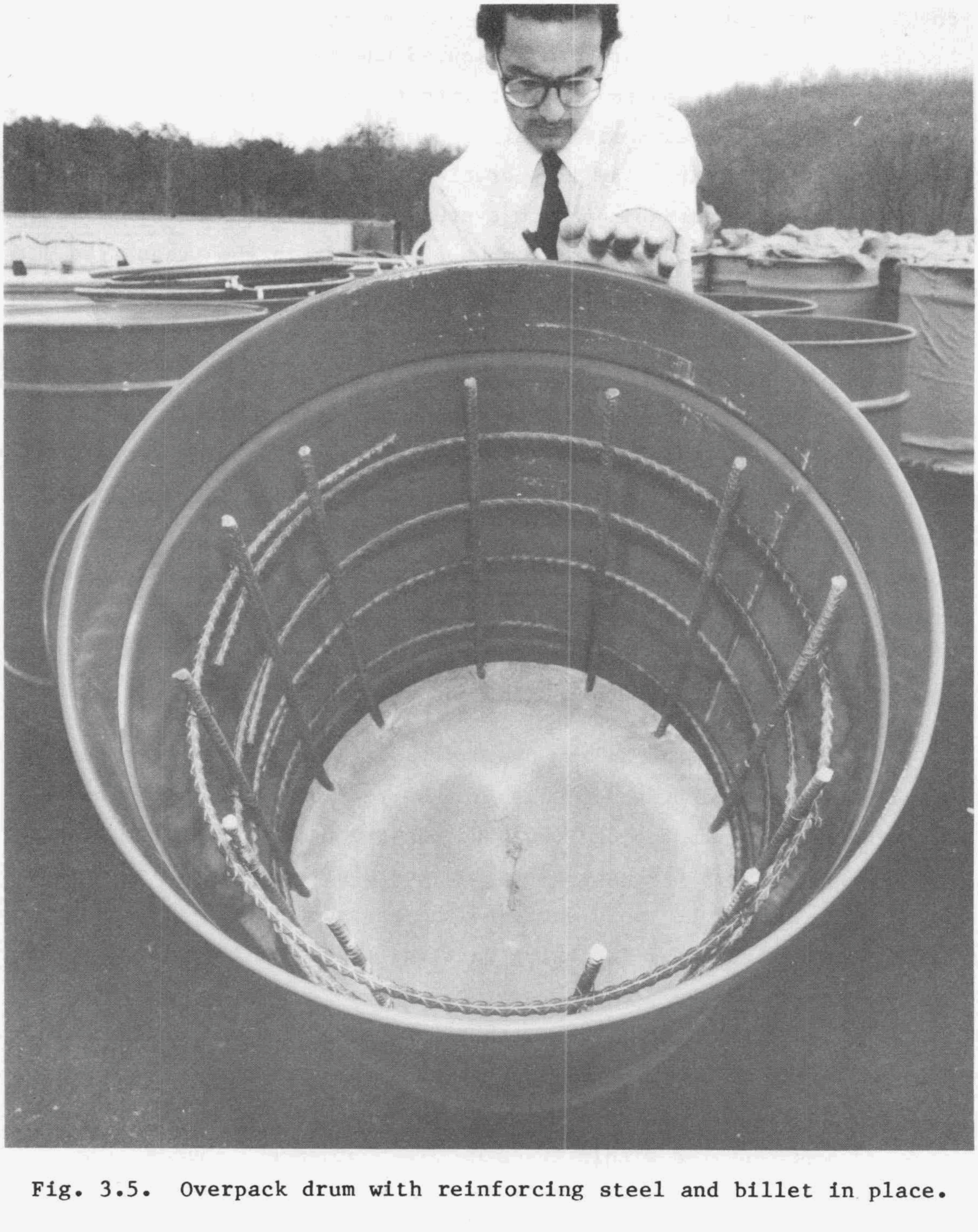

Fig. 3.5. Overpack drum with reinforcing steel and billet in place.

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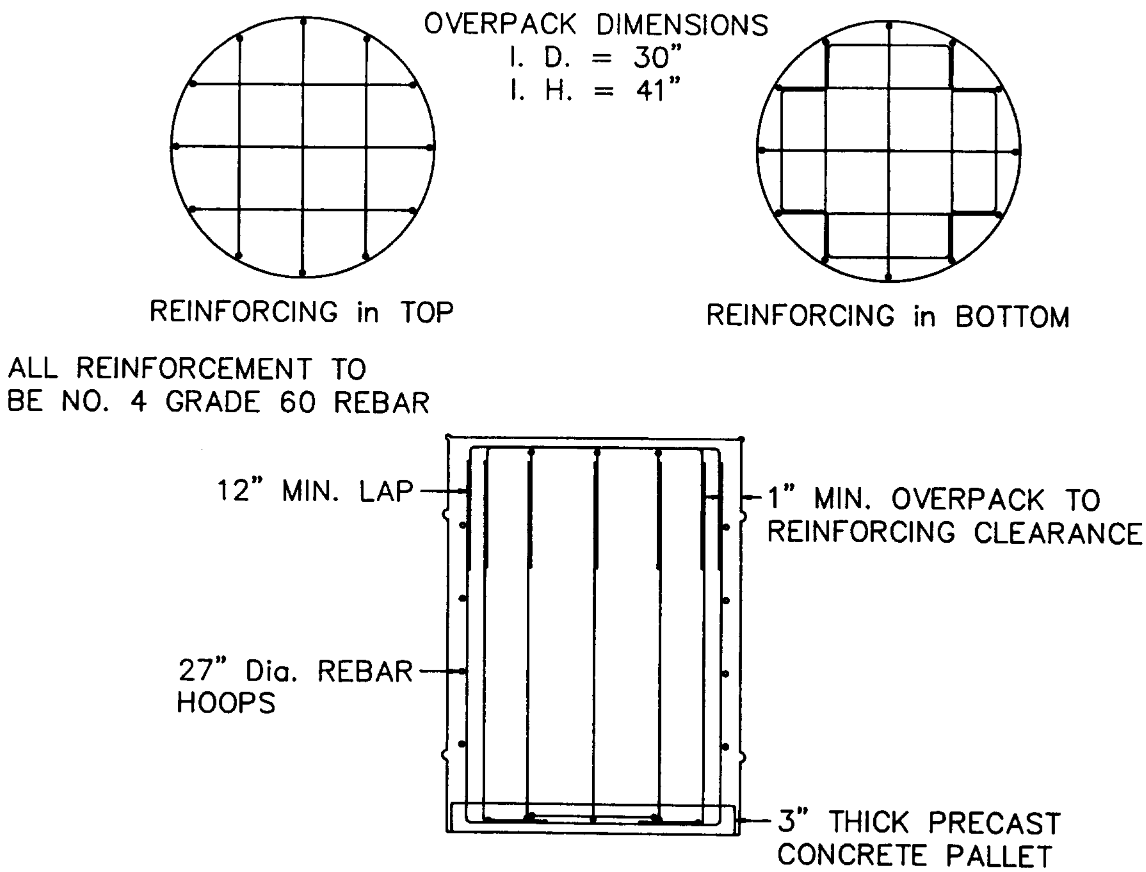

Fig. 3.6. Layout of steel reinforcing cage.

The placement of compacted drums into an overpack was stopped when a minimum of 3 in. of void space remained above the stack of pucks. At that time, the lid and bolt ring were installed on the overpack. The external surfaces were then wiped for smear surveys taken by Energy Systems health physics personnel to ensure that there was no contamination on the outside of the overpack. After each overpack was determined to be free of external contamination, it was moved outside of the radiological control enclosure until all supercompaction operations were completed.

Following completion of supercompaction, the drums were moved inside the air-lock structure of the radiological control enclosure one at a time for grouting. After each drum was brought into the air lock, a pneumatic vibrator was attached to the overpack, the lid of the overpack was removed, and the top section of the reinforcing steel was put in place. Cement grout, which was delivered to the site in tilt mixer trucks, was conveyed directly into the overpack from outside the enclosure via the chute provided with the truck, as shown in Fig. 3.7. The chute was wrapped in plastic to avoid the possibility of cross-contamination.

As each overpack was filled with grout, the vibrator was allowed to run for several minutes to ensure that all air voids would be filled.

After each overpack was filled with grout and adequately vibrated, the lids and bolt rings were reinstalled; and the overpack was removed from the enclosure and released to Energy Systems personnel.

3.6 POSTCOMPACTION DECONTAMINATION ACTIVITIES

The relatively minor amount of decontamination required prior to demobilization of the US Ecology equipment required approximately 39 work-hours by US Ecology personnel. The decontamination proceeded from the areas of lowest to highest contamination, beginning with the inlet side of the unit, which included the input conveyor and the loading gantry crane. As the equipment was disassembled, it was wiped down with an aqueous cleaning solution and rags and then surveyed by

ORNL PHOTO 2985-87

Fig. 3.7. Grouting of an overpack.

US Ecology's radiological technician. After the technician determined a particluar piece of equipment to be releasable, a follow-up survey was conducted by Energy Systems health physics personnel. As each piece of equipment was completely released, it was stored inside the auxiliary equipment shipping container.

After decontamination of the input side equipment, decontamination proceeded to the output side equipment. The same procedures that were used to decontaminate the input equipment were also used on the output equipment.

After decontamination of all external equipment was completed, efforts were directed toward decontamination of the hydraulic press equipment contained within the press compartment. Because the compaction compartment itself is shipped as a radioactive LSA (low-specific-activity) package, only DOT standards applied to the shipment of the closed, inoperative system.

3.7 CHRONOLOGY OF EVENTS

A chronology of significant events prior to, during, and after the demonstration is summarized in Table 3.1.

Table 3.1. Chronology of events

Date	Events
9/86–2/87	Preparation of environmental, health, safety, quality assurance, and work statement documentation and procurement activities were carried out, including project management activities and assembly and characterization of drums to be processed during the demonstration.
3/9/87	US Ecology arrived at SWSA-5 with the supercompaction equipment.
3/10/87	US Ecology personnel were given radiation protection, safety, and environmental orientation by Energy Systems personnel.
	Initial setup activities were conducted by US Ecology at the SWSA-5 site.
	Energy Systems Health Physics personnel conducted base-line survey of US Ecology equipment.
	Initial whole-body counts were conducted at ORNL on US Ecology personnel.
3/11/87	US Ecology and Energy Systems personnel met to discuss details of proceeding with the demonstration, including decontamination of the equipment which would be required before Energy Systems could permit compaction to occur. It was decided that the 100-dpm limit for transferrable (smear) alpha contamination specified in the SOW would be adhered to but that the requirements for fixed radiation would be waived since prior contamination of the unit rendered the removal of fixed radiation to meet ORNL "green tag" standards impossible to achieve.
3/12/87	The motor-generator unit was delivered from Y-12, set up near the demonstration site, and connected to the supercompaction equipment.
	US Ecology carried out decontamination of the press unit to meet Energy Systems requirements of $\leq$100 dpm of alpha contamination by transfer, to assure that prior contamination would not be transferred to the ORNL drums during compaction.
	Energy Systems craft personnel began construction of the enclosure on the outlet side of the trailer.
3/13/87	Energy Systems determined that the decontamination to remove transferrable radiation to $\leq$100 dpm for alpha was satisfactory.
	Construction of the enclosure continued.
	Testing of US Ecology's HEPA filter indicated an acceptable efficiency of 99.93% removal of particulates at the 0.3-μ level.
3/14/87	The enclosure was completed.
3/16/87	Site support activities were carried out, including the staging of the first 50 drums by Energy Systems and the provision of scales to weigh the drums.

Table 3.1 (continued)

Date	Event
3/16/87	US Ecology successfully processed a "clean drum" to verify that transferrable radiation requirements were being met.
	One waste drum was processed prior to equipment malfunction.
3/17/87	Compaction operations were initiated, with some equipment problems. Thirty-one drums were processed, many of which released a significant amount of liquids. The main source of the drums containing liquids was identified, and drums from this source were removed from the inventory to be processed during the demonstration.
	Videotapes of the RTR of the drums that produced liquids during supercompaction were reviewed, and the presence of free liquids was not observed on the tapes.
	Energy Systems health physics personnel conducted smear sampling of all drums processed to verify that transferrable radiation standards were being met.
3/18/87	Media coverage of the demonstration was provided by three local television stations and by The Oak Ridger, The Knoxville Journal, and The Knoxville News-Sentinel.
	Fifty-four drums were processed, although release of liquids continued. All drums processed were smear tested for surface contamination.
3/19/87	Sixty-six drums were processed, although the presence of some liquids and smear testing delayed operations.
3/20/87	Only 20 drums were processed because of delays resulting from liquid releases.
3/21/87	Tennessee Department of Health and Environment representative observed the demonstration.
3/24/87	Compaction of 300 drums was completed; 47 overpacks were filled, with 3 pucks loaded into the 48th overpack.
	US Ecology began cleaning and disassembly of the unit to meet DOT requirements.
3/25/87	All overpacks were grouted inside the enclosure.
3/26/87	US Ecology and Energy Systems began final cleanup and decontamination activities.
3/27/87	All demonstration activities were completed and approved, including health physics exit surveys of the equipment. Whole-body counting of US Ecology personnel indicated that there had been no increase in radiation contamination of personnel.
	US Ecology removed the trailer containing the compaction unit from SWSA-5.
3/30/87	WMTC informed Energy Systems Procurement that supercompaction and grouting activities were completed satisfactorily.
4/6/87	Radiation protection results from the demonstration were made available by Energy Systems.
7/30/87	US Ecology delivered a summary on the demonstration, approximately four months after the demonstration was completed.

4. RESULTS

4.1 INTRODUCTION

This chapter presents an analysis of the results of the supercompaction/packaging demonstration. Sections 4.2 and 4.3 provide a summary of the volume reduction and cost performance of the supercompaction/packaging demonstration. A systems analysis study was conducted to evaluate the results of this demonstration with respect to the applicability of this technology as an element of the solid LLW management system. The results of this systems analysis study are presented in Chap. 5.

4.2 VOLUME REDUCTION

The supercompaction of 300 drums (volume, 7.68 ft^3/drum) resulted in a disposal capacity savings of about 1958.3 ft^3, or 85% of the original disposal capacity needs. The packaging of 300 compacted drums, or pucks, into 47 overpacks (volume, 16.77 ft^3/overpack) decreased the disposal capacity savings from 1958.3 to 1518 ft^3, or 19%. The net disposal capacity savings realized from the demonstration project was about 66% of the original uncompacted waste volume.

As illustrated by Fig. 4.1, the overall volume reduction and packaging factors for this demonstration are as given below.

<u>Supercompaction</u>:

Volume reduction factor = Uncompacted waste volume/packaged waste volume
= 2304/345.7
= 6.66:1

<u>Supercompaction/Packaging</u>:

Volume reduction factor = Uncompacted waste volume/packaged waste volume
= 2304/788.2
= 2.9:1

Packaging factor = Packaged waste volume/unpackaged waste volume
= 788.2/345.7
= 2.28:1

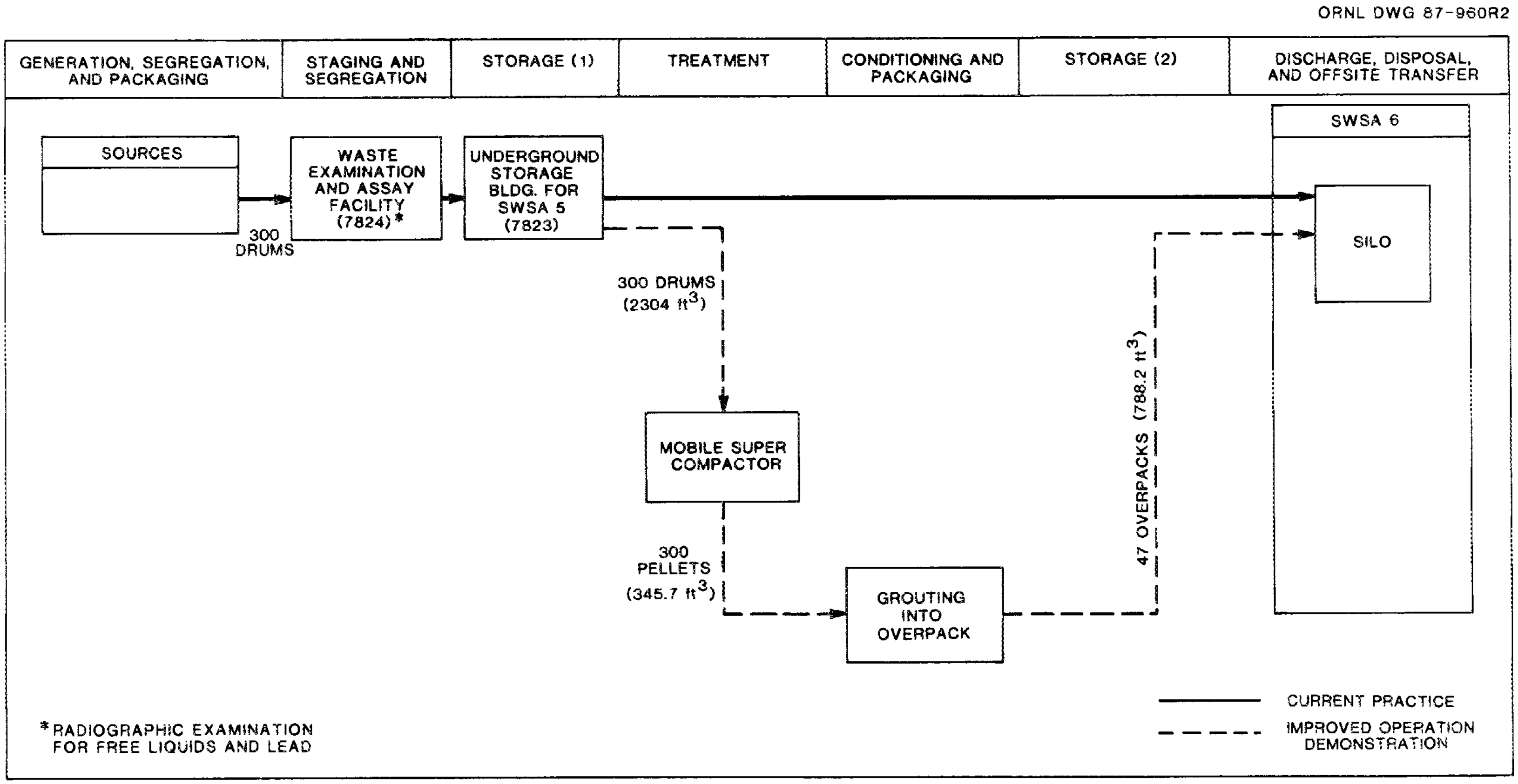

Fig. 4.1. Systems analysis framework for the ORNL supercompaction and packaging of solid LLW.

4.3 COSTS

The costs accounted for in this demonstration project are summarized in Table 4.1. The total cost for the project is estimated to be about \$195K, which includes about \$100K in additional demonstration costs over and above those for the subcontractor and the direct on-site support costs. The variable operating (subcontract) cost for supercompaction was \$8700, or \$29/drum. This cost resulted in an average supercompaction cost of about \$3.78/ft^3 of uncompacted waste.

The total variable operating (subcontract) cost for packaging the compacted drums was \$19,025.60, or \$404.80/overpack (Table 4.2). This cost resulted in an average packaging cost of about \$8.26/ft^3 of uncompacted waste. Direct materials accounted for 80% of the packaging cost, while direct labor accounted for the other 20%.

Table 4.1. Supercompaction demonstration preliminary cost summary
Basis: Initial volume of 300 55-gal drums (57.4-gal capacity) = 2304 ft^3.

Demonstration phase	Task	Cost element	Variable cost ($)	Fixed cost ($)	Incremental unit cost ($/$ft^3$) Variable	Fixed	Total	Demo phase subtotal unit cost ($/$ft^3$)
Preoperational	Preparation of Statement of Work	Direct labor		7,700		3.34	3.34	
	Subcontract award	Direct labor		950		0.41	0.41	
	QA, safety, and environmental documentation	Direct labor		7,700		3.34	3.34	
	Mobilization of supercompaction equipment	Total		5,200		2.26	2.26	
	Construction of containment tent	Direct labor		7,765		3.37	3.37	
		Direct materials		4,500		1.95	1.95	
		Subtotal		33,815		14.67	14.67	14.67
Operational	Project management	Direct labor	7,700			3.34	3.34	
	Supercompaction	Total (@ $29/drum)	8,700		3.78		3.78	
	Packaging	Total (47 @ $404.80)	19,025.6		8.26		8.26	
		Direct materials - misc.	500		0.22		0.22	
	Power supply	Direct materials	3,180		1.38		1.38	
	Health physics/monitoring	Direct labor	5,040		2.19		2.19	
		Direct materials	160		0.07		0.07	
	HEPA filter testing	Direct labor	219		0.10		0.10	
	Drum staging and on-site labor support	Direct labor	14,840		6.44		6.44	
	Project documentation		25,400			1.02	1.02	
		Subtotal	87,764		22.44	14.56	36.80	36.80
Postoperational	Demobilization of supercompaction equipment	Total		7,800		3.38	3.38	
	Demolition of temporary structure	Direct labor		2,000		0.87	0.87	
	Disposal of containment tent	Total		1,000		0.43	0.43	
	Preparation of project assessment report	Direct labor		20,000		8.68	8.68	
		Subtotal		30,800		13.36	13.36	13.36
Subtotal			51,665	97,715	22.44	42.39	64.83	63.83
Overhead (30%)			15,500	29,315	6.73	12.72	19.45	19.45
Total			67,165	127,030	29.17	55.11	84.28	84.28
Grand total			$194,195					

Table 4.2. Supercompaction demonstration packaging cost summary

Cost element	Cost ($)	Cost ($)
Direct materials		
Overpack (47 at 0.30 x $404.80)	5,707.70	
Reinforced precast concrete (47 at 0.24 x $404.80)	4,566.14	
Reinforced grout (47 at 0.26 x $404.80)	4,946.64	
		15,220.48
Direct labor		
Grouting (47 at 0.20 x $404.80)	3,805.12	3,805.12
Total cost		19,025.60
Total packaging unit cost ($/overpack)		404.80

5. SYSTEMS ANALYSIS

5.1 INTRODUCTION

The three major objectives of solid LLW volume reduction and packaging are to (1) develop an improved waste form for greater confinement, (2) reduce the waste volume to extend the life of the current disposal sites, and (3) accomplish the other two objectives in a cost-effective manner. As will be shown in Sects. 5.2 and 5.3, the ability to demonstrate the achievement of objective 3 will depend on the performance of the waste management cost tracking systems used both for current practices (no volume reduction and packaging) and for technology demonstrations of, or service contracts for, waste volume reduction and packaging.

Sections 5.2. and 5.3 evaluate the performance of supercompaction/packaging in terms of the disposal capacity savings and the cost-effectiveness of this waste management alternative in achieving the disposal capacity savings.

5.2 VOLUME REDUCTION PERFORMANCE ASSESSMENT

Table 5.1 presents a summary of the results from the supercompaction/packaging demonstration on an overpack basis. To identify the type of distribution resulting from the supercompaction, the final height of the compacted drums and the associated volume reduction factor were grouped on an increment of one unit, and the midpoint of the range was plotted vs the number of drums in that range (frequency).

Figures 5.1 and 5.2 present a summary of the results from the supercompaction/packaging demonstration on a frequency (number of drums) basis. These data do not reflect a normal distribution. Such information is useful when comparing data for the same technology.

It was proposed that the volume reduction factor was determined by the difference between the initial and final densities of the waste stream. It was further anticipated that the final density of the compacted waste, as determined by the pressure of the compactor, would reach a saturation value.

Table 5.1. Summary of results of supercompaction/packaging demonstration

Overpack No.	No. of pucks	Total puck height (in.)	Puck height (in.) after supercompaction
1	9	32.25	2.5/4.5/3.75/4.5/3.5/5/4.5/2.5/1.5
2	7	33.00	5/3.5/7.75/2/7.5/3.5/3.75
3	8	31.50	5.5/5/1/5.25/4.5/3.5/2.5/4.25
4	8	30.25	3/3.5/2.5/4/4.25/4/5.5/3.5
5	8	31.00	5.5/5/2.5/4/3.5/3.75/3.25/3.5
6	9	31.75	3.25/3.5/3.25/5/3.5/3.5/3.25/1.5/5
7	8	32.50	5.5/4.5/3.75/3.25/2.75/5/5/2.75
8	7	35.50	7/5/3/10.5/3.5/3.5/3
9	7	31.25	4.25/4/4/4.5/4.5/5/5
10	8	35.50	3.5/4.5/3.5/4/4/4.5/5.5/6
11	7	30.00	5.5/2.5/7/4.5/3.5/4/3
12	9	31.50	5.5/2.5/3.5/4.75/4/3/4/3/1.25
13	8	33.00	5.5/3.5/3.25/2/4.25/6.5/5/3
14	8	32.00	2.75/4.5/5.5/6.5/2.5/4.5/4.25/1.5
15	7	30.25	6.5/2.75/4.25/4.25/4.25/4.5/3.75
16	9	31.25	2.5/4.5/3.5/6.5/5/2.75/2.5/1.5/2.5
17	9	30.00	2/1.5/3.5/1.25/6.5/3.75/5.5/4.5/1.5
18	8	30.75	3.5/4.25/4/3.75/1.5/4/6.25/3.5
19	8	32.50	4/3.5/4.25/3.25/4.5/5.25/4/3.75
20	5	35.00	4.5/7.25/13.5/5.75/4
21	4	33.25	7.25/6.25/17/2.75
22	6	31.50	4.5/4.5/4/10.5/4.5/3.5
23	4	29.50	8.25/6.5/10.75/4
24	6	33.25	5.5/4/3.5/15/2.75/2.5
25	7	32.75	5.25/7.75/3.5/3.75/5.5/5/2
26	4	33.50	4/13.5/6/10
27	8	32.00	1.5/6.25/2.25/4.75/5.5/2/5.5/4.25
28	4	31.25	12/8/9.75/1.5
29	3	34.00	13/11.5/9.5
30	6	33.75	4.5/8/4/6/6/5.25
31	6	32.25	7.75/10/5.5/4.75/2.25/2
32	6	32.25	5.75/9.5/3.5/5.5/4.5/3.5
33	5	31.75	10.75/7.75/6/3.75/4
34	6	30.75	7.5/3.75/3.5/6/4/6
35	3	31.00	12/12.5/6.5
36	6	33.50	4.5/5.75/3/10.5/3.75/6
37	5	33.25	6.5/5/4/11.75/6
38	7	33.50	6.5/4.5/4.5/4.75/4.5/4.25/4.5
39	7	32.00	3/3.5/6/2.75/3.5/4.75/8.5
40	6	34.75	9/10.25/4/2.5/5.5/3.5
41	7	30.25	3.75/3.25/11/3.5/2.75/2.5/3.5
42	5	34.50	3.5/3.5/5.25/9/13.25
43	4	34.75	5.25/11.5/12.25/5.75
44	5	31.50	9.5/4.5/3.75/4/9.75
45	5	35.75	5/11.5/9.5/6.25/3.5
46	5	32.00	4/10.25/11.5/2.75/3.5
47	3	13.00	4.5/4.5/4
Total	300	1502.50	

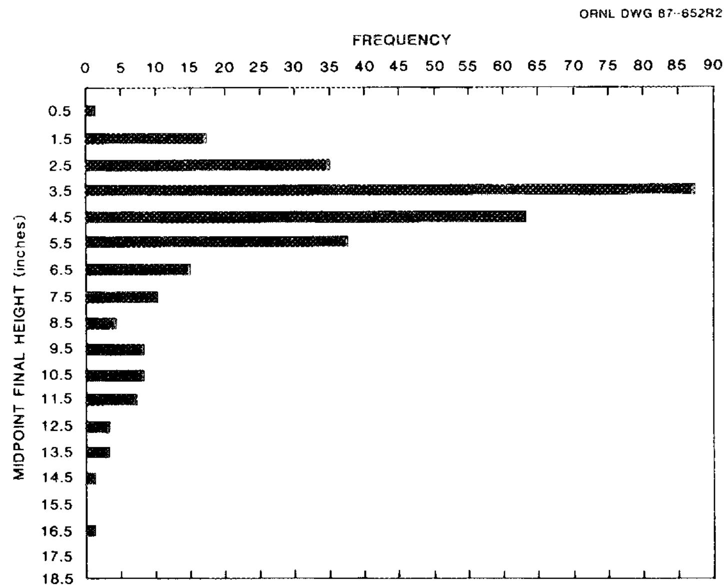

Fig. 5.1. Distribution of drum heights after supercompaction.

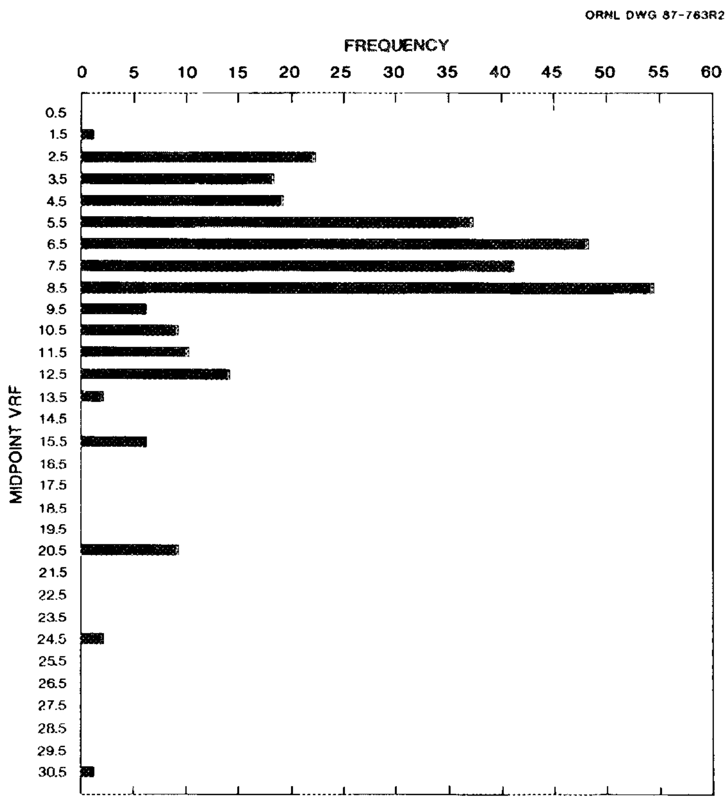

Fig. 5.2. Distribution of volume reduction factors (VRFs) after supercompaction of 300 drums.

As shown in Table 5.2, about 40% (121) of the 300 drums had uncompacted densities of 10 to 15 lb/ft^3. The densities of all the drums before supercompaction were less than 55 lb/ft^3. The densities after supercompaction (see Table 5.3) showed a wide spread, ranging from 30 to 270 lb/ft^3. About 66% of the compacted drums had densities between 75 and 140 lb/ft^3.

The relationship between the volume reduction factor and the uncompacted waste density is shown in Fig. 5.3. A volume reduction factor less than 10 is associated with an uncompacted waste density greater than 12 lb/ft^3. For uncompacted densities lower than 12 lb/ft^3, a volume reduction factor of 10 to 30 was obtained.

The disposal capacity savings resulting from volume reduction is related to the volume reduction factor as follows:

$$\text{Disposal capacity savings (\%)} = \frac{\text{VRF} - 1}{\text{VRF}} \; 100 \; ,$$

where VRF is the volume reduction factor, defined as

$$\text{VRF} = \frac{\text{uncompacted waste volume}}{\text{compacted waste volume}} \; .$$

As shown in Fig. 5.4, the rate of disposal capacity savings is a decreasing function of the volume reduction factor, diminishing considerably after a VRF of 10. The cost of supercompaction does not seem to be affected by this relationship. However, this finding should be kept in mind when selecting a compaction technology for application with the type of solid LLW compacted in this demonstration. The net savings in disposal are enhanced by the scale of the demonstration when VRFs above 10 are desired.

5.3. ECONOMIC ASSESSMENT

For supercompaction to be a cost-effective alternative for volume reduction of solid LLW, the following criterion must be met:

$$\text{Net cost savings from supercompaction/packaging} \geq \text{cost of supercompaction/packaging} \; .$$

Table 5.2. Distribution of waste stream densities before supercompaction

Density range (lb/ft^3)	Midpoint	Frequency	Cumulative frequency	Percent	Cumulative percent
0–5	2.5	0	0	0	0
5–10	7.5	19	19	6.4	6.4
10–15	12.5	121	140	40.6	47.0
15–20	17.5	61	201	20.4	67.4
20–25	22.5	33	234	11.1	78.5
25–30	27.5	28	262	9.4	87.9
30–35	32.5	19	281	6.4	94.3
35–40	37.5	10	291	3.4	97.4
40–45	42.5	4	295	1.3	99.0
45–50	47.5	2	297	0.7	99.7
50–55	52.5	1	298	0.3	100

Table 5.3. Distribution of waste stream densities after supercompaction

Density range (lb/ft^3)	Midpoint	Frequency	Cumulative frequency	Percent	Cumulative percent
30-35	32.5	0	0	0	0
35-40	37.5	2	2	0.7	0.7
40-45	42.5	1	3	0.3	1.0
45-50	47.5	1	4	0.3	1.3
50-55	52.5	1	5	0.3	1.7
55-60	57.5	0	5	0	1.7
60-65	62.5	5	10	1.7	3.4
65-70	67.5	7	17	2.3	5.7
70-75	72.5	9	26	3.0	8.7
75-80	77.5	14	40	4.7	13.4
80-85	82.5	12	52	4.0	17.4
85-90	87.5	11	63	3.7	21.1
90-95	92.5	16	79	5.4	26.5
95-100	97.5	26	105	8.7	35.2
100-105	102.5	21	126	7.1	42.3
105-110	107.5	13	139	4.3	46.6
110-115	112.5	21	160	7.1	53.7
115-120	117.5	18	178	6.0	59.7
120-125	122.5	13	191	4.4	64.1
125-130	127.5	11	202	3.7	67.8
130-135	132.5	12	214	4.0	71.8
135-140	137.5	10	224	3.4	75.2
140-145	142.5	8	232	2.7	77.9
145-150	147.5	3	235	1.0	78.9
150-155	152.5	3	238	1.0	79.9
155-160	157.5	3	241	1.0	80.9
160-165	162.5	8	249	2.7	83.6
165-170	167.5	4	253	1.3	84.9
170-175	172.5	5	258	1.7	86.6
175-180	177.5	4	262	1.3	87.9
180-185	182.5	5	267	1.7	89.6
185-190	187.5	5	272	1.7	91.3
190-195	192.5	2	274	0.7	92.0
195-200	197.5	3	277	1.0	93.0
200-205	202.5	1	278	0.3	93.3
205-210	207.5	3	281	1.0	94.3
210-215	212.5	3	284	1.0	95.3
215-220	217.5	6	290	2.0	97.3
220-225	222.5	0	290	0	97.3
225-230	227.5	2	292	0.7	98.0
230-235	232.5	3	295	1.0	99.0
235-240	237.5	1	296	0.3	99.3
240-245	242.5	1	297	0.3	99.6
245-250	247.5	0	297	0	99.6
250-255	252.5	0	297	0	99.6
255-260	257.5	0	297	0	99.6
260-265	262.5	0	297	0	99.6
265-270	267.5	1	298	0.3	99.9

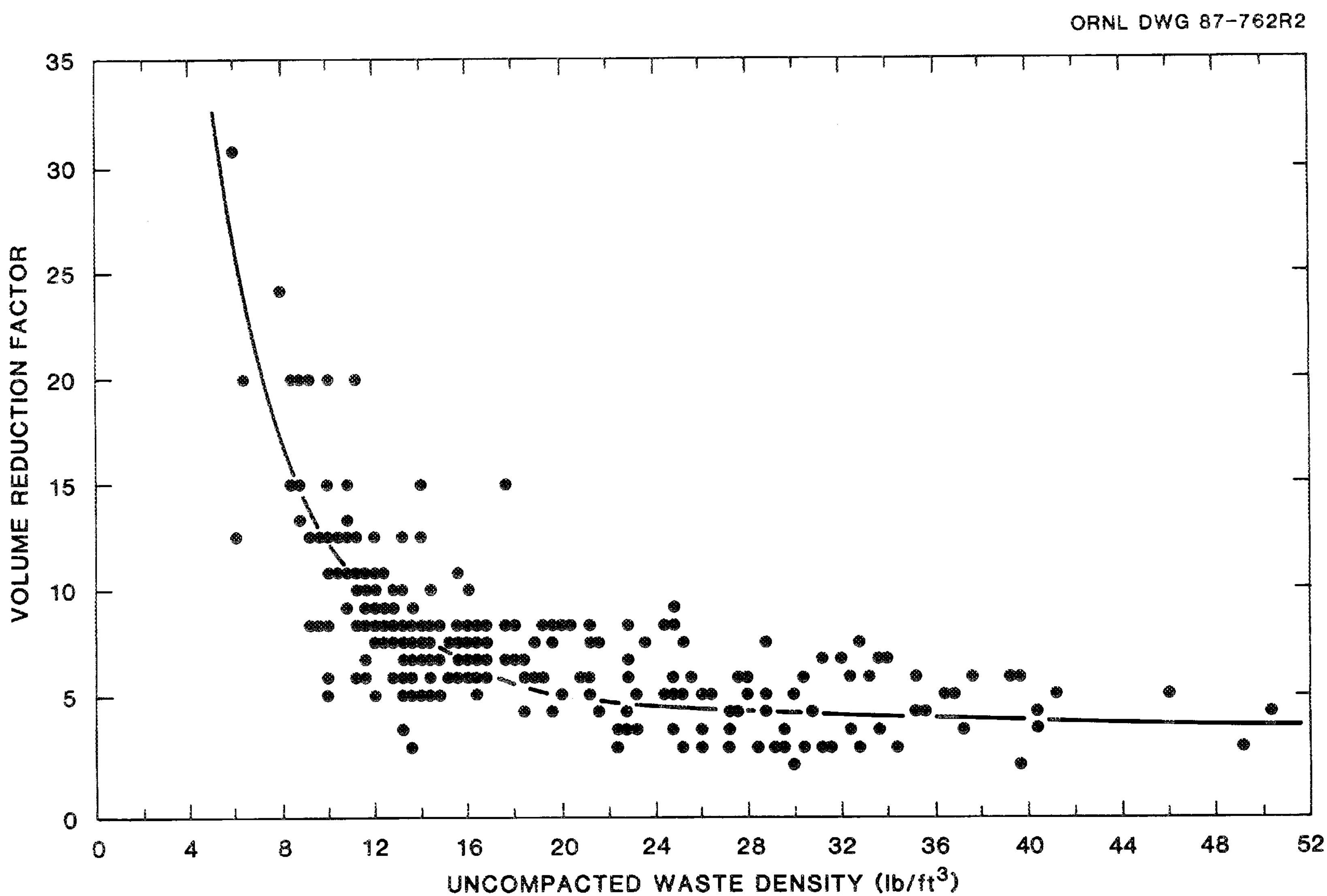

Fig. 5.3. Performance profile for the volume reduction of 300 drums of solid LLW at ORNL.

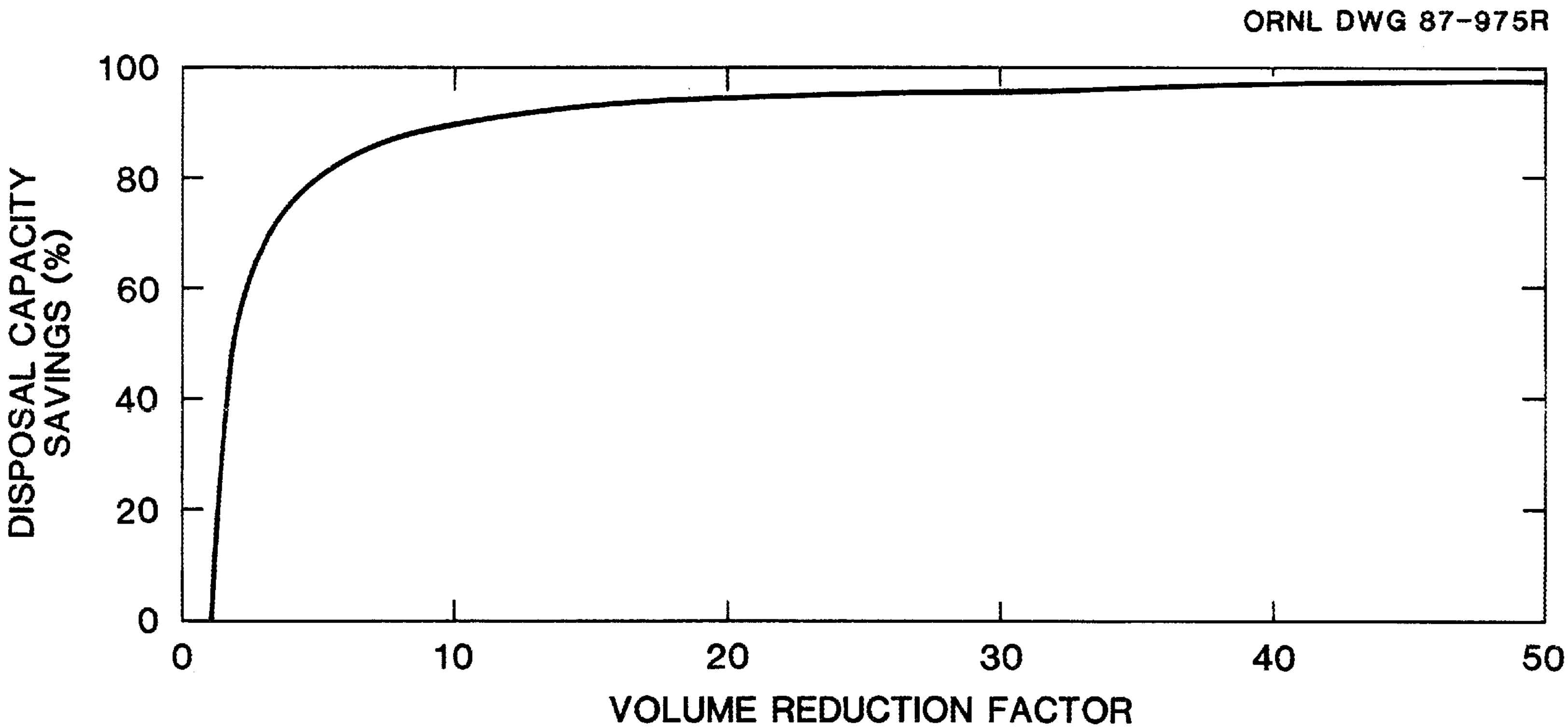

Fig. 5.4. Disposal capacity savings as a function of the volume reduction factor.

The cost elements considered in the differential cost analysis for this demonstration are based on the system analysis model shown in Fig. 4.1 and summarized in Table 5.4. A differential cost analysis was performed on those elements of the waste management system that are not common to current practices and to the scenarios used in this demonstration project. Those elements of the waste management system that are common to these scenarios were considered as sunk costs and were not entered into the economic comparison.

The differential cost criterion or net savings requirements for the cost-effectiveness application of supercompaction/packaging technology can be expressed mathematically as

$$(N_1C_T - N_2C_t) + (N_1C_D - N_2C_d) - (N_1C_s + N_2C_p + M) - C^* \geq 0 \ ,$$

where

$(N_1C_T - N_2C_t)$ = cost savings of waste transport from staging area to the disposal unit;

$(N_1C_D - N_2C_d)$ = cost savings of waste disposal;

$(N_1C_s + N_2C_p + M)$ = supercompaction/packaging external, or subcontract, cost;

C^* = demonstration operations on-site support, or internal, cost.

Table 5.5 defines the terms used in the differential cost criterion for cost-effectiveness of supercompaction/packaging.

If the demonstration operations on-site support, or internal, cost C^* is defined in terms of the fraction of the overall cost for the demonstration as

$$f = \frac{C^*}{C^* + (N_1C_s + N_2C_p + M)} \ , \qquad 0 \leq f < 1 \ ,$$

then the cost-effectiveness factor (CEF) for the demonstration or service contract can be expressed as

$$CEF = (N_1C_T - N_2C_t) + (N_1C_D - N_2C_d) - (N_1C_s + N_2C_p + M)\left(\frac{1}{1 - f}\right), \geq 0 \ .$$

Table 5.4. Waste management elements of cost used in establishing the cost-effectiveness of supercompaction/packaging scenarios

Cost	Description
	1. Disposal of uncompacted waste (current practices)
T_1	Cost of transporting uncompacted drums from staging area to the disposal unit.
D_1	Cost of disposal of uncompacted drums. This cost includes site preparation, materials, installation, drum handling (labor), and disposal unit closure.
	2. Disposal of supercompacted/packaged waste
S_2	Cost of supercompaction.
M	Cost of mobilization/demobilization of supercompaction unit.
P_2	Cost of packaging compacted drums.
C^*	Cost of demonstration operation support. This cost includes cost of procuring the volume reduction/packaging services, the operational support services, and quality assurance/safety and environmental documentation.
D_2	Cost of disposal of the overpacks. This cost includes site preparation, materials, installation, drum handling (labor), and disposal unit closure.
T_2	Cost of transporting overpacks from staging area to the disposal unit.

Table 5.5. Definition of terms used in the differential cost criterion for the cost-effective application of supercompaction/packaging technology at ORNL

The waste management cost elements introduced in Table 5.4 are related to the differential cost criterion as follows:

$$S_2 = N_1C_s,$$

$$P_2 = N_2C_p,$$

$$D_2 = N_2C_d,$$

$$T_1 = N_1C_T,$$

$$T_2 = N_2C_t,$$

$$D_1 = N_1C_D,$$

where

N_1 = number of drums used during the supercompaction demonstration;

N_2 = number of overpacks used during the packaging demonstration;

C_s = cost of supercompaction, \$/drum;

C_p = cost of packaging, \$/overpack;

C_T = cost of uncompacted drum transport from staging area to the disposal unit, \$/drum;

C_D = cost of uncompacted drum disposal, \$/drum;

C_t = cost of overpack transport from staging area to the disposal unit, \$/overpack;

C_d = cost of overpack disposal, \$/overpack.

The implications for ORNL in the use of supercompaction/packaging service contracts for the management of solid LLW is that the cost-effectiveness of the operation can be increased by

1. increasing the scale of the operation, N_1.
2. increasing N_1/N_2, or
3. decreasing the f fraction.

The ratio N_1/N_2 is determined by the volume reduction performance of the compactor, the packaging efficiency, and the design of the overpack to minimize volume loss during the packaging operation. If the overpack can be disposed of as a disposal unit, an additional cost and disposal capacity savings could be obtained. The effect of the N_1N_2 ratio on the packaging cost for this demonstration is shown in Table 5.6.

The effects of the demonstration operations on-site support costs are examined in terms of their impact on the cost-effectiveness of the demonstration project or the service contract. Given the following costs associated with this project,

N_1 = 300 drums,
N_2 = 47 overpacks,
C_T = \$30.72/drum or \$4/ft^3,
C_t = \$67.08/overpack or \$4/ft^3,
C_s = \$29/drum,
C_p = \$404.80/overpack,
M = \$13,000,

the minimum on-site disposal cost, d^* (\$/ft^3), under current practices which is required to make this demonstration a cost-effective operation is calculated as

$$d^* \geq \frac{(N_1C_s + N_2C_p + M)\left(\frac{1}{1 - f}\right)}{(7.68\ N_1C_T - 16.77\ N_2C_t) + (7.68\ N_1C_D - 16.77\ N_2C_d)} ,$$

Table 5.6. Economic implications of the combined volume reduction performance of supercompaction and packaging.[a] This performance is measured by the N_1/N_2 ratio.

Number of compacted drums per overpack $(N_1/N_2)^b$	Number of overpacks, N_2	Total drums, N_1	Packaging cost ($/overpack)	Packaging cost $(\$/ft^3)^c$	Packaging cost ($/drum)
3	4	12	404.80	18.04	134.93
4	3	12	404.80	13.53	101.20
5	8	40	404.80	10.82	80.96
6	8	48	404.80	9.02	67.47
7	9	63	404.80	7.73	57.83
8	10	80	404.80	6.76	50.60
9	5	45	404.80	6.01	44.98
Total or average	47	300	404.80	8.26	64.42

[a]The packaging factor (unpackaged waste volume/packaged waste volume) for this demonstration is 2.28:1.

[b]Average (N_1/N_2) for the demonstration = 300/47 = 6.38:1.

[c]Based on uncompacted drums (7.68 ft^3/drum). The average packaging cost for the demonstration (300 drums) is \$8.26/ft^3 of uncompacted waste.

$$d^* \geq \frac{\$40,725.60}{\$2,273.77}\left(\frac{1}{1 - f}\right) ,$$

$$d^* \geq \$17.91 \left(\frac{1}{1 - f}\right) ,$$

where 7.68 is the volume (ft^3) per drum and 16.77 is the volume (ft^3) per overpack.

The demonstration operations on-site support, or internal, cost was defined as a fraction of the overall cost for the demonstration project. The implication for DOE/ORO facilities in the use of supercompaction/packaging service contracts for the management of solid LLW is that the cost-effectiveness of the operation can be increased by (1) increasing the scale of the operation; (2) increasing the number of drums per overpack; and (3) decreasing the internal costs.

It should be noted that the value of carrying out demonstrations or service contracts of this type is not measured in purely economic terms. The savings in disposal capacity and the extension of the useful life of the current disposal sites is very critical in maintaining continuity of operations on the Oak Ridge Reservation.

The effects of the demonstration operations on-site support, or internal, costs were examined in terms of their potential impact on the cost-effectiveness of the service contract. These effects are shown in Fig. 5.5.

The current cost of compactible solid LLW disposal in a silo at SWSA-6 is in the range of \$25 to \$45/ft^3. For this project to be cost-effective at a disposal cost of \$25 to \$45/ft^3, the demonstration operations internal cost fraction should not exceed a value of 0.3 for \$25/ft^3 and 0.6 for \$45/ft^3. Based on the cost elements presented in Table 4.1, it is possible to maintain this fraction below the maximum value allowed for cost-effectiveness. It is anticipated that a service contract (nondemonstration) could provide these benefits because most of the information-gathering costs associated with a demonstration would be eliminated.

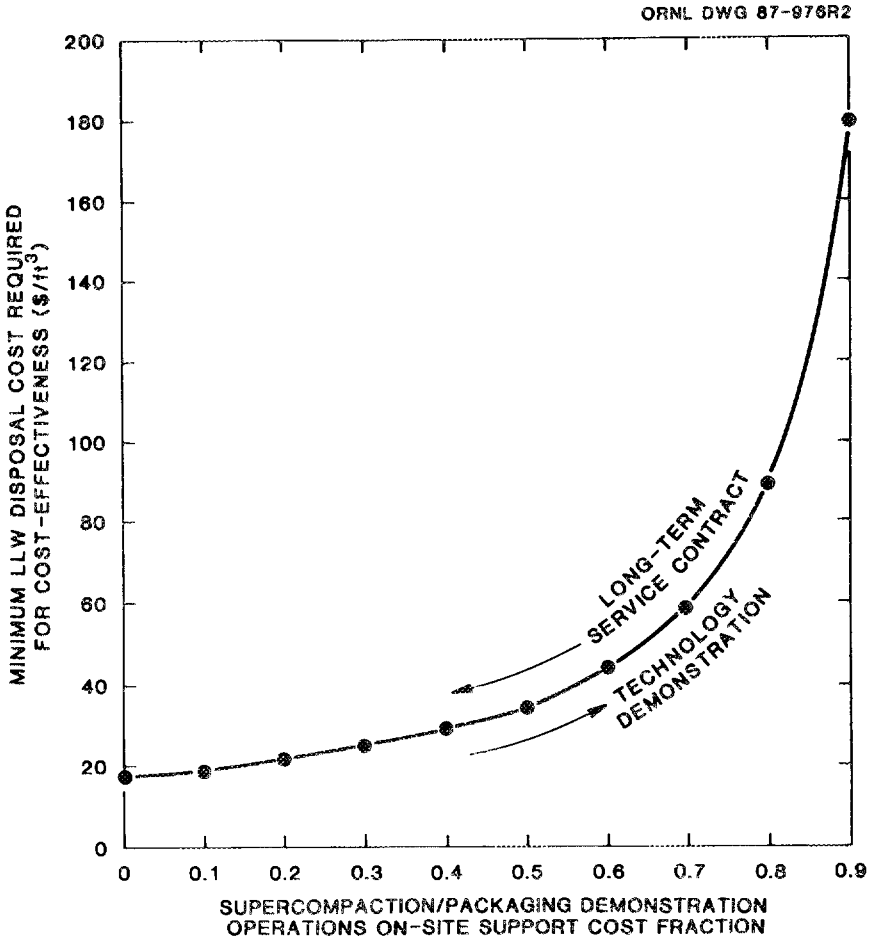

Fig. 5.5. Effect of the on-site support cost fraction on the minimum disposal cost required for demonstration cost-effectiveness.

There are several internal costs associated with a demonstration that could be reduced or eliminated during a service contract. Based on Table 4.1, the fixed costs that could be reduced during an on-site service contract include (1) preparation of the Statement of Work; (2) QA, safety, and environmental documentation; and (3) documentation of the project.

A service contract for off-site operations appears to be an attractive alternative to on-site operations. Evaluation of this alternative is planned for future demonstrations.

5.4 CONCLUSIONS AND RECOMMENDATIONS FROM THE SYSTEMS ANALYSIS

The economic assessment for this project revealed that the cost-effectiveness of on-site demonstrations is, as expected, very sensitive to the demonstration operations on-site support, or internal, costs. The cost-effectiveness of this alternative for waste management will improve during an on-site service contract based on this demonstration project. The cost-effectiveness of off-site demonstrations of supercompaction technology will be evaluated as planned off-site demonstrations are performed.

In most economic assessments of volume reduction technology, the disposal cost is the most commonly used parameter in the establishment of the cost-effectiveness of volume reduction. In an economic sense, this cost does not represent the economic value of disposal capacity. For future economic assessments, an alternative measure of the economic value of disposal capacity is recommended. This new measure of economic value for disposal capacity is defined as the disposal capacity asset value (DCAV), which is composed of the following elements:

$$\text{DCAV} = \begin{array}{l}\text{disposal cost}\\ \text{associated with}\\ \text{waste management}\end{array} + \begin{array}{l}\text{capacity replacement}\\ \text{cost or resource}\\ \text{depletion cost}\end{array} + \begin{array}{l}\text{strategic value}\\ \text{of disposal}\\ \text{capacity.}\end{array}$$

The strategic value of disposal capacity represents the asset value of disposal capacity to the organization in terms of its mission impact, the ability of the organization to continue operations, and the ability to grow and maintain a competitive position in the marketplace. The

DCAV can be interpreted as the price the waste generator is willing to pay to extend the life of the disposal sites. Quantification of the DCAV provides the required economic incentives for the investments in volume reduction, waste reduction, waste recycling, and resource recovery technologies.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 EQUIPMENT IMPROVEMENTS

Needed equipment improvements identified during the demonstration are summarized as follows:

1. An improved liquid collection system around the clamshell, which encloses the piston during the compaction operation, would eliminate most of the liquid collection problems experienced with the configuration used during the demonstration.
2. A higher-capacity internal air withdrawal system is needed to provide additional airflow during the compaction process.
3. A field-erectable, vendor-supplied enclosure on the outlet side of the compactor trailer would significantly reduce site support costs.
4. Solid enclosure doors on the inlet and outlet sides of the compactor trailer, as opposed to sectional doors, would provide improved operability.

6.2 COST FACTORS

Cost factors contributing to the significant internal support costs for this demonstration are summarized as follows:

1. Costs for constructing an enclosure on the outlet side of the compactor were significant.
2. The need for a mobile motor-generator unit to supply the power for the operation of the compactor system, and a full-time attendant to operate the unit, added to site support costs.
3. Extensive equipment downtime while liquid releases were being cleaned up after the compaction of drums increased site support costs.

6.3 CHARACTERISTICS OF WASTE DRUMS

The characteristics of waste drums observed during the demonstration which contributed to compaction-related problems are summarized as follows:

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