DISCLAIMER

MANAGEMENT OF DEFENSE BETA-GAMMA CONTAMINATED SOLID LOW-LEVEL WASTES

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ABSTRACT

In DOE defense operations, ~70,000 m^3 of beta-gamma low-level radioactive waste are disposed of annually by shallow land burial operations at six primary sites. Waste generated at other DOE sites are transported on public roads to the primary sites for disposal. In the practice of low-level waste (LLW) disposal in the U.S., the site hydrology and geology are the primary barriers to radioactive migration. To date, little emphasis has been placed on waste form improvements or engineered site modifications to reduce migration potential. Compaction is the most common treatment step employed.

The performance of ground disposal of radioactive waste in this country, in spite of many practices that we would consider unacceptable in today's light, has resulted in very little migration of radioactivity outside site boundaries. Most problems with previously used burial grounds have been from subsidence at the arid sites and subsidence and groundwater contact at the humid sites. The radionuclides that have shown the most significant migration are tritium, ^{90}Sr, and ^{99}Tc. The unit cost for disposal operations at a given DOE site is dependent on many variables, but the annual volume to be disposed is probably the major factor. The average cost for current DOE burial operation is approximately $\$170/m^3$.

1. INTRODUCTION

Defense waste is any radioactive waste generated directly as a result of nuclear activities of the DOE, its contractors, or subcontractors. Essentially all wastes generated at DOE sites are classified as defense wastes.

Low-level waste is any solid, liquid, or gaseous waste not classified as high-level waste, TRU waste, spent nuclear fuel, or mill tailings. While this definition permits relatively high specific

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activities for beta and gamma emitters, the regulations specify that low-level waste will contain less than 100 nCi/g of transuranic material.

These waste definitions are contained in DOE Order 5820 which establishes the policies and guidelines by which the Department of Energy manages its radioactive waste, waste byproducts, and radioactively contaminated surplus facilities. The part of DOE Order 5820 which deals with low-level waste has not been officially released, but the order has undergone extensive review and revision through a series of drafts, and the final version is expected to become effective by the end of this year. The DOE order for LLW is relatively general but does establish performance requirements comparable to the regulations governing the private sector. The regulation governing commercial LLW disposal is the Nuclear Regulatory Commission's (NRC) regulation 10 CFR 61. Both the DOE order and the NRC regulation are subject to performance standards established by the Environmental Protection Agency. The EPA has issued a letter of intent to establish the LLW disposal standard in 40 CFR 193 within the next several years. It is expected that the performance standard established by the EPA will essentially be consistent with the NRC performance standards in 10 CFR 61 (which limits the maximum off-site exposure to an individual to 25 millirems to the body and 75 millirems to critical organs).

The DOE Order 5820 is written to accommodate differences in hydrology and geology between the various sites and the type of waste being handled. All existing DOE burial grounds are located on large multipurpose sites and usually the disposal operation is relatively small compared to the total operation at the site. This is contrasted to commercial burial grounds which are usually stand-alone facilities.

The definition of LLW permits the disposal of relatively high-activity material as low-level waste, and the treatment and disposal methods in use for low-level waste are varied to account for the relative activity of the material which is involved. The treatment and disposal methods also vary according to the area in which they are disposed and whether or not transportation over public highways is required to reach the disposal area.

Many of the DOE sites do not have facilities for the disposal of low-level waste, so that transportation and the preparation for transportation provide the major constraints on low-level waste operations at these sites. All of the waste from these sites are disposed of at other DOE sites; essentially no DOE waste is sent to commercial sites. The packaging and transportation of these wastes are governed by Department of Transportation regulations which are identical to those imposed on commercial operators.

2. DISPOSAL PHILOSOPHY

In the practice of low-level waste disposal in the U.S., the site hydrology, geology, and geochemistry have been and still are the primary barriers to radioactive migration. Packaging is designed primarily to contain surface contamination and provide any necessary shielding and structural form during the disposal process. In past operations, little emphasis has been placed on either waste form improvements or engineered barriers to reduce migration potential. Operating criteria in the past has involved selection of a site to minimize interaction with ground and surface waters, maximize ion exchange properties of the available geology in humid sites, and provide radiation protection during and after disposal through application of appropriate health physics procedures and maintenance of an appropriate soil cover over the disposed waste. Monitoring through the use of wells, surface water monitors, air monitors, and necessary maintenance during institutional control have provided adequate environmental protection at all DOE shallow land burial sites.

The requirements of DOE Order 5820 assure greater attention to the long-term hazards and mobility potential of low-level waste in shallow land burial. The subject order provides specific requirements related to waste acceptance criteria, disposal site selection, disposal site design, disposal site operations, and disposal site closure and post-closure activities for the siting and development of new disposal areas. These requirements ensure an early and thorough consideration of the long-term concerns prior to opening of a new disposal area.

Waste acceptance criteria must be developed which specify allowable quantities and/or concentrations of radioactivity as well as other materials which may in themselves be hazardous or toxic or which may contribute to enhanced migration of radionuclides. Waste package requirements, restrictions on physical properties of the waste, and concerns such as criticality are also addressed in the waste acceptance criteria.

Disposal sites at existing DOE facilities will be expanded as required to accommodate on-site needs and waste transported from other sites. Site selection for this expansion involves a preliminary screening process to investigate potential sites for acceptability with regard to hydrology, geology, soils, land use, socioeconomics, and ecology/meteorology. The preferred site or sites, as identified by the screening process, then undergoes an extensive site characterization study. Site characterization involves a comprehensive field study of site geology and hydrology, laboratory analysis of field samples, a site monitoring program, and finally a pathways analysis utilizing all the data generated during site characterization as well as input from the waste acceptance criteria.

Disposal site design and operations enhance the findings of the site characterization effort and ensure adequate safety, environmental protection, waste handling procedures and practices, site maintenance, disposal records, and quality assurance requirements. Monitoring programs are developed which provide information on groundwater hydraulics and quality, surface water discharge rates and quality, air quality, atmospheric weather data, and, in some cases, bioassay of vegetation and animal life. Closure and post-closure planning involves consideration of residual radioactivity and long-term site stabilization, security, maintenance, identification, monitoring, and corrective measures.

Although DOE Order 5820 recognizes that some low-level waste may require greater confinement disposal than afforded by shallow land burial, neither the means of such disposal nor the wastes needing greater confinement have been defined. One approach that will be demonstrated is burial at a depth (~150 ft) greater than shallow land burial but less than geologic disposal. This demonstration is currently under construction at the Nevada Test Site. Another approach is the use of improved waste forms and/or containers. Some development work on waste forms is currently under way in the DOE LLW management R&D program.

3. INVENTORIES AND PROJECTIONS

Defense low-level waste is generated at 13 principal DOE sites around the country. Those sites which do not have on-site disposal facilities package their low-level waste and transport it to sites which maintain operating burial grounds. Figure 1 shows the relative amounts accumulated through 1982 at those sites with disposal facilities. The principal DOE disposal sites currently operated are at Savannah River Plant (SRP), Oak Ridge Reservation (OR), Idaho National Engineering Laboratory (INEL), Hanford Operations (HANF), Nevada Test Site (NTS), and Lawrence Livermore National Laboratory (LLNL). The size of each dot is proportional to the volume of waste and does not indicate the amount of radioactivity involved. The volume of defense waste generated at DOE facilities in 1982 is illustrated in Fig. 2. The amount of waste shown for Nevada includes a large quantity of waste from old weapons test sites. Figure 3 illustrates that the DOE, the commercial fuel cycle, and the institutional and industrial (I/I) generators produce about equal amounts of low-level waste. In Fig. 4, it can be seen that the volume of non-DOE waste will grow much more rapidly than that from DOE over the next two or three decades.

Although the volume of waste from DOE defense activities will grow less rapidly than that from commercial activities in the years to come, the commercial low-level waste will be disposed of at sites to be selected and operated by the states or groups of states, whereas under existing DOE policy, the present DOE sites will have to accommodate the

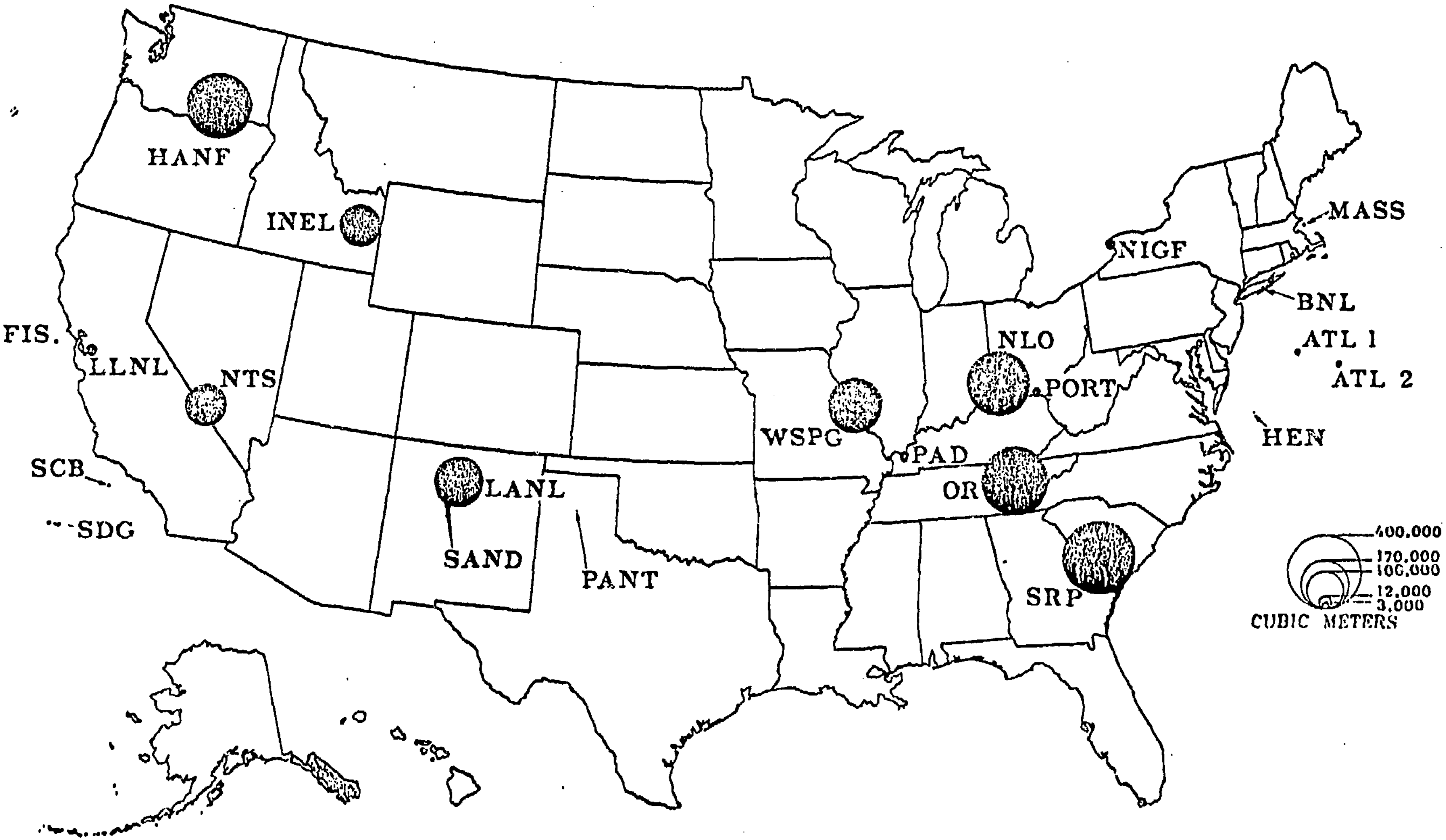

Fig. 1. Location and total volume of buried DOE/defense LLW through 1982.

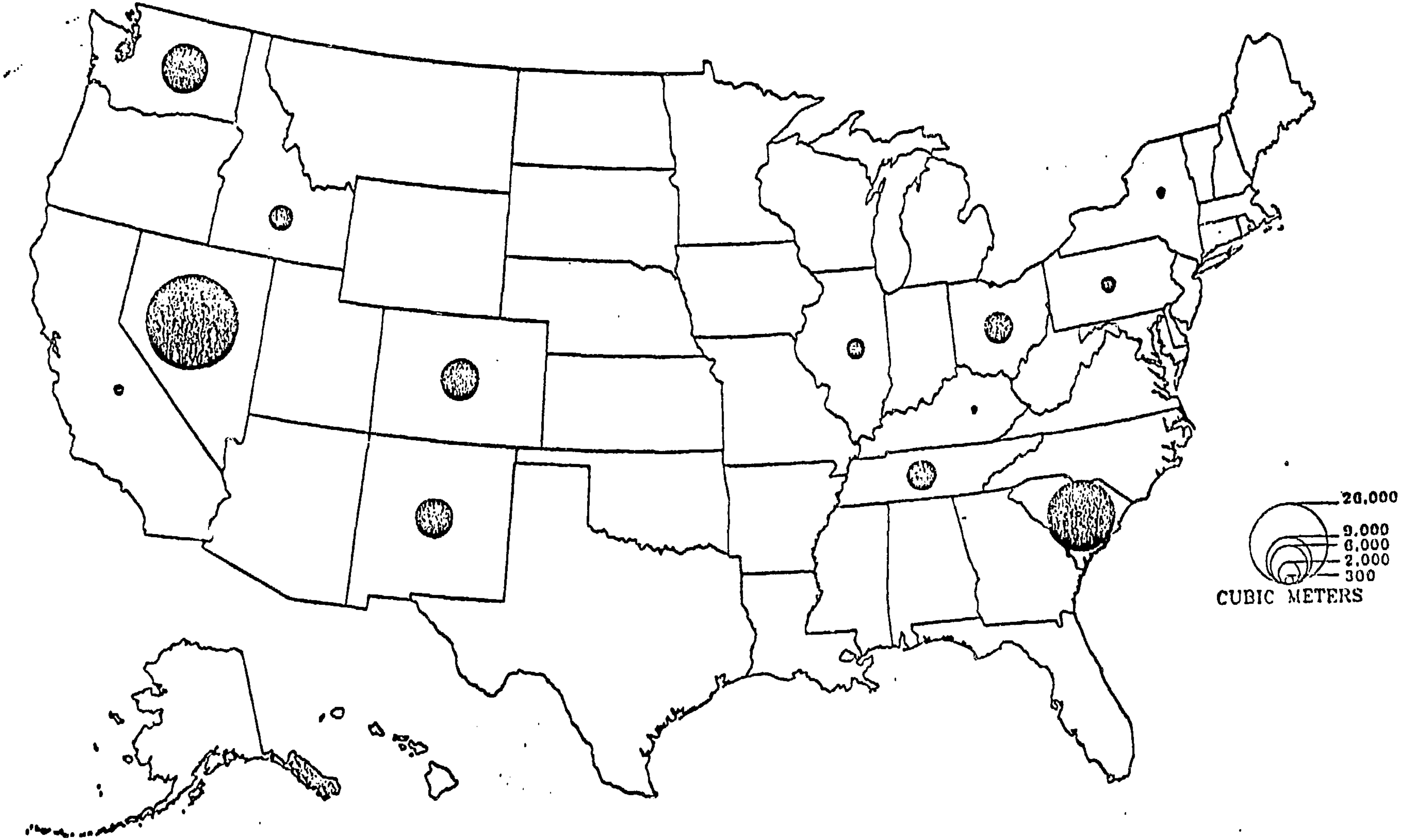

Fig. 2. Volume of DOE/defense LLW generated in 1982.

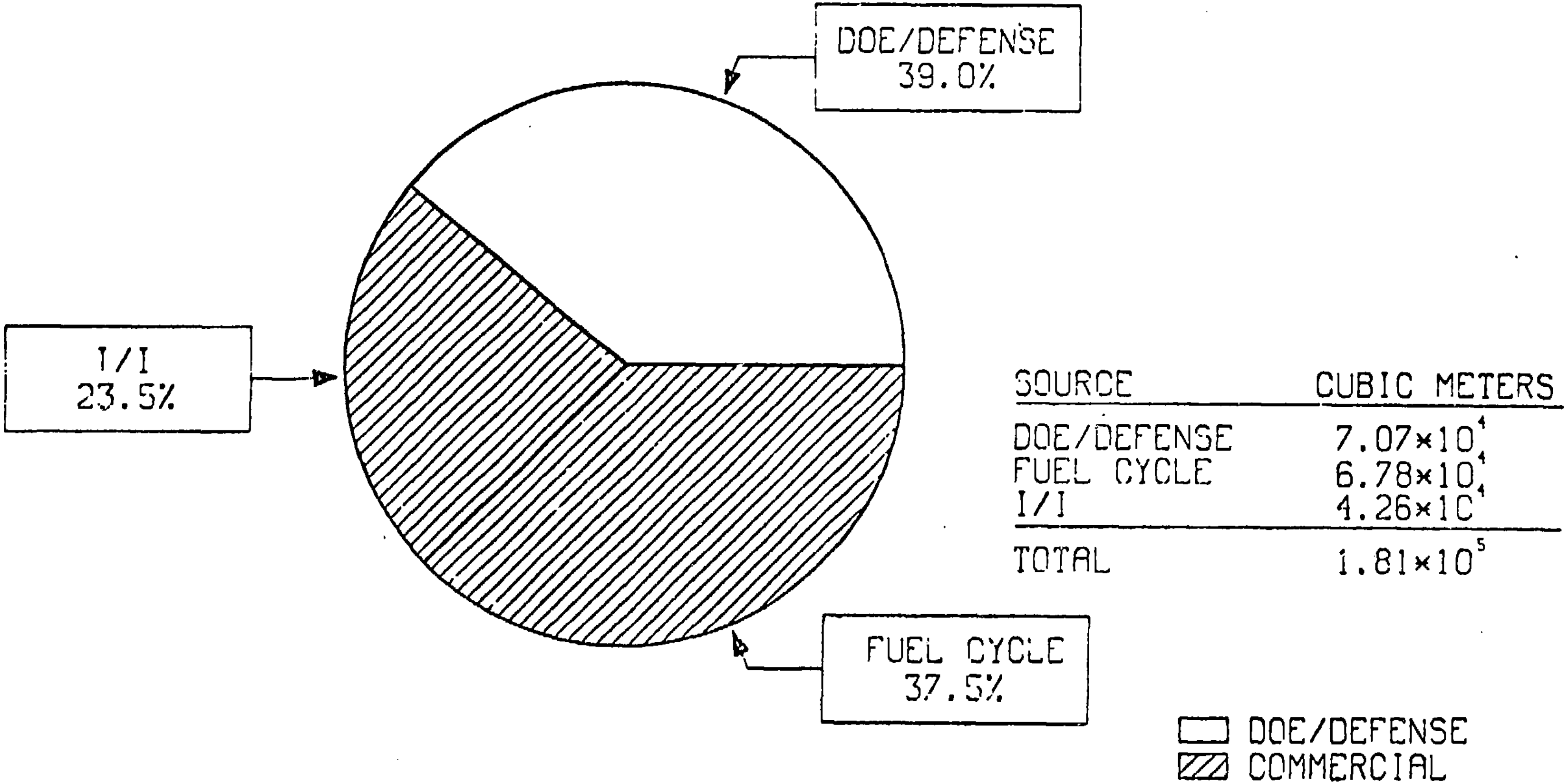

Fig. 3. Volume generation rate of LLW projected for 1983.

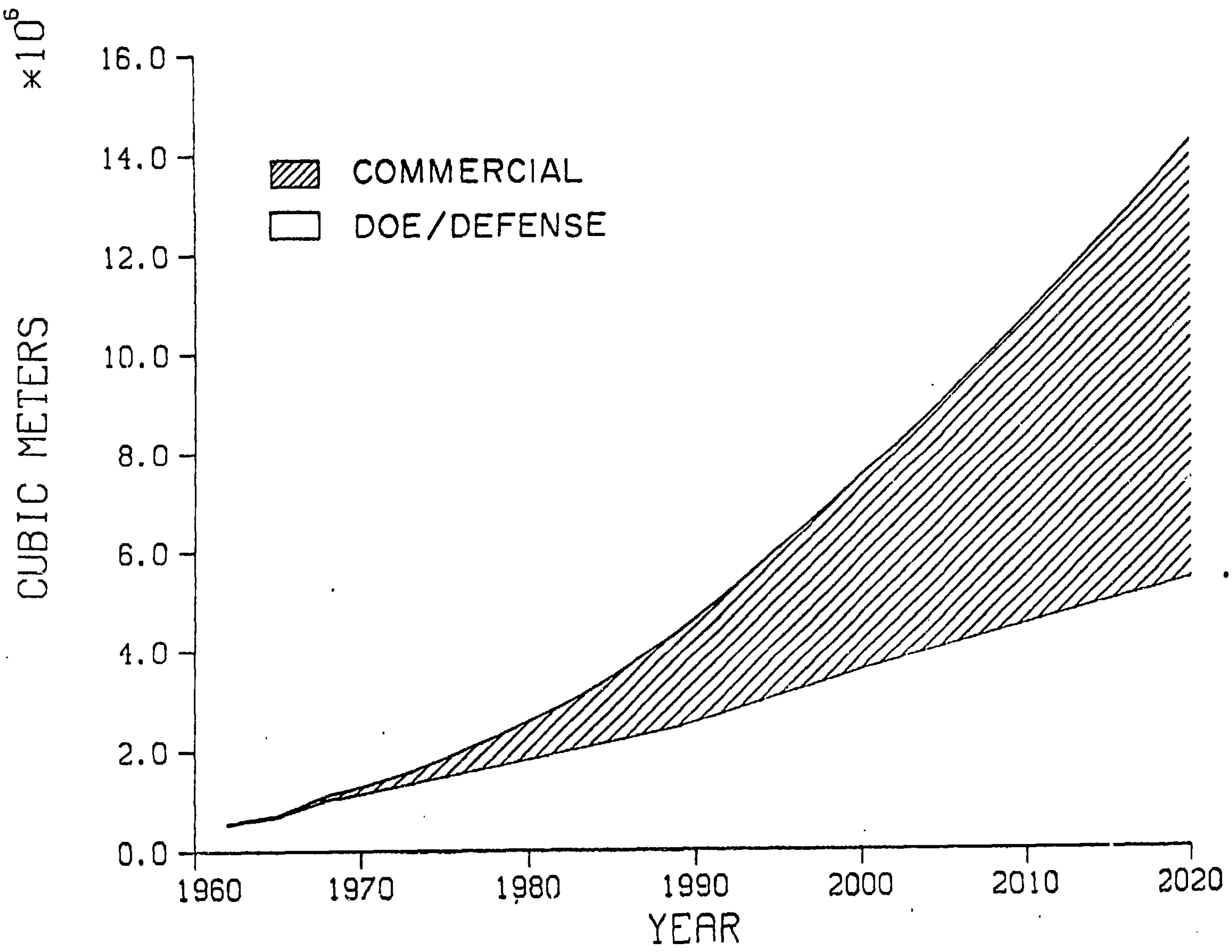

Fig. 4. Historic and projected volume of LLW (cumulative).

growing volume of defense waste. Most existing DOE disposal sites have adequate burial space for the immediate future; however, siting of new burial grounds will be necessary in the near term. The siting of a new burial facility in the Oak Ridge area is currently in progress.

4. WASTE TREATMENT AND CONDITIONING

Compaction is by far the most common treatment for low-level waste in the DOE system. Typically, compaction provides a volume reduction factor of from four to about eight. This volume reduction provides a direct savings in burial space required and reduces the amount of void space in the burial trenches. The reduction in void space contributes to burial ground stability. A typical compactor used at several DOE sites is shown in Fig. 5. Compaction may be done in containers when off-site transportation is involved, but for burial on-site, the compaction is commonly done to form bales which are not packaged prior to disposal. Argonne National Laboratory, which must ship its waste off-site for disposal, uses a compaction method in which small compactable objects are placed in 10-cm-diam by 23-cm-high cans which are then sealed and compacted around the waste material with a volume reduction factor of 4 to 5. The compacted cans are then collected in a metal drum for shipment.

Solidification is used for wastes which contain residual water or which require stabilization for shipment off-site. The most common solidification agent is Portland cement. Cement has been used as a solidification agent since the earliest days of the nuclear industry. The use of cement for dry solids would normally only be for material which must be shipped or which is extremely soluble or easily dispersible.

Considerable development work has been done on incineration; however, it is not widely used for treatment of low-level waste at DOE sites. A number of incinerators have been considered and tested for radioactive wastes. Several of these have been found useful for transuranic or special types of waste, but to date none have been routinely applied to solid low-level beta-gamma waste. In most cases, the costs of operation and maintenance are high enough to offset any savings in shipping or burial ground space. However, Savannah River Plant is presently testing a controlled-air incinerator for their low-level waste. In the controlled-air incinerator, the combustion takes place initially in a primary burning chamber in which the solid material is pyrolyzed to ash. The combustion gases are then burned completely in a second chamber which has an auxiliary heat source such as a gas or oil flame. Excess air is also provided to the secondary chamber for complete combustion. In the Savannah River incinerator, a water spray quench cools the combustion gases and removes some of the particulates. Then the gas is

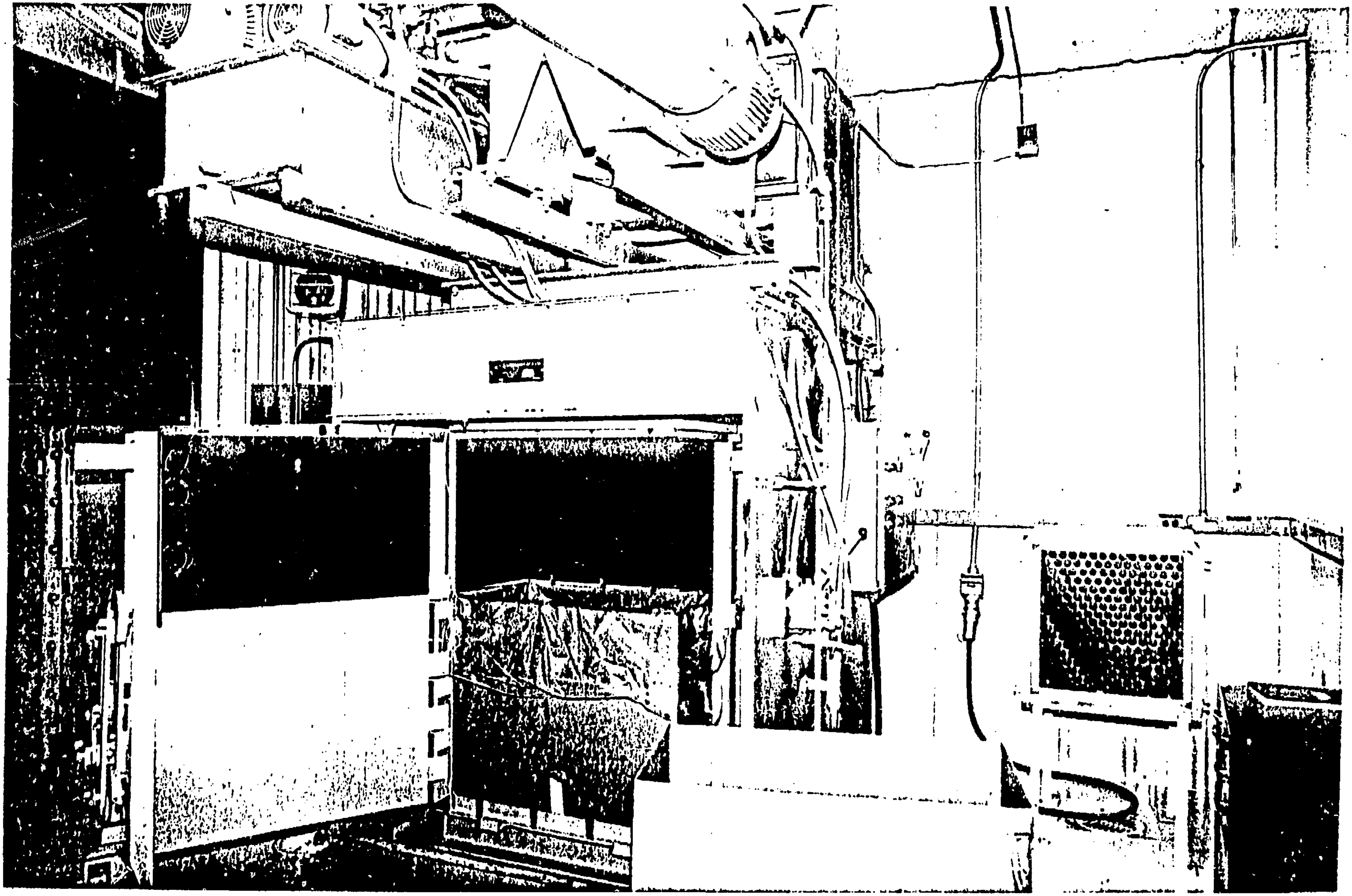

Fig. 5. Low-level waste compactor/baler at Los Alamos disposal site.

passed through bag filters before being released to the atmosphere. A test with non-radioactive waste was completed last year in which 15,700 kg of solid waste and 5.7 m^3 of solvent were incinerated. Performance has been satisfactory for both solids and organic liquids. Emissions of off-gas components were well below South Carolina standards. Volume reductions of 20:1 for solid waste and 7:1 for solvent/lime slurry were achieved. Beginning in 1984, a two-year demonstration will be conducted using the facility to incinerate slightly radioactive (<1.7 mCi/m^3) and suspect level (<1 mR/h at surface) solid wastes. This incinerator, as tested at Savannah River Laboratory (SRL), is shown in Fig. 6. The incinerator has now been installed at the SRP, as shown in Fig. 7.

5. TRANSPORTATION

About 20% of defense low-level beta-gamma contaminated waste is shipped off-site for disposal. These shipments must be packaged and transported in accordance with the Department of Transportation (DOT) regulations. The primary DOT regulation applicable to shipment of radioactive material is 49 CFR 173. The regulation specifies container designs and test procedures and defines what containers may be used for different types of material. The regulations governing the transport of radioactive materials are currently undergoing change that will make them consistent with the system proposed by the IAEA.

The Type A containers must prevent dispersal and retain shielding efficiency under normal conditions of transport. Approved Type A containers include a wide variety of steel drums ranging in volume from 19 to 210 L, a 210 L aluminum drum, plywood boxes from 4 to 230 L, and fiberboard drums from 57 to 210 L. Type A containers must be able to withstand a temperature range of -40°C to +54°C, a 4-ft drop while wet, the normal vibration associated with shipment, and a reduction of external pressure to 0.5 atm. A number of shielded casks are also available to meet the Type A specification.

Type B packaging requires that an inner container be used which meets the standards for Type A packaging and that the inner container be surrounded by an overpack which will assure that under accident conditions: (1) loss of shield will not result in a dose rate greater than 1000 mR/h at 3 ft and (2) no radioactive material will be released.

Type A quantities of dry waste are normally packaged in cardboard boxes, wooden boxes, or metal drums with removable lids. Waste containing residual liquid must be packaged with sufficient absorbent material to absorb at least twice the volume of liquid, or must be immobilized with a

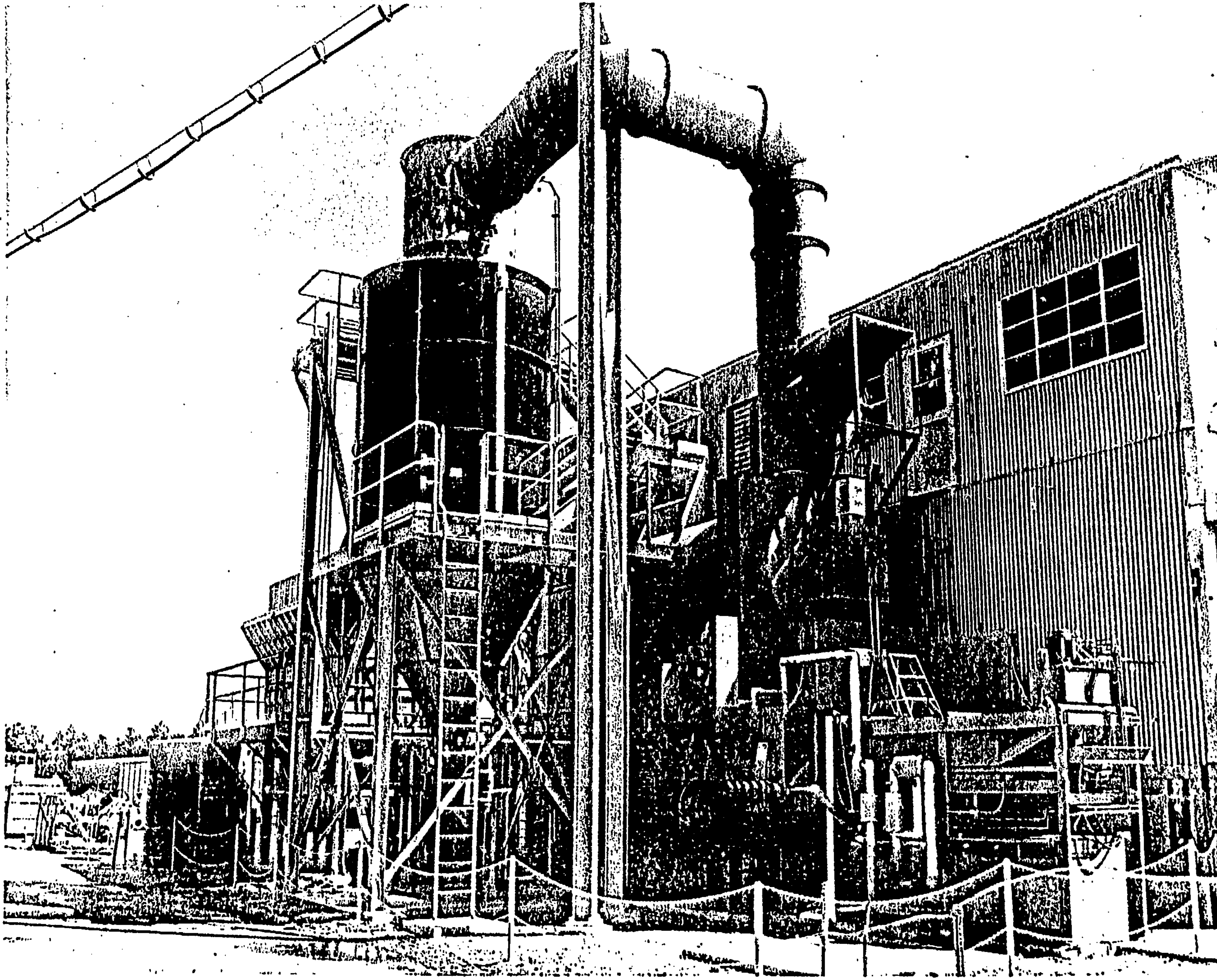

Fig. 6. Incinerator test at Savannah River Laboratory.

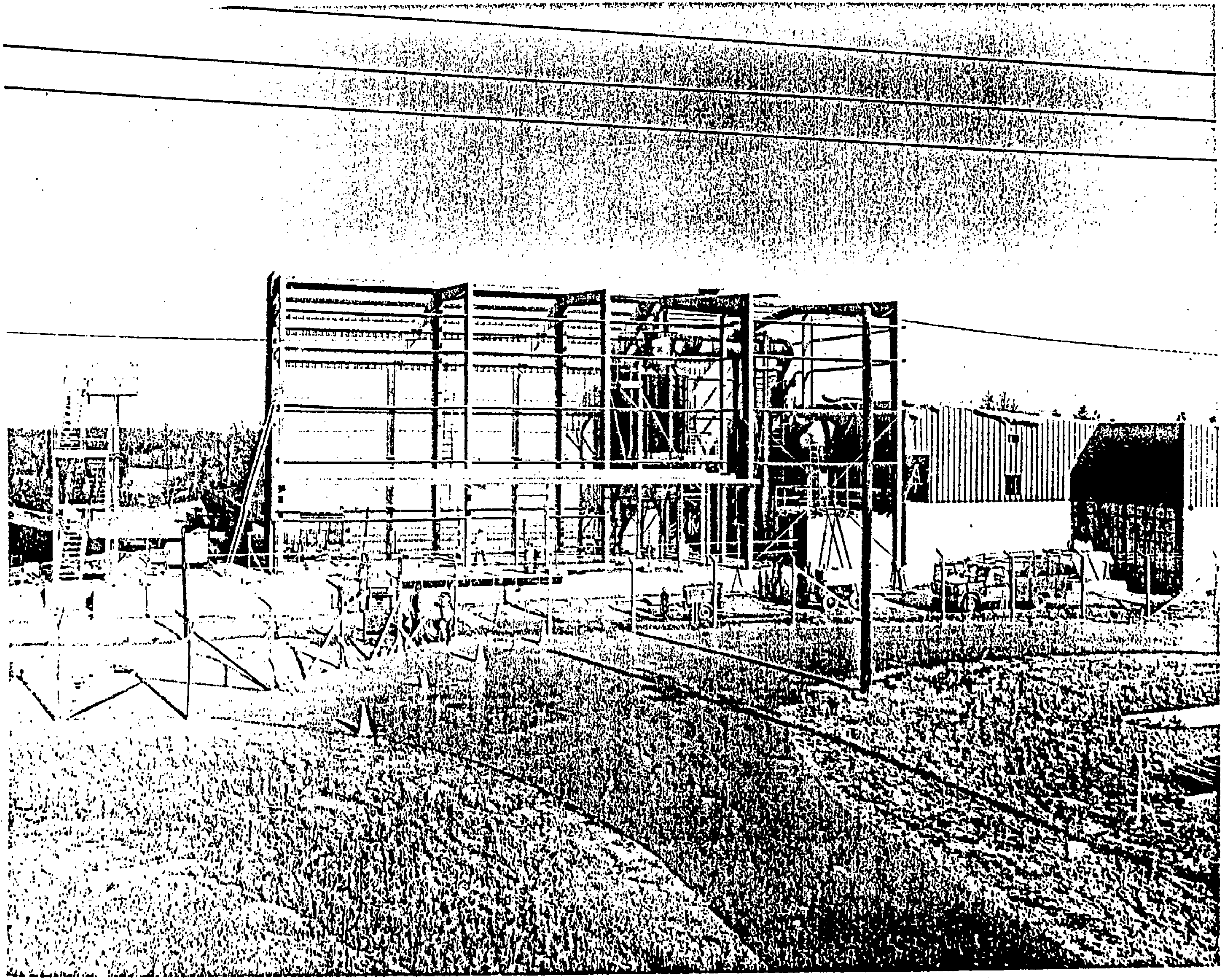

Fig. 7. Installation of incinerator at Savannah River Plant.

solidification agent such as cement. It should be noted that compliance with the shipping regulation is not sufficient, since the waste must also comply with the waste criteria of the disposal site.

The cost of transporting low-level waste is of course heavily dependent on both the distance and the amount of shielding required. The unit transportation costs for truck shipment, the most common mode, are shown in Table 1.

Table 1. Unit transportation charges for shipment of LLW ($\$/m^3$ of waste)[a,b]

Distance to disposal site (miles)	(km)	Unshielded waste[c]	Shielded waste[d]
100	160	34	271
500	800	78	520
1000	1600	131	939
1500	2400	190	1380

[a]Basic assumptions:

Shipping mode:	Truck
Shipping speed, miles/day:	500
Cask rental fee:	\$250/day
Cask capacity:	4.2 m^3
Truck capacity for unshielded LLW from nonreactor sources:	28.3 m^3
Truck capacity for unshielded LLW from reactors:	14.2 m^3

[b]1983 dollars.

[c]Based upon costs in the Western U.S. for reactor waste. Costs in the Eastern U.S. are slightly lower than those shown. Transportation costs for unshielded LLW from nonreactor sources are one-half of those shown.

[d]Assumes cask is returned by truck to point of origin.

6. DISPOSAL OPERATIONS

Disposal operations in the U.S. for defense low-level waste consist primarily of shallow land burial. In this technique, low specific activity material is emplaced in trenches excavated to a depth of from 3 to 8 m depending on the site characteristics. The trench length also depends on the site characteristics and the operating procedures. The length varies from 15 m at Oak Ridge to as much as 275 m at the INEL disposal site. Trench width varies from 3 m for the shorter trenches to as much as 100 m for the very long trenches. Typically the waste is placed to within about 1 or 2 m of the surface. A greater backfill depth may be required to reduce the surface dose rate to an acceptable value. Mounding of the backfill to 0.5 to 1 m above the original grade is applied at some sites. Generally the surface is seeded with an appropriate vegetative cover after the trench is closed. Fig. 8 shows a typical trench for low specific activity low-level waste at the Hanford site. Figure 9 is a photo of one of the very broad trenches at the Nevada Test Site. Waste packages can vary from plastic bags to metal drums to plywood boxes. For on-site disposal, conformal packaging that can be compacted in place from the pressure of overburden and backfilling machinery are preferred to rigid containers which may have void space (i.e., plywood boxes). Figure 10 illustrates some of the compactible containers ready for burial at Hanford. The use of less durable conformal containers by commercial operators is not permitted under 10 CFR 61.

Emplacement of low-specific activity material in the trench varies from random dumping directly from the truck as can be seen in Fig. 11 to offloading and stacking with forklift equipment as shown in Fig. 12. The random emplacement and conformable containers are especially suited to a burial technique in which each day's accumulation of waste in a trench is covered with a shallow layer of soil as shown in Fig. 13. This method makes use of the weight of operating machinery to consolidate the backfill and the waste, thus minimizing void spaces. The method also provides interim isolation of the waste prior to complete filling of the trench. The generic category of low-level waste includes beta-gamma material with sufficiently high-specific activity to require shielding to reduce personnel exposure. The shielding may be integral with and buried with the package as shown in Fig. 14 or it may be a reusuable cask as shown in Fig. 15. In either case, high-specific activity material requires more elaborate equipment and procedures.

Some wastes, usually those of high-specific activity, are emplaced in boreholes. These are vertical holes of from 1 to 5 m in diameter. At Oak Ridge, these holes are drilled to a depth of about 7 m. At arid sites, the holes may be much deeper. Waste packages are emplaced individually, and each package is covered with earth until the dose rate

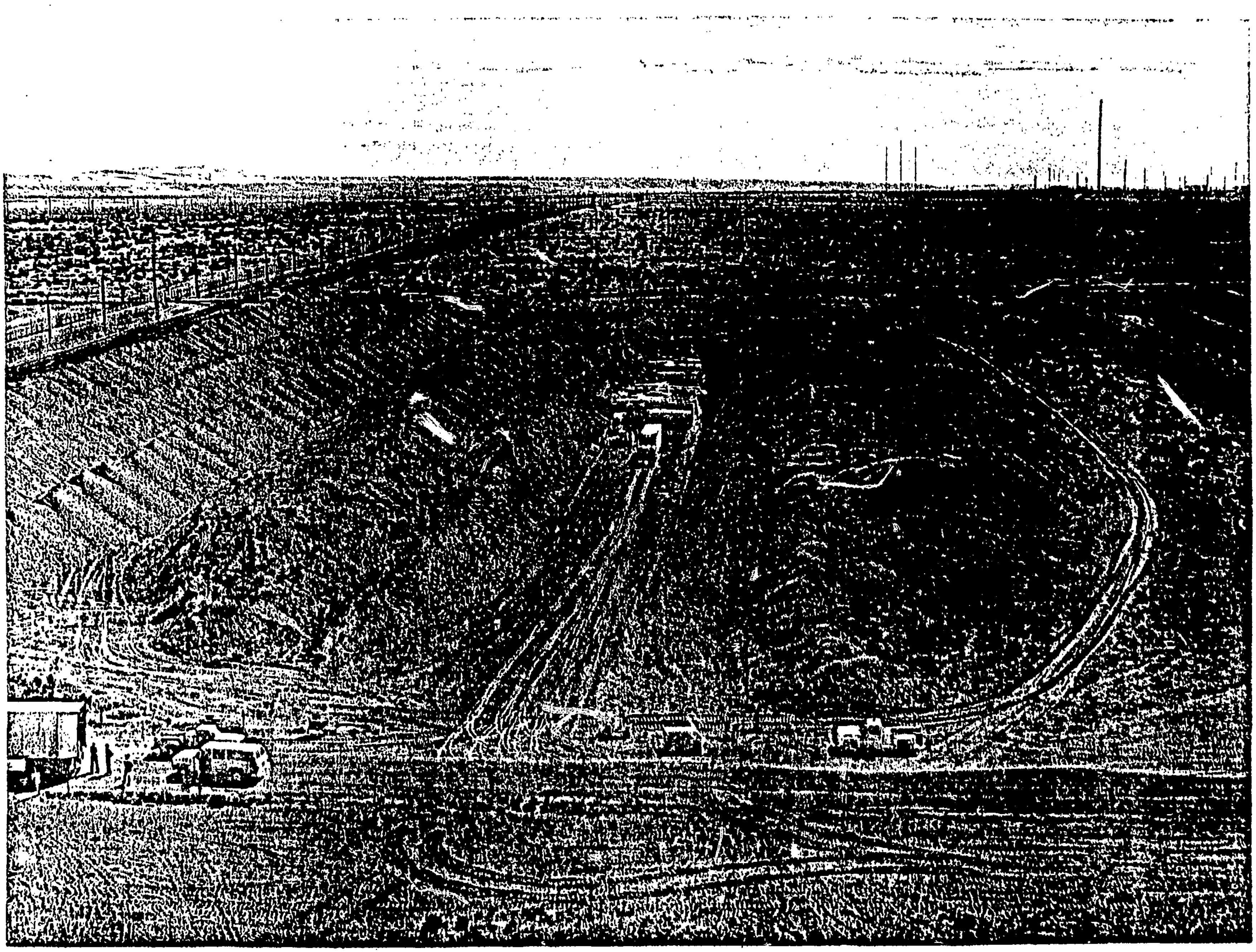

Fig. 8. LLW disposal operations at the Hanford site.

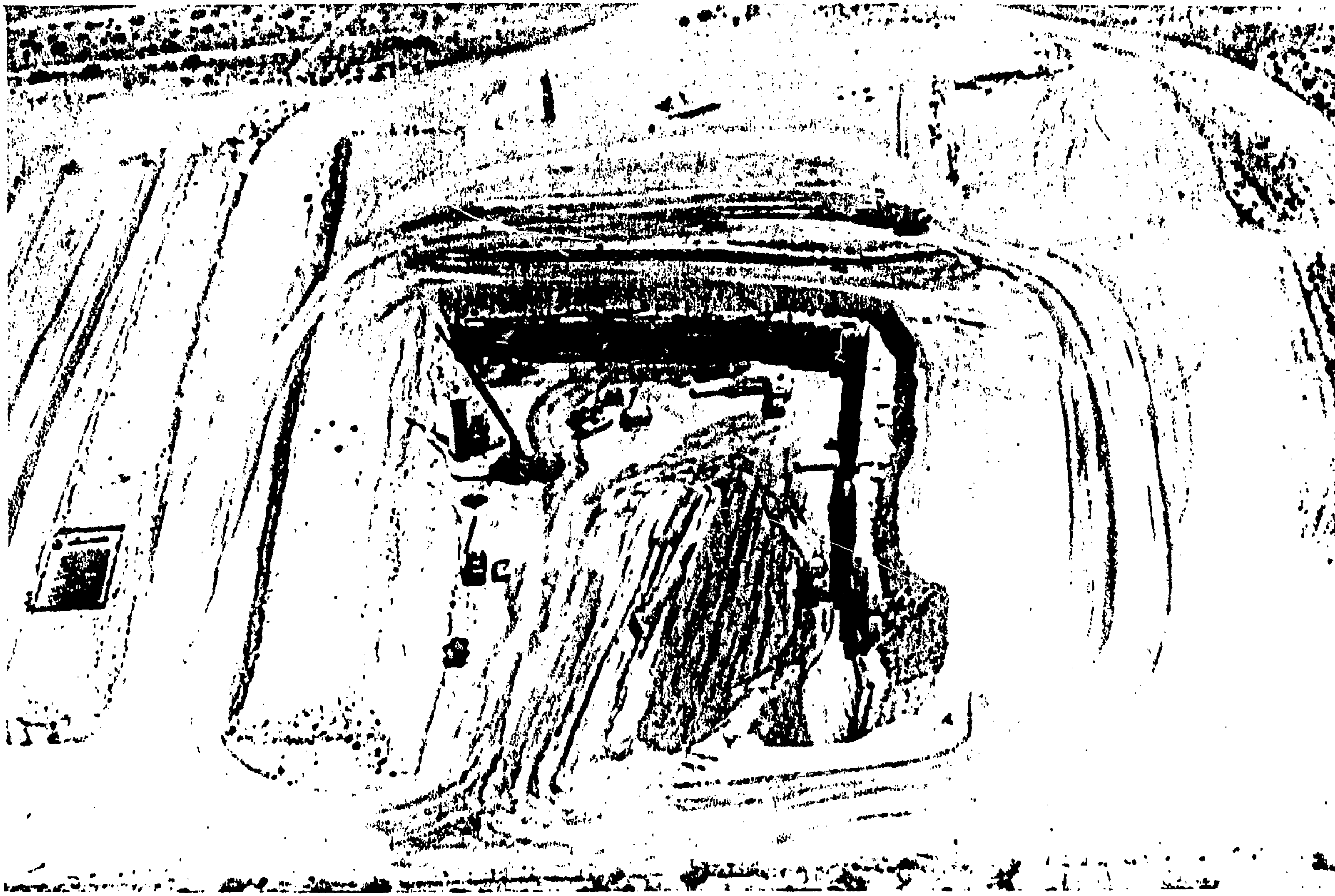

Fig. 9. Use of large trench concept at the Nevada Test Site.

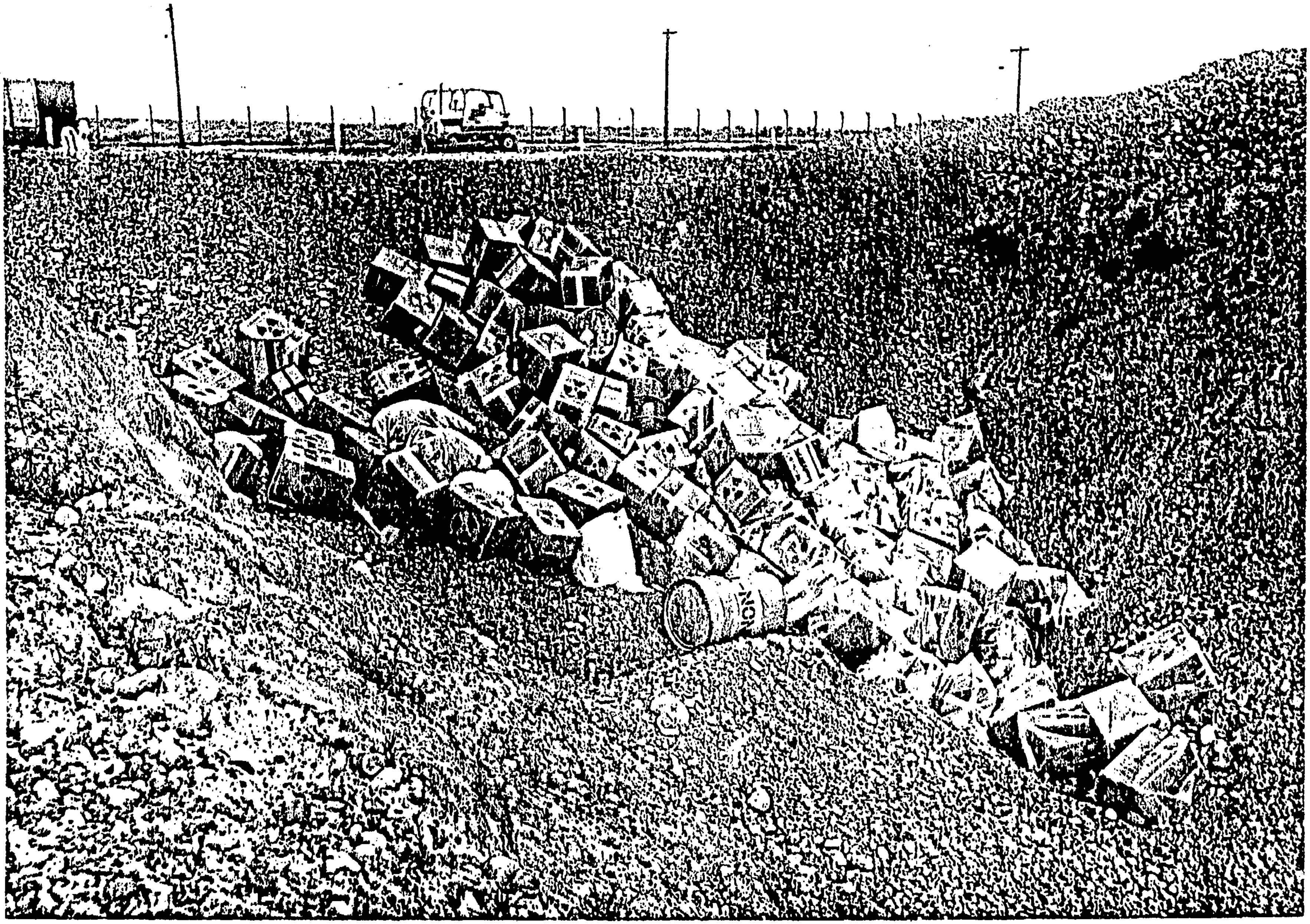

Fig. 10. Compactable waste containers ready for burial.

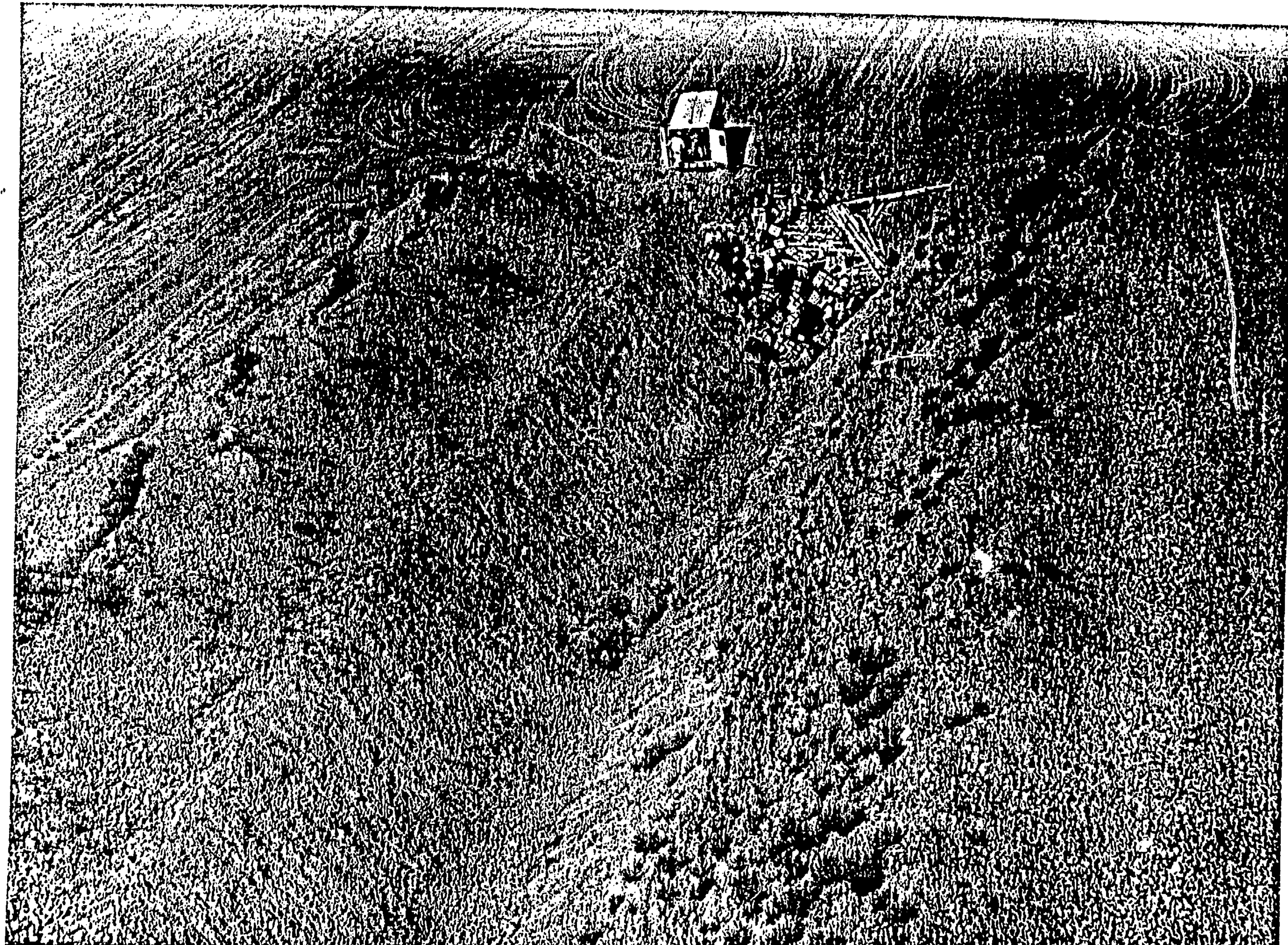

Fig. 11. Random dumping method of waste emplacement.

Fig. 12. Organized stacking of waste in disposal trench.

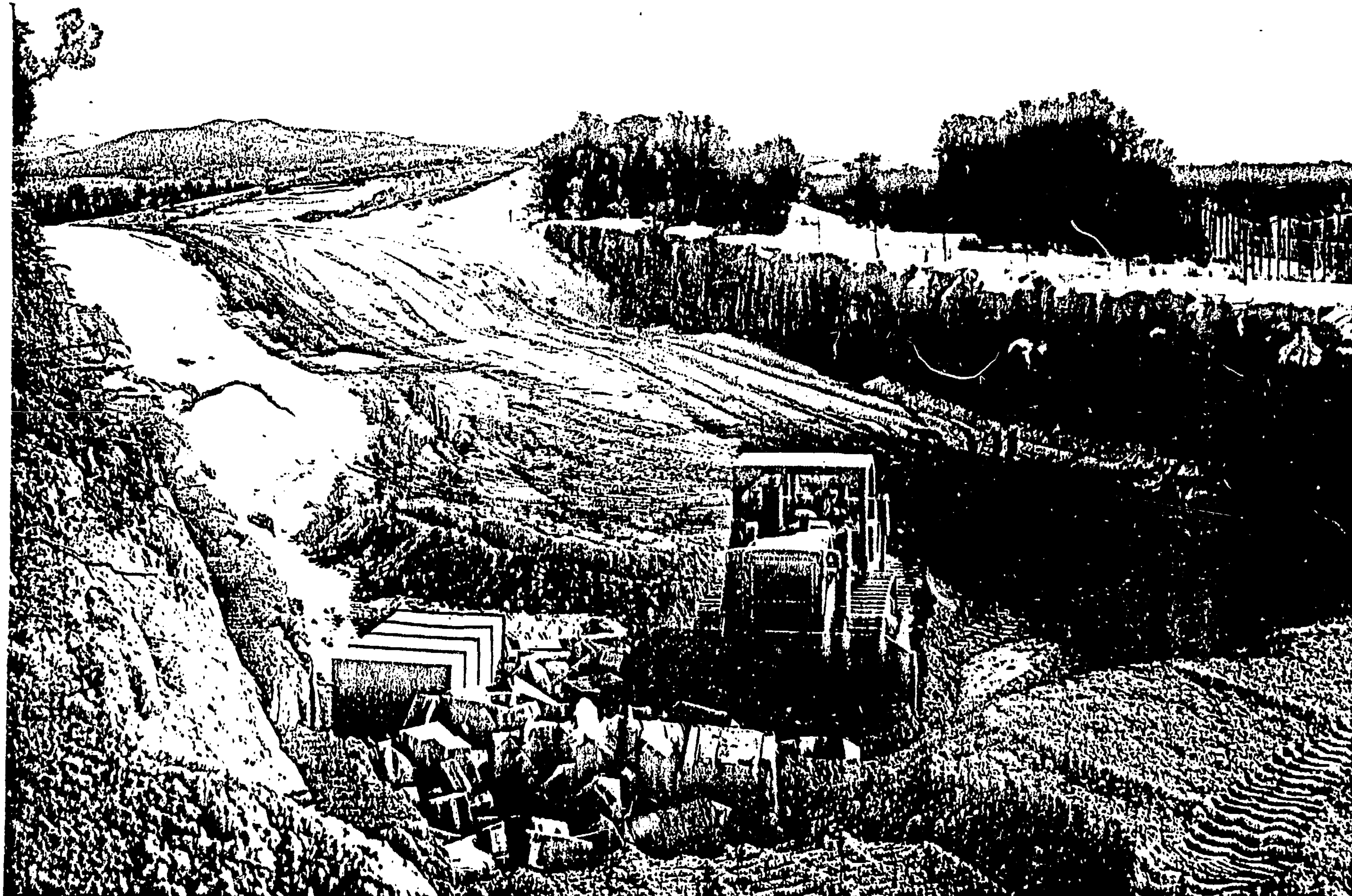

Fig. 13. Layering technique of shallow land burial - Los Alamos site.

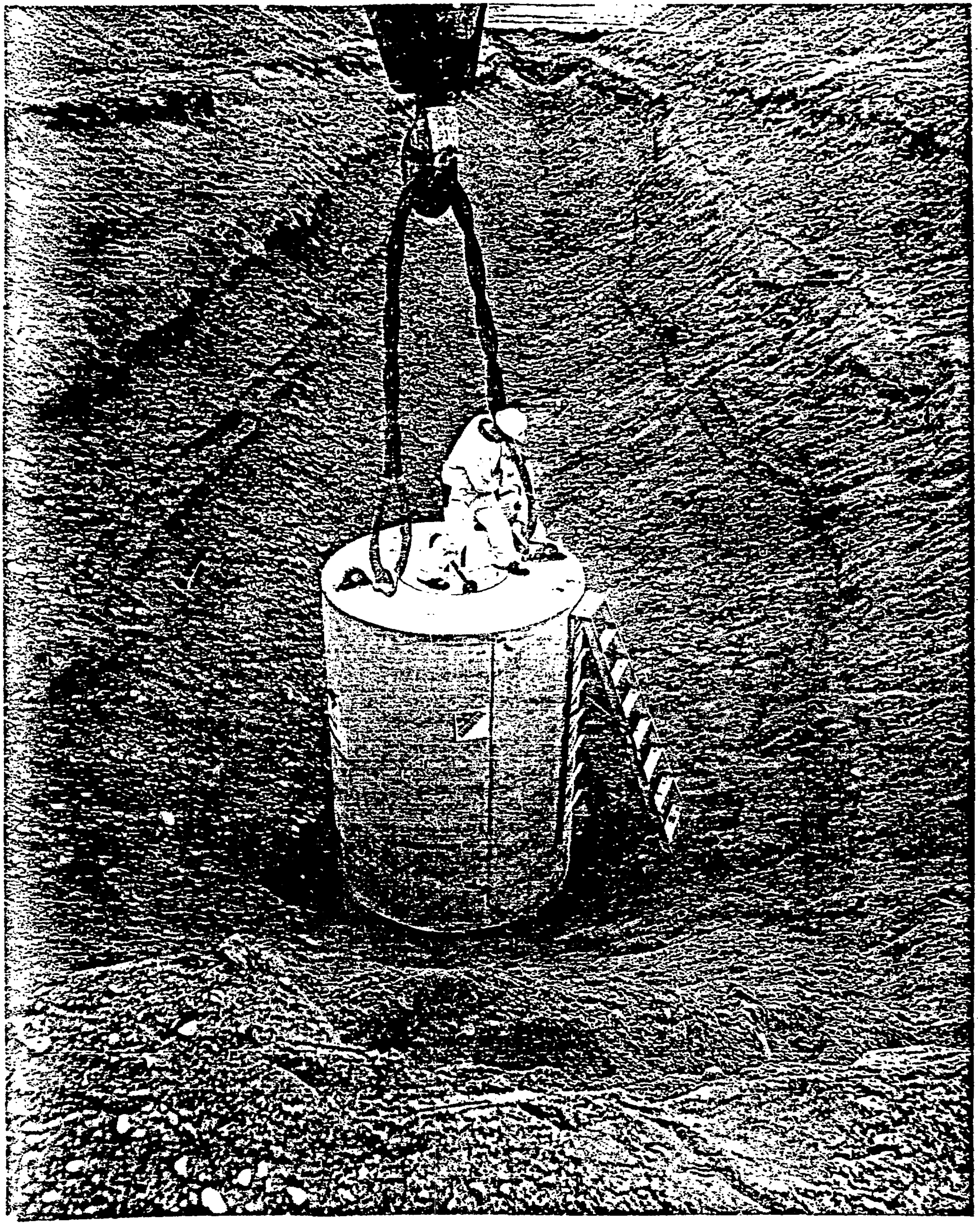

Fig. 14. Shielded waste container ready for burial.

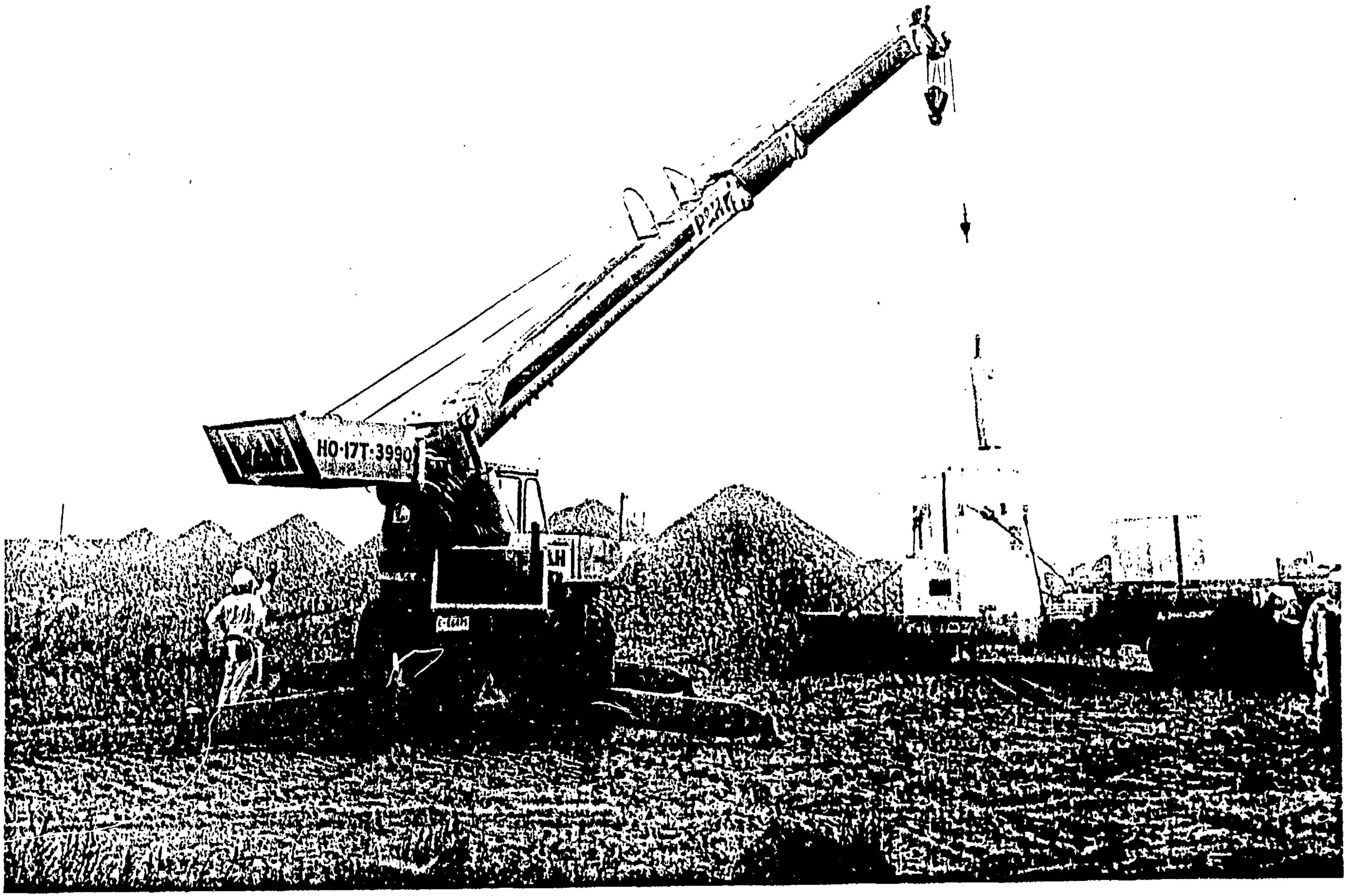

Fig. 15. Application of reusable shielded cask for transport and emplacement of high-activity waste.

is reduced to 100 mR/h. When the hole is full, it is capped with concrete. Los Alamos uses a similar scheme as shown in Fig. 16. Los Alamos has adapted this approach to the use of bottom unloading transfer casks as shown in Fig. 17. Larger diameter boreholes are sometimes used for the disposal of equipment whose shape is not well suited to trench disposal.

7. BURIAL GROUND PERFORMANCE AND CORRECTIVE MEASURES

The performance of shallow land disposal in this country, in spite of early practices that we would consider unacceptable today, has resulted in very little migration outside site boundaries. The cesium and strontium and the heavy metal isotopes that have been disposed by shallow land burial have shown little migration. In arid sites, we have seen almost no migration; however, at the humid sites we are seeing some migration of tritium, ^{90}Sr, and ^{99}Tc. In no case do these represent a hazard to the public. Prior to 1970, many sites intermixed TRU with beta-gamma waste, and until recently, little concern was given to chemically hazardous waste. The presence of TRU and hazardous wastes tend to complicate long-term stabilization of previously used burial grounds. In addition, in early days, liquid seepage pits were used for ground disposal of supernate liquids from high-activity liquid waste processing at several sites. The practice of using seepage ponds was abandoned; however, these old ponds account for a large percentage of the curie content of buried radioactive waste, particularly at Oak Ridge.

Experience at existing DOE low-level solid waste burial sites has shown that conditions occur after burial which cause problems in maintaining waste isolation, and that often requires corrective measures to minimize the resulting hazards. Even with burial practices that continue to improve, the burial medium remains part of a dynamic system subject to natural changes that affect waste isolation.

The shallow land burial trench is part of a complex environment involving interaction with climatologic, geologic and hydrologic, and biologic components. Effective corrective measures must anticipate and adequately accommodate these interactions. DOE shallow land burial experience has indicated that buried wastes are especially vulnerable to water movement. The erosive action of water damages the trench cover and produces opportunities for infiltration and intrusion by plant roots and animals and eventual exposure of trench contents. Entry of water into the trench solubilizes radionuclides and makes them susceptible to migration by groundwater movement, contaminating deeper groundwater or emerging in surface seepage. In addition, subsidence is accelerated by saturation. The resulting areas of collapse in the trench cover enable

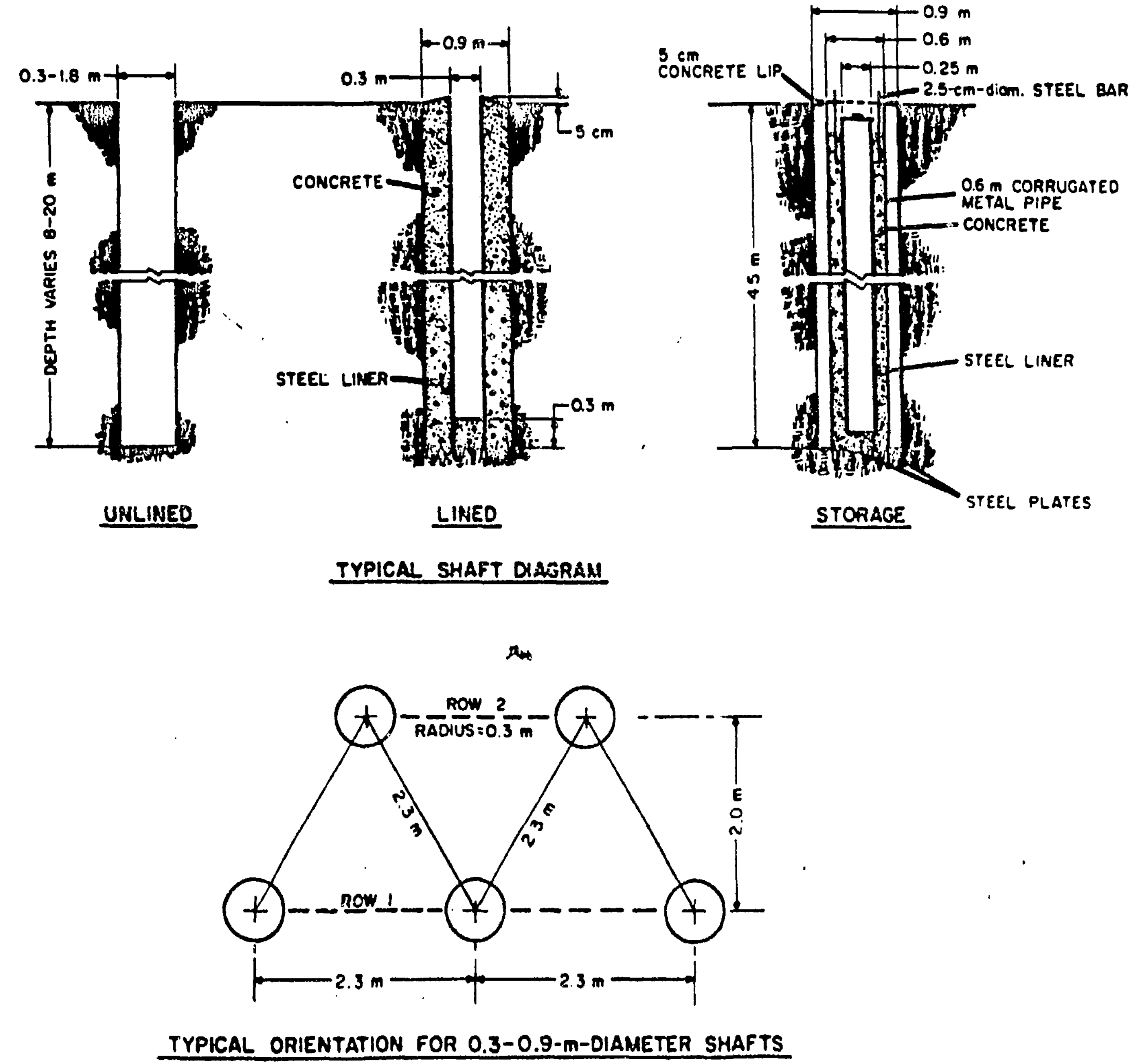

Fig. 16. Borehole disposal shaft design at the Los Alamos site.

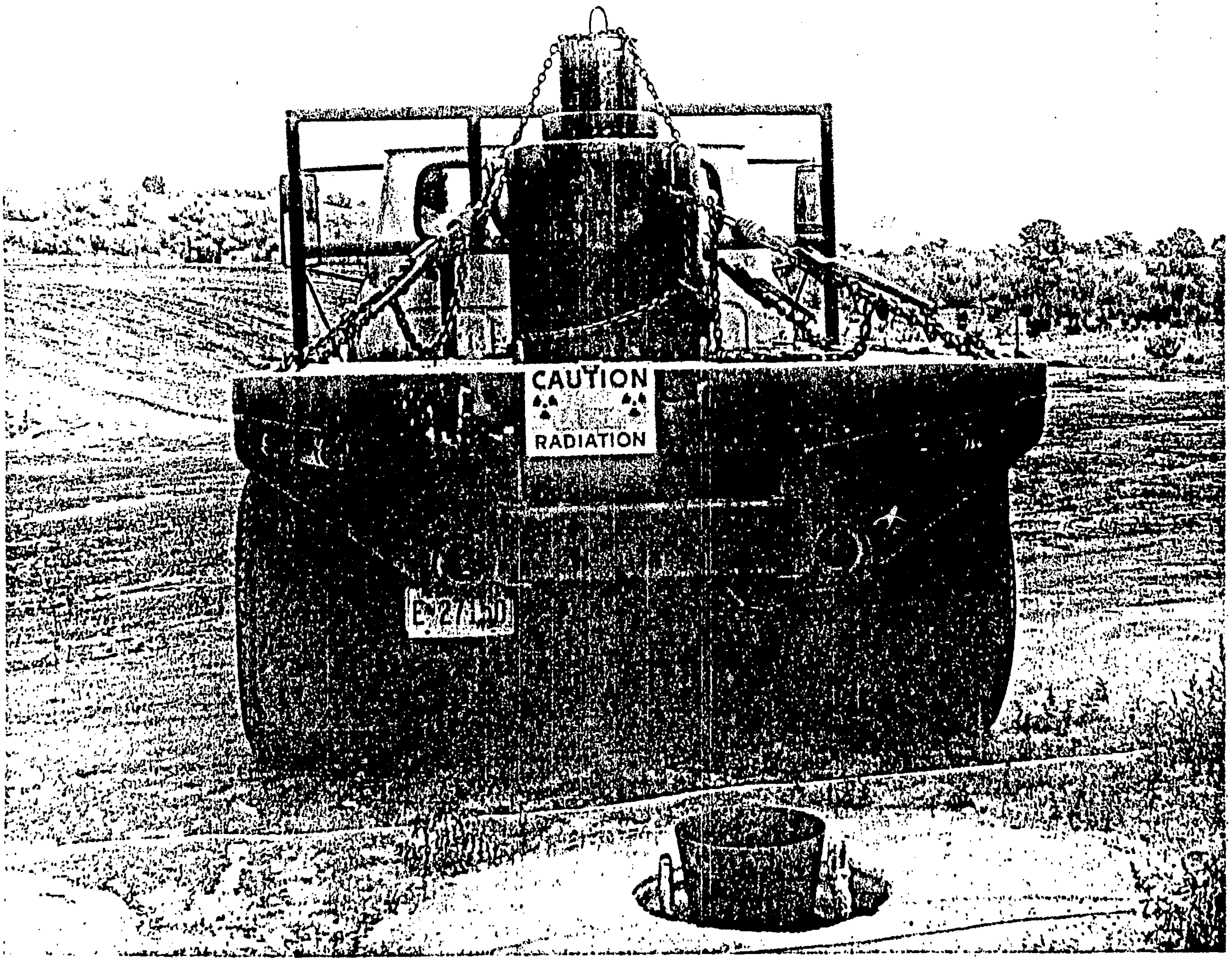

Fig. 17. Truck with bottom unloading cask backing over waste disposal shaft.

entry of more water. Finally, fractures in the surrounding soil matrix may provide pathways for rapid subsurface movement of contaminants from the trench. Any approach to problems involving radionuclide migration in water and the planning of any activities involving the trench environment that may affect water movement require a good understanding of the hydrologic cycle as it relates to the geology and topography of the burial site. In arid environments, opportunities for radionuclide migration are substantially more limited. The burial trench is many meters above the underlying groundwater table, and the cover is subject to the erosive action of rainfall and surface runoff only on a seasonal basis. In such cases, the most significant pathways of contaminant movement are biologic, from intrusion by deep-rooted plants, and burrowing animals.

As outlined above, six conditions requiring corrective actions are being addressed at DOE defense shallow land burial sites:

1. eroding trench covers,
2. permeable trench covers,
3. subsidence,
4. groundwater entering trenches,
5. intrusion by deep rooted plants, and
6. intrusion by burrowing animals.

Soil erosion, has occurred at all DOE shallow land burial facilities, and can undermine protective soil covering and remove topsoil which is needed in the establishment of vegetative covers. Fig. 18 illustrates particularly severe wind erosion where a waste container has actually been exposed. DOE experience has shown that vegetative stabilization with appropriate grasses generally provides the best approach to long-term erosion control. Water diversion systems and non-vegetative stabilization materials have application as temporary control measures. At some sites, establishment of a sound vegetative cover is impractical, and in some applications it is desirable to use stabilization and diversion systems in conjunction for long-term erosion control.

Cover material and backfill used in shallow land disposal operations are susceptible to infiltration of surface water which can result in accumulation of water in trenches. Water diversion can reduce the infiltration, or the permeability of the trench cover can be reduced by addition and compaction of fill or by the application of sealing material to the cover. Several varieties of soil material have suitably low permeability to be used as sealers. If local soils are not suitable, soils of high purity and low permeability are commercially available (bentonite clay). Since the trench cover must support vegetation and yet resist penetration by water, plants, or animals, the multiple layer concept for trench covers is receiving greater attention. In Fig. 19 a multi-layer cover which incorporates a geomembrane is being installed.

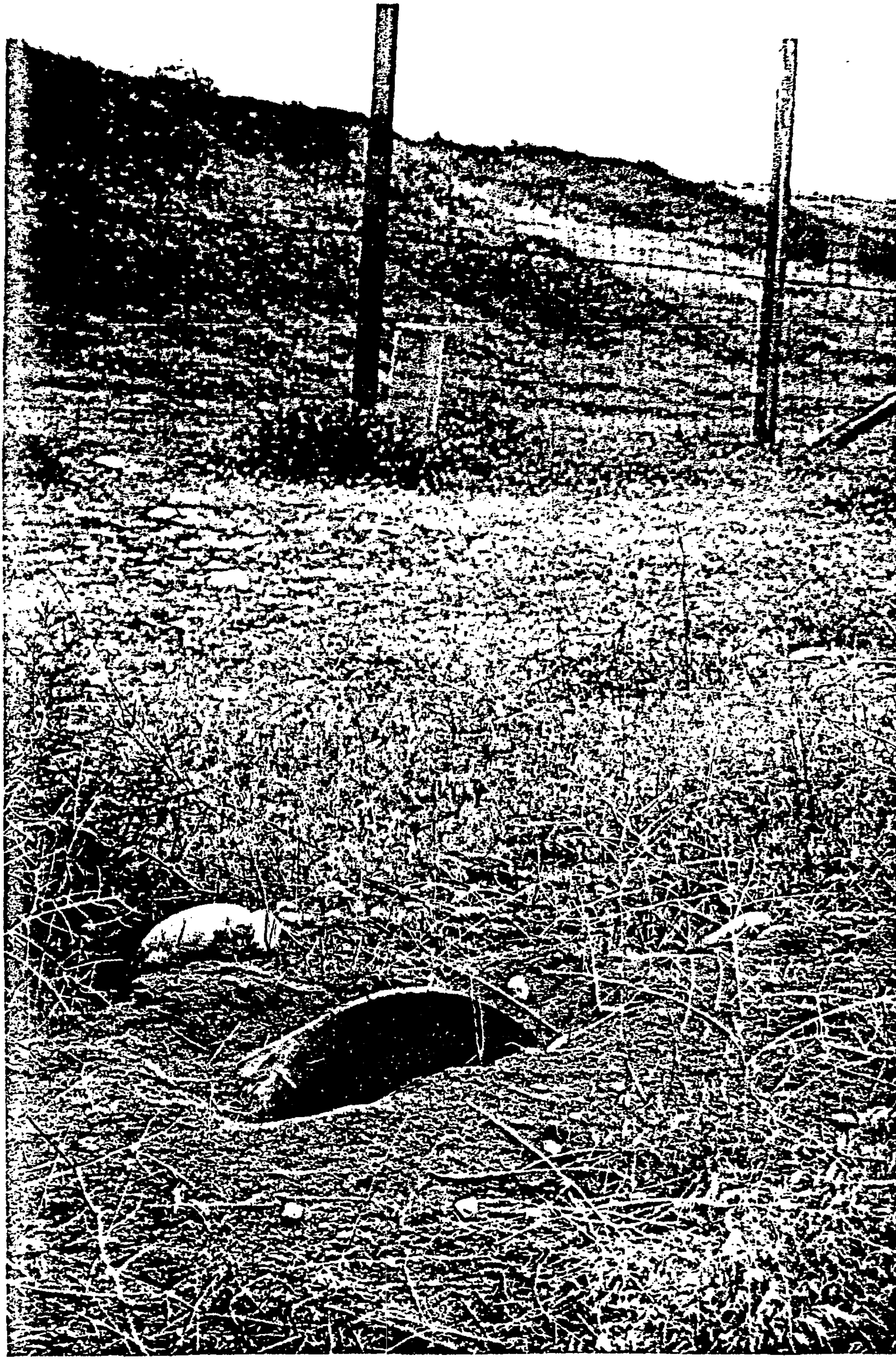

Fig. 18. Effects of wind erosion on trench cover.

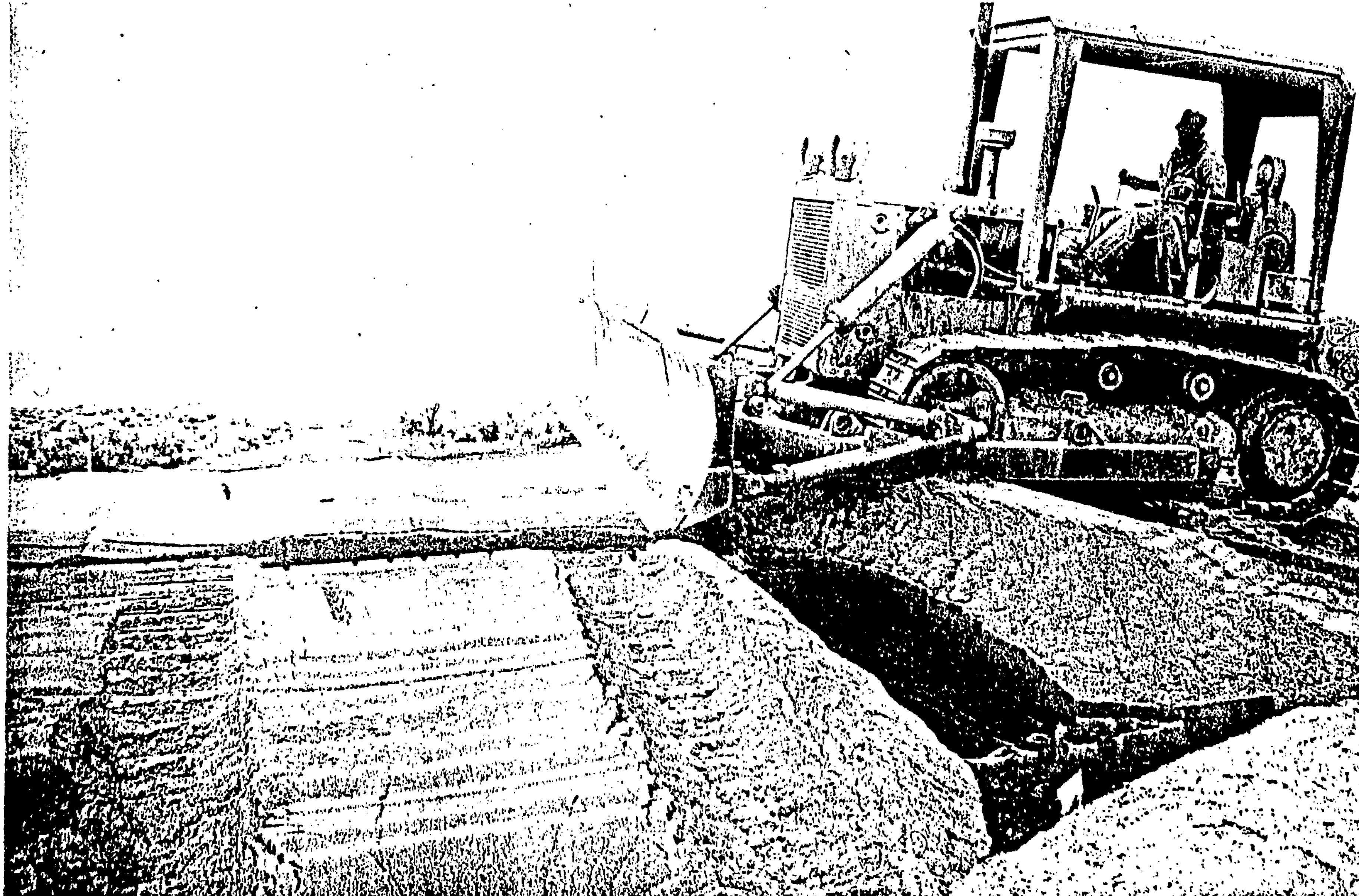

Fig. 19. Multi-layer barrier method for decreasing trench cap permeability.

Subsidence is the slumping of fill and waste material into void spaces between waste containers and within containers which have lost their mechanical integrity. It is evident at the ground surface by holes, cracks, and general area depressions. The holes, cracks, and depressions create problems in water management by facilitating infiltration and erosion. Fig. 20 illustrates a relatively small subsidence feature. The most common corrective approach at DOE facilities has been to fill and regrade the trench cover as subsidence events occur. Compaction and surcharging with static loads have also been used to repair subsidence.

In-situ grouting and falling mass compaction are currently being evaluated as ways of avoiding subsidence. Fig. 21 shows a pile driver in use for subsidence correction. The economic and technical merits of continuing a repair program versus corrective measures to eliminate future subsidence must be evaluated for each existing shallow land burial facility.

One humid area DOE disposal facility has had groundwater enter the trenches. To correct this situation, surface water may be diverted before it enters the ground to recharge the groundwater system or the groundwater may be diverted away from the trench by passive subsurface drains. The subsurface drain provides a preferential flow path around the trenches and lowers the groundwater table. At the problem site, a combination surface water diversion and subsurface water drain has been installed to lower the groundwater table.

Root intrusion by plants can lead to transport of contamination to the surface where it may enter the food chain or be dispersed by wind and water erosion. Corrective measures include encouraging desired vegetation, limiting the maturation of undesired vegetation or inhibiting all plant growth. Generally sites which have a well-established grass surface cover find that periodic mowing provides adequate control over intrusion by deep-rooted plants at low cost. When mowing is ineffective, application of herbicides or physical barriers to root penetration have been used.

Burrowing animals sometimes intrude into buried waste and transport material to the surface where dispersion by surface runoff or wind erosion may occur. Burrows destroy the integrity of the trench, promote subsidence, and increase infiltration and erosion by surface water. Corrective measures for animal intrusion include filling existing burrows, application of physical barriers, and application of rodenticides. A layer of material such as cobble, cobble-gravel, or bentonite clay between the buried waste and the surface cover provides the best protection against burrowing animals.

Fig. 20. Subsidence conditions at a LLW burial site.

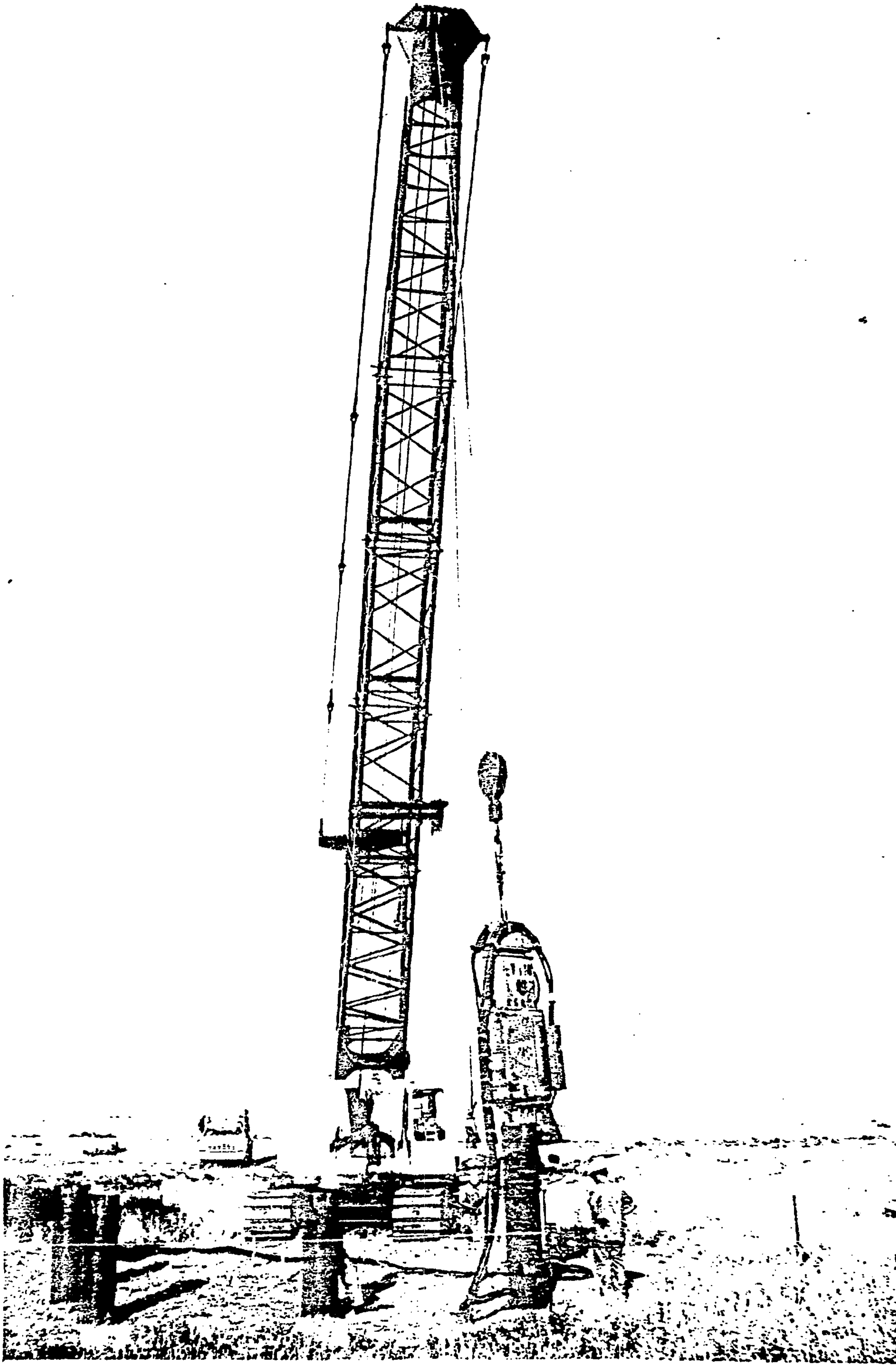

Fig. 21. Use of pile driving technique for compaction of trench structure.

It is important that the installation of corrective actions includes means for evaluating their effectiveness. DOE experience has shown that periodic inspection is necessary, especially after climatologic events that present added stress. These inspections provide early warning of failure or unanticipated problems. Adjustments after installation may be key factors in whether a corrective approach works.

8. COSTS

The unit cost of disposal operations at a given DOE site is dependent on many variables, but the annual volume to be handled is probably the major factor. The effect of volume on the unit cost is illustrated in Figs. 22-23. These figures show that fixed costs for site development have a major influence on the total costs. When charges are levied, the policy of DOE defense waste management is to charge the generators of the waste the cost of current disposal operations. No attempt is made to charge the generators for the cost of burial ground siting, site closure, or long-term maintenance and corrective measures of the site. Base charges at DOE burial sites for low activity waste vary from $85/m^3$ at NTS, to $140/m^3$ at Hanford, to $215/m^3$ at Oak Ridge. Not all DOE sites charge generators. The charges at NTS do not represent full cost recovery, and charges at Hanford are expected to increase this year. The nominal cost for current burial operations at DOE sites is estimated to be about $170/m^3$. In comparison, the charges at the commercial burial facilities are approximately $650/m^3$ for low-activity waste, based on a disposal rate of approximately 34,000 m^3/year. The commercial sites and several of the DOE sites have fees tied to the activity of the waste. The charges for highly active low-level waste may be as much as 30 times greater than the base charge. These commercial charges include fees to the state and charges for closure, for perpetual care, and for siting new burial grounds. The actual cost for current commercial burial operations is probably about the same as at DOE sites. A cost factor that has a significant influence in the overall disposal cost is the cost for packaging waste for shipment. All commercial waste must be packaged for shipment; however, about 80% of DOE defense waste is disposed of on-site and does not require packaging.

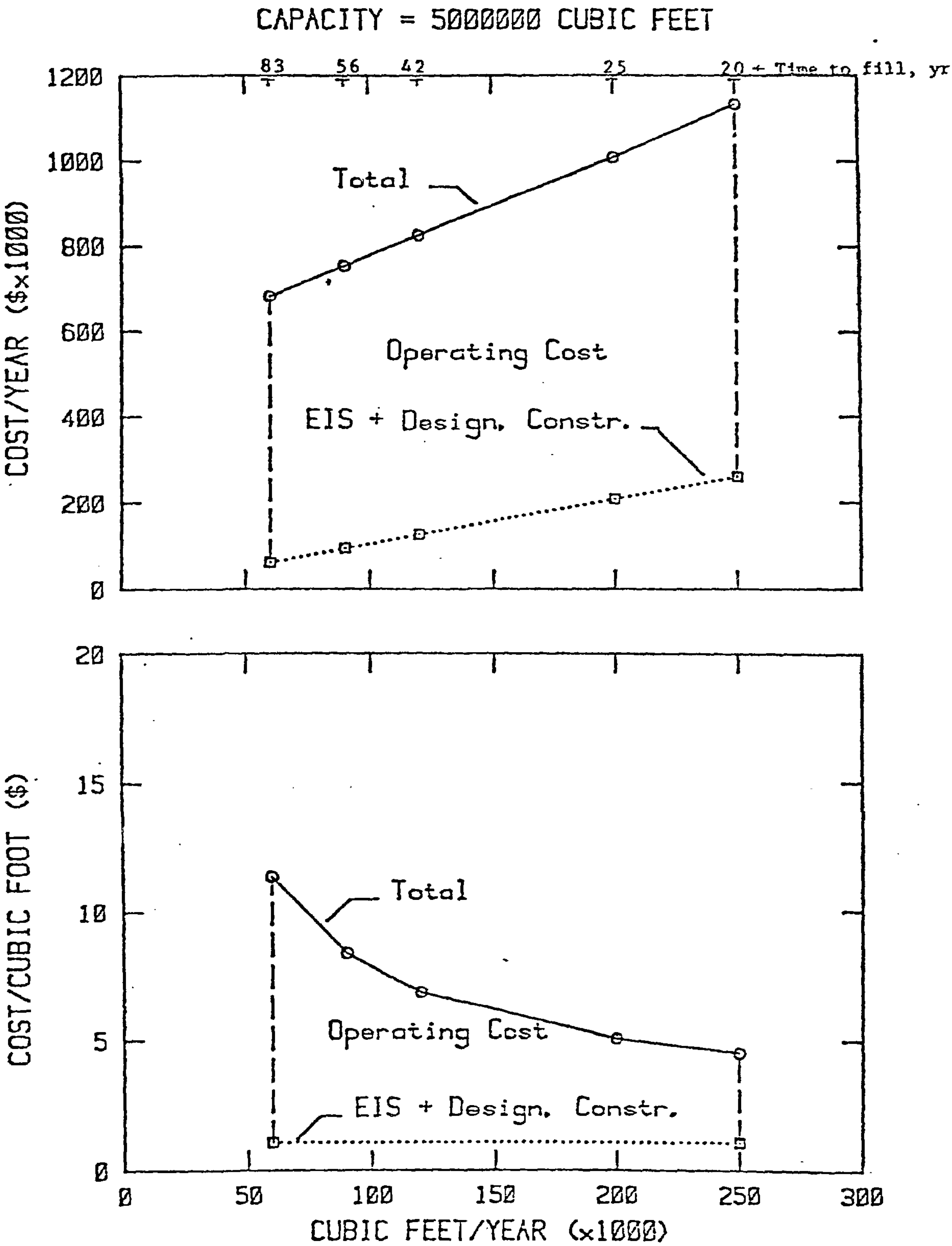

Fig. 22. Disposal costs based on utilizing the full capacity of the site.

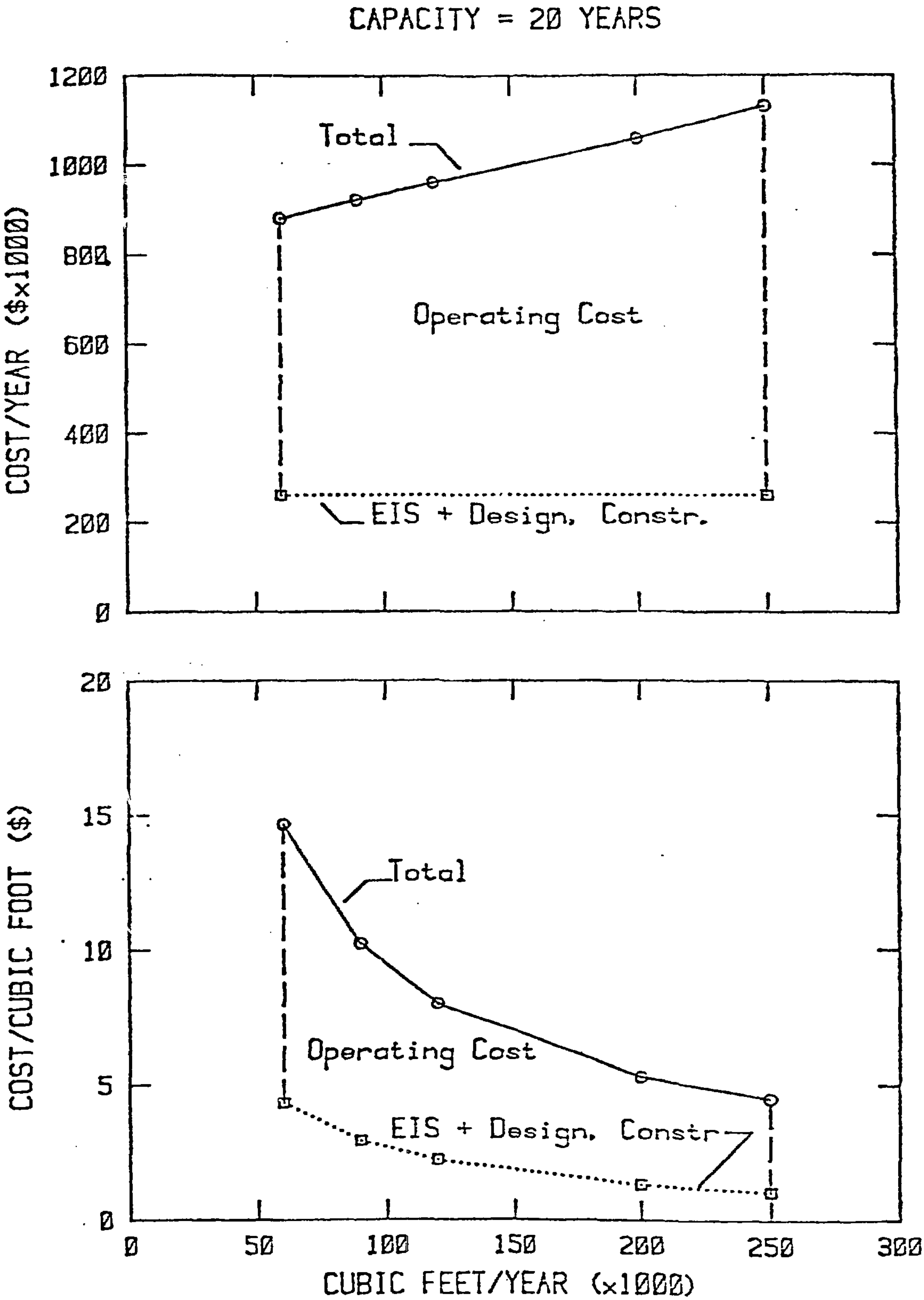

Fig. 23. Disposal costs based on exactly 20 years of operation.