SUBSURFACE DISPOSAL OF LIQUID LOW-LEVEL RADIOACTIVE WASTES AT OAK RIDGE, TENNESSEE

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Abstract

At Oak Ridge National Laboratory (ORNL) subsurface injection has been used to dispose of low-level liquid nuclear waste for the last two decades. The process consists of mixing liquid waste with cement and other additives to form a slurry that is injected under pressure through a cased well into a low-permeability shale at a depth of 300 m (1000 ft). The slurry spreads from the injection well along bedding plane fractures and forms solid grout sheets of up to 200 m (660 ft) in radius.

Using this process, ORNL has disposed of over 1.5 x 10^6 Ci of activity; the principal nuclides are ^{90}Sr and ^{137}Cs. In 1982, a new injection facility was put into operation. Each injection, which lasts some two days, results in the emplacement of approximately 750,000 l (180,000 gal) of slurry. Disposal cost per liter is approximately $0.30, including capital costs of the facility.

This subsurface disposal process is fundamentally different from other operations. Wastes are injected into a low-permeability aquitard, and the process is designed to isolate nuclides, preventing dispersion in groundwaters. The porosity into which wastes are injected is created by hydraulically fracturing the host formation along bedding planes.

The site is in the structurally complex Valley and Ridge Province. The stratigraphy consists of lower Paleozoic rocks. Investigations are under way to determine the long-term hydrologic isolation of the injection zone and the geochemical impact of saline groundwater on

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nuclide mobility. Injections are monitored by gamma-ray logging of cased observation wells to determine grout sheet orientation after an injection. Recent monitoring work has involved the use of tiltmeters, surface uplift surveys, and seismic arrays.

Recent regulatory constraints may cause permanent cessation of the operation. Federal and state statutes, written for other types of injection facilities, impact the ORNL facility. This disposal process, which may have great applicability for disposal of many wastes, including hazardous wastes, may not be developed for future use.

Introduction and Purpose

At Oak Ridge National Laboratory (ORNL), low-level radioactive wastes are routinely disposed of by a subsurface injection process termed "hydrofracture." The liquid wastes are mixed with cement and other solids to form a slurry that is pumped under pressure through an injection well into underlying strata. The slurry follows fractures in the strata and sets to form a solid grout, which contains and immobilizes the radioelements.

This process has been successfully developed at ORNL over the last quarter century (de Laguna et al., 1968). Initial development work was performed at test facilities; in the mid-1960s, the process became operational. A new injection facility was put into operation in 1982. A total of over 1.5 million curies of radioelements has been disposed of; the principal nuclides are Sr^{90} and Cs^{137}, although others, including H^3, Co^{60}, Ru^{106}, and isotopes of Eu, Cm, Mn, U, Am, and Pu, also occur in the wastes. This process represents the only permanent geologic disposal of nuclear wastes in the United States.

The disposal operation is unique and is based on the common practice of hydrofracturing, which is routinely used by the petroleum industry to increase porosity and permeability in reservoir rocks by fracturing the rocks with water injected under pressure. This technique has potential application to the management of many kinds of wastes. Our purpose is to discuss the basic principles of the subsurface injection program at ORNL, to discuss development of monitoring techniques, and to review the application of existing regulatory requirements to the ORNL process.

The Hydrofracture Process

A complete review of the history of the subsurface injection operation and a description of the process can be found in previously published works (deLaguna, et al., 1968; Weeren, et al., 1982; IAEA, 1983). The process is a large-scale batch operation (Fig. 1). Liquid wastes are stored in underground tanks and disposed of typically every one to two years. The waste solutions, which are alkaline and nitrate-rich (1-2 M $NaNO_3$), are blended with cement and other additives to form a slurry, which is pumped under approximately 21-MPa (3000 psi) pressure into the cased injection well. The casing is slotted at a depth of approximately 300 m (1000 ft). Fractures in the host rock, a shale of low permeability, are initiated along bedding planes by pumping a few thousand liters of water into the well; this is followed immediately by the slurry, which spreads radially from the injection well along the fractures. The slurry sets to form a thin (less than a few cm) grout sheet that extends up to several hundred meters from the well. No grout sheet has been detected more than 220 m (725 ft) from the injection point. Later injections are made through slots cut at shallower depths in the well, thus allowing maximum use of the host injection strata.

Disposal is normally done over a two-day period in two eight to ten-hour shifts. The total volume disposed of ranges from 350,000 to 700,000 l (88,000 to 175,000 gal). Although some operational problems (Weeren et al., 1984) have arisen over the years, the technique has been highly successful. A major reason for this success is that the engineering and operational aspects of this technique are not unique but rather are standard practice in the petroleum industry.

The costs for disposal at ORNL are approximately \$0.30/l (\$1.20/gal). About half of this is operational cost, including dry solids and personnel. The other half represents amortization of the capital cost (\$5.4 million) of the facility prorated for disposal of 40×10^6 l (10^7 gal) of waste. The costs are sensitive to process parameters (batch size, injection rate, etc.), which were chosen to fit ORNL requirements.

Principle of Waste Isolation

The basic objective of the ORNL subsurface injection program is to effectively isolate the wastes from the accessible environment. This is achieved through immobilization of the wastes in a variety of ways. The cementitious waste carrier is the primary barrier and is tailored to retard the two principal isotopes that occur in the wastes, Sr^{90} and Cs^{137}. Highly sorbing illitic clay is added to help retain the Cs^{137}. Most of the Sr^{90} occurs as a fine-grained precipitate in the waste; this precipitate is physically entrapped in the cement, and Sr^{90} is largely immobilized in this fashion. The secondary barrier is the shale, which has a high content of illite. If isotopes such as Cs^{137} should escape the grout, they should readily be sorbed by the shale. Equally important is the fact that the 100-m-thick (330 ft) host shale formation is of low permeability, contains small amounts of groundwater, and is removed from any fresh-water aquifer by over 100 m (330 ft) of intervening strata.

One of the most significant aspects of the waste isolation operation at ORNL is the generation of bedding plane fractures. It is critical that the radioactive slurry remain in the impervious host horizon and not travel through vertical fractures into strata that might have hydrologic communication with the environment. As noted later, the great mechanical anisotropy of the shale and the fact that the injections are apparently shallow enough so that the least principal stress is vertical are factors that cause the nearly horizontal bedding plane fractures. The production of fractures with a nearly horizontal orientation represents one of the most significant differences with the standard hydrofracture methods used in industry, where the fracturing is done at much greater depths with the intent of producing vertical fractures that cross many strata.

Site Selection Criteria

Idealized Criteria

A set of idealized geologic criteria that should be considered in selecting a site for a hydraulic-fracturing subsurface injection facility has been developed (Weeren et al., 1982; IAEA, 1983). The criteria are similar to many used in the selection of repository sites for high-level commercial nuclear wastes (CFR, 1984). For instance, a properly located subsurface injection facility should be in an area that is tectonically stable and has few, if any, natural resources that might be sought in the future. The injection horizon should be thick and laterally extensive enough to contain and to help isolate the wastes, and it should be hydrologically isolated from the accessible environment. The host strata and waters contained within should have geochemical characteristics that enhance immobility of the wastes through retardation and should produce uniform and predictably oriented fractures. Because of the importance of the host formation to the success of hydraulic-fracturing subsurface waste disposal, the role of the host formation is discussed below.

Host Formation Considerations

After injection, the grout acts as a waste package for the radioactive waste. The grout is the primary containment feature and is responsible for retention and isolation of the radioactive wastes. The role of the host formation is as an isolation medium for the wastes. Because of the host formation's important role in enhancing and augmenting the isolation and containment functions of the grout, several specific criteria for the evaluation of potential host formations have been formulated. In general, host formation must have the ability to (1) hydraulically fracture in a predictable manner, (2) hydrologically isolate the grout sheets, and (3) retard radionuclide migration and promote long-term grout stability. The importance of each of these properties is briefly discussed below.

To ensure that all injected grout sheets stay within the host formation, it must have properties that result in hydraulic fractures oriented parallel to its top and bottom contacts. Ideally, such fractures should maintain a constant orientation throughout their extent and remain in the particular stratigraphic interval in which they were initiated.

The host formation should have low porosity and low permeability. Such properties minimize the quantities of groundwater that could come into contact with the grouts and prevent the flow of fluids introduced during injection operations.

The mineralogy and geochemistry of the host formation should promote the retention of radionuclides contained in the grout sheets. Clay minerals, such as illite and smectite, which have large capacities to sorb radionuclides, should be abundant. The geochemical environment within the host formation also must be compatible with the chemical and physical stability of the radionuclide-bearing grouts.

Characteristics of the ORNL Site

The site at ORNL, although selected prior to systematic identification of these idealized siting parameters, conforms to them fairly well. A summary of the site geology of the ORNL subsurface injection facility is included below. A more comprehensive description of site geology and a discussion of the relationship between geological features and subsurface waste injection is presented by Haase et al. (1985).

Geologic Setting

The ORNL site is located in the Valley and Ridge Province of the Appalachian orogenic belt (Fig. 2). The Valley and Ridge Province in east Tennessee is characterized by a series of regional thrust faults that strike parallel to the borders of the province. Motion along these faults during the Alleghanian orogeny (230 to 250 My ago) resulted in southeast to northwest crustal shortening of 100 to 150 km (60 to 90 mi) (Harris and Milici, 1977). Within the sediments on each of the thrust sheets, a significant amount of small-scale folding and faulting results in a complex structural fabric within all rocks.

The ORNL subsurface injection site is on the leading edge of the Copper Creek thrust sheet within 1 km (0.6 mi) of where the fault comes to the surface (Fig. 3). The strike of strata at the site is N 45° to 55° E and the dip of the strata is variable. Within 500 m (1600 ft) of the fault trace, dip values range from 45° to 90° to the SE. At the injection facility, dip values range from 10° to 20° to the SE.

The stratigraphic sequence in the basal portion of the Copper Creek fault block consists of, from bottom to top, the Rome Formation, the Conasauga Group (which includes the host formation), and the Knox Group. The Rome Formation ranges from 100 to 150 m (330 to 500 ft) in thickness and consists of sandstones, siltstones, shales, and mudstones. The Conasauga Group ranges from 550 to 600 m (1800 to 2000 ft) in thickness and consists of six formations, that are, in ascending order, the Pumpkin Valley Shale (the host formation), the Rutledge Limestone, the Rogersville Shale, the Maryville Limestone, the Nolichucky Shale, and the Maynardville Limestone. The clastic-rich formations, including the Pumpkin Valley Shale, consist of thinly bedded siltstones and laminated shales and mudstones. The carbonate-rich formations consist of coarse- to fine-grained limestones, conglomerates, and calcareous siltstones and shales (Haase et al., 1985). The Knox Group consists of carbonates and locally abundant sandstones.

The Pumpkin Valley Shale Host Formation

The Pumpkin Valley Shale is 105 m (345 ft) thick and can be divided into a siltstone-rich, lower member that is 45 m (150 ft) thick and a shale-rich, upper member that is 60 m (195 ft) thick (Haase, 1982; Haase et al., 1985). The lower contact of the formation is gradational into sandstones of the upper Rome Formation. The upper contact is also gradational into limestones and calcareous shales of the Rutledge Limestone. The Pumpkin Valley Shale is composed of mudstones, shales, and siltstones. The two members differ principally in the relative proportions of the different lithologies, in the character of the interstratification sequences of the different lithologies throughout the member, and in the nature of the primary bedding structures within the constituent lithologies (Haase et al., 1985; Haase, 1982, 1983).

Shales and mudstones from throughout the Pumpkin Valley Shale contain 75 to 95% clay-sized material composed of illite/vermiculite + illite ± kaolinite ± chlorite + quartz. The shales typically contain 5 to 25% silt-sized material composed of detrital quartz, plagioclase and potassium feldspars, muscovite, and biotite. The mudstones contain up to 5% silt-sized material and have the same clay mineral assemblage as do the shales (Haase 1982, 1983).

Deformation features are ubiquitous in the Pumpkin Valley Shale. Joint sets, fractures, folds, and faults occur throughout the shale (Ossi, 1979; Sledz and Huff, 1981). At least two and, locally, as many as four joint sets have been identified (Sledz and Huff, 1981). All of these can be related to major structures, such as the Copper Creek thrust fault or specific folding events. Joint spacing, length, and density are variable within lateral distances of several hundreds of meters

Small-scale folds and faults are common throughout much of the Pumpkin Valley Shale. Folds have amplitudes of 0.5 to 3 m (1.5 to 10 ft) and are tight and rarely isoclinal. Many folds are associated with small-scale faults that occur throughout the shale. Such fault zones are 0.1 to 3 m (0.3 to 10 ft) thick and typically have nearly vertical dips, although lower-angle faults have been observed (Haase et al., 1985; Sledz and Huff, 1981).

The hydrology of the ORNL hydraulic-fracturing subsurface injection facility site is complex and not understood in detail. Available data suggest that the subsurface groundwater regime consists of a shallow freshwater system and a deep saline system (Haase et al, 1985). The permeability (values typically less than 0.1 md) and porosity (values from less than 0.1 to 3.0%) of the Conasauga Group are low, and flow directions for much of the shallow groundwater system are influenced by structural fabric elements, such as joints and fractures (Sledz and Huff, 1981; Vaughan et al., 1982; Rothschild et al., 1985). The shallow groundwater system at the site extends to depths of 30 to 150 m (100 to 500 ft). Groundwater within this system is fresh, with TDS values less than 5000 ppm. Within the upper portions of the zone of shallow fresh groundwater, at depths of less than 30 m (100 ft), the weathered portions of the Conasauga Group strata contain moderate amounts of groundwater. Below this depth, borehole geophysical logs suggest that fresh groundwater is increasingly confined to fracture and fault zones. At present, little is known about the behavior of groundwater at the bottom of the shallow zone.

The nature of the deep, saline groundwater system within the lower portions of the strata of the Conasauga Group is not known. Waters within this deeper system appear to be high-TDS fluids with chloride concentrations ranging from 100,000 to 120,000 ppm (Switek et al., in press). Because of the dramatic compositional differences between shallow and deep groundwaters, the deep system is thought to be largely separate from the shallow system. Details of possible coupling between the two systems are not known. By analogy with the shallow groundwater system, it is hypothesized that the flow directions of the deep system are largely controlled by the fracture permeability related to structural fabric elements.

Summary

Empirical data gathered largely from operational experience over the past 25 years at the ORNL site (Weeren, 1974, 1976, 1980, 1984) suggest that the Pumpkin Valley Shale has many of the necessary attributes required of a successful host formation. The formation fractures in a regular fashion so that injected grout sheets have predictable orientations and remain within the stratigraphic extent of the formation. The formation has low intrinsic permeability. The ambient groundwater in the formation is saline and therefore not in rapid communication with overlying freshwater groundwater systems. The mineralogy of the formation is an efficient sorption agent for some radionuclides, especially ^{137}Cs, that occurs in the ORNL waste.

Development of Monitoring Procedures

Monitoring Methods

A variety of techniques can be used to determine the location of a grout sheet. The most accurate method involves drilling a large number of boreholes to intersect the emplaced grout. Such a method, however, is expensive, time-consuming, and jeopardizes the ability of the site to geologically isolate future slurry injections. Therefore, it is desirable to consider other methods of determining the orientation and extent of the grout sheets. Methods being developed at ORNL entail both post-injection and real-time monitoring. Post-injection methods consist of gamma-ray logging of cased observation wells and accurate leveling of benchmarks in the vicinity of the hydrofracture facility. Real-time monitoring methods entail use of tiltmeters installed at the ground surface and geophone arrays at the surface and in deep wells at the site. Stow et al. (1985) reported on these monitoring techniques.

When wastes are injected at 300 m (1,000 ft) depth, the ground surface undergoes slight, but measurable, deformation. (Davis 1983; Pollard and Holzhausen 1979) The shape and location of this ground deformation reflect the orientation and extent of the subsurface grout sheet. By accurately measuring the surface deformation, either during or after an injection, and comparing it to elastic models, the geometry and orientation of the subsurface sheet can be estimated.

Leveling Surveys

At ORNL, a series of 75 benchmarks has been installed along roads in a radial pattern up to 650 m (2000 ft) from the injection facility (Fig. 4). During eight bimonthly injections in 1982 and 1983, precise leveling surveys were made before and after each injection to determine the amount of surface deformation.

Systematic uplift patterns were observed after each of the injections. The uplift pattern from the October, 1983, injection is shown in Fig. 4. This pattern is representative of those associated with other injections, although the extent and shape of the surface deformations vary with each injection. For the October injection, the area of maximum uplift is offset by some 100 m (330 ft) to the southwest from the injection well and that the maximum uplift is over 2.5 cm (1 in). The uplift decreases in a fairly systematic way outward from the highest point and, although not shown in Fig. 4, extends beyond the 600-m (2,000-ft) limit of the benchmarks. The volume of the uplift significantly exceeds the volume of the injected grout.

The geometry of the uplift pattern indicates that the grout sheet spread to the north, which is in an updip direction. This orientation would be expected because the slurry should preferentially migrate in the direction of least lithostatic pressure, i.e., in an updip direction along bedding planes. Post-injection gamma-ray logging in the observation wells within 150 m (500 ft) of the injection well confirms the extension of the grout sheet in a northerly direction.

Thirty days after the October injection, the leveling survey was rerun; noticeable changes had occurred over this time period (Fig. 5), similar to those detected after other waste injections. The area of maximum uplift was found to correspond to the location of the downhole injection point and the maximum uplift had decreased to approximately 10 mm (0.4 in) in this area. The subsidence of the uplift after the injections is thought to result from a complex set of factors including an attempt toward mechanical relaxation of the stressed strata and dissipation of pressure following the injection. As noted later, microseismic signals continue for weeks after an injection. It is important to note that the volume of the uplift measured 30 days after an injection roughly corresponds to the volume of radioactive slurry injected.

Tiltmeter Surveys

Tiltmeter measurements represent a monitoring technique that provides information on the ground deformation that occurs during and after an injection. (Evans and Holzhausen 1983; Riley 1961). Eight tiltmeters were installed in September 1983 in shallow wells at radii of 120 and 180 m (400 and 600 ft) from the injection point. Measurements were taken for the October and November injections and for the intervening period. The net ground deformation resulting from the October injection is shown in Fig. 6. The arrows indicate the vector tilt of the ground surface at each site. The length of each arrow is proportional to the amount of tilting, measured in microradians. The October injection covered two days. Tilt rates for the second day significantly exceeded those of the first day, suggesting a nonlinear response of the strata over the injection zone. The data reveal that maximum uplift is slightly north of the injection point. Elastic modeling of a purely dilatational fracture would suggest that this uplift pattern corresponds to a grout sheet that propagated upward and to the south (Davis 1983). This result is obtained using both an isotropic elastic model and a transversely isotropic model in which rock stiffness parallel to bedding is five times greater than stiffness perpendicular to bedding. This conclusion does not, however, agree with that drawn on the basis of leveling surveys and on the gamma-ray logging of observation wells.

A possible explanation for this northward shift of the center of uplift may be related to shear induced in the hydraulic-fracture plane during grout injection. Horizontal crustal compression in the Oak Ridge area should induce an in-plane shear component because the grout sheets are inclined to this inferred principal stress direction. In-plane shear on a southward-dipping fracture would result in maximum uplift to the north of the injection well. When added to the uplift caused by fracture dilation, the net tilt would resemble that measured during the October and November 1983 injections. A more complete discussion of the interpretation of the tiltmeter data are found in a recent article by Holzhausen et al. (1985).

Tiltmeter data were also gathered between the October and November injections. Figure 7 shows the net tilt change for the first eight days of this period. Vector directions indicate that subsidence occurred, an observation that corresponds closely with the results of the leveling surveys (Fig. 5). Apparently, this subsidence caused a shift in the center of uplift from slightly north of the injection point to slightly south of the injection point.

Because the tiltmeter data are acquired on a continuous basis, it is possible to monitor ground deformation in real time during an injection. During the October and November injections, it was observed that surface deformation patterns changed continuously with time and that areas of maximum deformation shifted frequently. These observations suggest that the injected grout sheet forms in a discontinuous fashion as lobes that are extended in different directions at different times during an injection.

In evaluating their use for monitoring, it is important to note the sensitivity of the tiltmeters. The instruments used during the October and November injections can resolve 5 nanoradians (5×10^{-9} radian) of movement. On October 25, fracture initiation was caused by injection of a few thousand liters of water at the 300-m (1,000-ft) depth; tilting was immediately detected. Cessation of tilting was noted immediately when injections were ceased, and a slight reversal of tilt was noted between the night of October 25 and the morning of October 26. These data indicate that tiltmeters are a very sensitive indicator of surface deformation associated with subsurface injections. With appropriate modeling of the data, tiltmeters may represent a feasible method of real-time monitoring of the orientation and extent of the grout sheet.

Microseismic Monitoring

It was anticipated that detection of microseismic signals resulting from a propagating fracture might provide a basis for determination of the location and rate of formation of the fracture and for the failure mechanism by which the fracture propagates. Three geophone arrays were used; two high-frequency (20-250 Hz) arrays were placed 125 to 180 m (415 to 600 ft) down in drillholes overlying the injection zone. The geophones were "sanded into" the wells to ensure good transmission of signals from the rock. A third array was placed at the ground surface. Low-frequency (0.03 Hz) signals were also recorded with a surface-mounted vertical component seismometer.

Numerous microseismic events occurred during the injection; most represent shear failure associated with stress field changes in the rock envelope surrounding the fracture. Few tensile events—those that could be created by bedding plane opening—were detected. Long-period events occurred throughout the injection and correlated closely with slight decreases in pumping pressure. Events also were noted for days after an injection ceased, suggesting that a physical readjustment of the slurry and/or overlying strata was taking place. These post-injection events gradually decreased with time.

Mapping the fractures as they form has not been successful to date. The chief reason for this is that the events associated with fracture propagation are of very low energy and geophones must be close to the fracture for detection of the events. In the case at ORNL, the geophones were over 100 m (330 ft) above the fracture; most of the energy from the fracturing apparently was absorbed by the intervening strata.

Overview

There is considerable work yet to be done on development of monitoring techniques, especially those that provide real-time data during an injection. The two methods that do provide such data (tiltmeter, microseismic) show promise; of the two, the tiltmeter method appears to be better developed at present. Stow et al. (1985) provide more detail on the relative evaluation of the techniques. While it is anticipated that future subsurface disposal operations may require installation of real-time monitoring systems, direct techniques, such as gamma-ray logging, will probably also be required.

Federal and State Regulations

Comparison of ORNL's Injection Process with Others

It has recently been determined that ORNL's subsurface injection facility is regulated by federal and state statutes. These are the EPA UIC Program (40 CFR 124, 144, 146, 147) and the State of Tennessee UIC regulations of the Water Quality Control Board (Chapter 1200-4-6). Although the state regulations are more stringent than the federal ones, Tennessee does not yet have primacy. Both of these statutes were written for the more commonly practiced subsurface injection techniques rather than for the ORNL process.

It is important to compare the ORNL process with those for which the legislation was written because there are significant similarities and differences. Such aspects as the intent to prevent contamination of potable groundwater, the desire for high integrity of the injection well, and monitoring of the injection operations represent facets where the legislation is in full concert with the ORNL process. However, a number of characteristics of the ORNL process make it apparent that the legislation was written for injection operations radically different from that at ORNL (Table 1). The principle of waste isolation through creation of a solid waste form (cement) and injection into an aquitard rather than an aquifer represents a primary difference. In other injection operations mixing of liquid waste with groundwater occurs and

Table 1

Comparison of the ORNL Subsurface Injection Well
with Other Types of Injection Wells

Factor	ORNL	Others
Waste Form	Solid-cement	Liquid
Waste Fate	Isolated, retarded	Diluted
Host Stratum	Aquitard	Aquifer
Porosity	Created by Fracturing	Natural
Structure of Host	Dipping	Horizontal
Volume of Waste	Small	Large
Frequency	One-two Years	Continuous

causes eventual dilution; the ORNL process is directed toward retardation of wastes and isolation from groundwater. Most hazardous waste injection operations do not operate at pressures sufficient to fracture the host strata because the strata have inherent high porosity and permeability. At ORNL, porosity necessary to accommodate the wastes must be created by fracturing the host strata with high injection pressures. Although strictly a site-specific difference, the ORNL process involves injection into dipping strata that outcrop within one mile (1.6 km) of the injection well; other injection wells involve relatively horizontal strata so that surface outcrops do not occur within the area of review. Because of the situation at ORNL, there are many shallow monitoring wells, associated with operations other than the injection well, that penetrate the injection zone. These wells must be addressed in plugging and abandonment plans. Finally, at ORNL, relatively small volumes of waste (800,000 l or 200,000 gals) have been injected at annual or biannual intervals; other operations involve continuous injection of millions of gallons of waste.

Well Classification

The classification of the ORNL injection well has not been firmly established. At present, it appears that it will be a Class V well, largely because it does not fit into any other classification. In all likelihood the well would be Class I, except that the application of injection pressures sufficient to initiate fracturing at the host shale is not allowed for Class I wells. For obvious reasons, the well cannot be a Class II, III, or IV; thus a Class V assignment will probably be made.

Present Status

For a variety of reasons, it has been decided by the Department of Energy, for which ORNL works, that a permit application for future injections will not be sought at present. Recent efforts at ORNL are resulting in significant volume reduction and, therefore, a decreased need for frequent injections. In addition, the cost of preparation for a permit application, including possible development of additional groundwater monitoring systems, determination if a USDW occurs below the injection zone, possible construction of a new injection well, and plugging of numerous monitoring wells that penetrate the host strata, have led to this decision. Also, the status of Class I wells relative to the 1988 "hammer" clause in the RCRA has created significant uncertainty from a regulatory viewpoint as to the future of the facility.

Future Directions

Use of the Technique for Hazardous Wastes

It is felt that the hydraulic-fracturing subsurface injection technique may have significant potential for disposal of certain types of hazardous wastes. Because the operational aspects of the disposal operation are fairly routine, attention is directed here toward waste forms and carriers that are compatible with the injection process and typical host formations.

It may be possible to use the method for disposal of certain heavy metals. For instance, chromium could be precipitated as a highly insoluble sulfate, or other transition metals might be fixed by chelating agents. The insoluble salts or chelated metals could then be mixed with a cementitious carrier and injected. Cement might also be a useful carrier for PCBs.

There is no reason why materials other than cement might not be considered as waste carriers. Polyacrylamide grouts might prove to be chemically compatible with certain wastes and thus offer sufficient waste isolation potential. Alternatively, phenol or amine polymers might be developed as waste forms and carriers that could be pumped into an injection zone before polymerization.

For certain wastes it might be feasible to produce a microencapsulated waste form that could be mixed with cement or an organic-based carrier for disposal. The cost of microencapsulation would probably dictate the use of such a method for only a limited number of very toxic wastes. Particle size should be kept below 1 mm.

Need for Regulatory Reconsideration

As discussed previously in the regulatory considerations section, the subsurface injection of waste by the hydraulic-fracturing technique differs substantially from the technologies for which current regulations were adopted. For the merits of the hydraulic-fracturing techniques to be fully evaluated, some regulatory reconsideration must be granted. The need for regulatory reconsideration is reflected in the current "on hold" status of the facility at ORNL. It is hoped that after 1988 and resolution of the RCRA "hammer" clause decision for Class I wells, research on and progress toward permitting the hydraulic-fracturing subsurface injection technology can be resumed. Such action would be helped by expansion and/or modification of existing underground injection regulations. It would be desirable to develop regulations that specifically address this method of waste disposal, so that the technology is not lost if the more common methods of subsurface injection cannot be continued.

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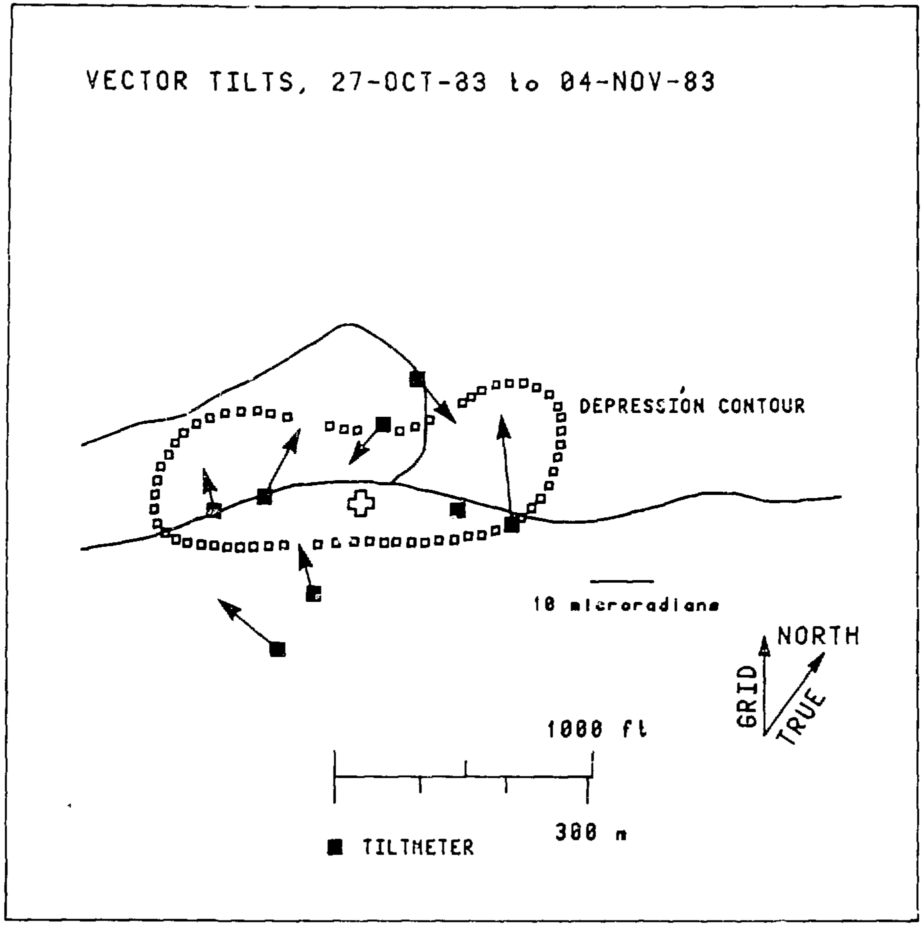
VECTOR TILTS, 27-OCT-83 to 04-NOV-83
DEPRESSION CONTOUR
10 microradians
NORTH
GRID
TRUE
1000 ft
300 m
■ TILTMETER

Figure 7

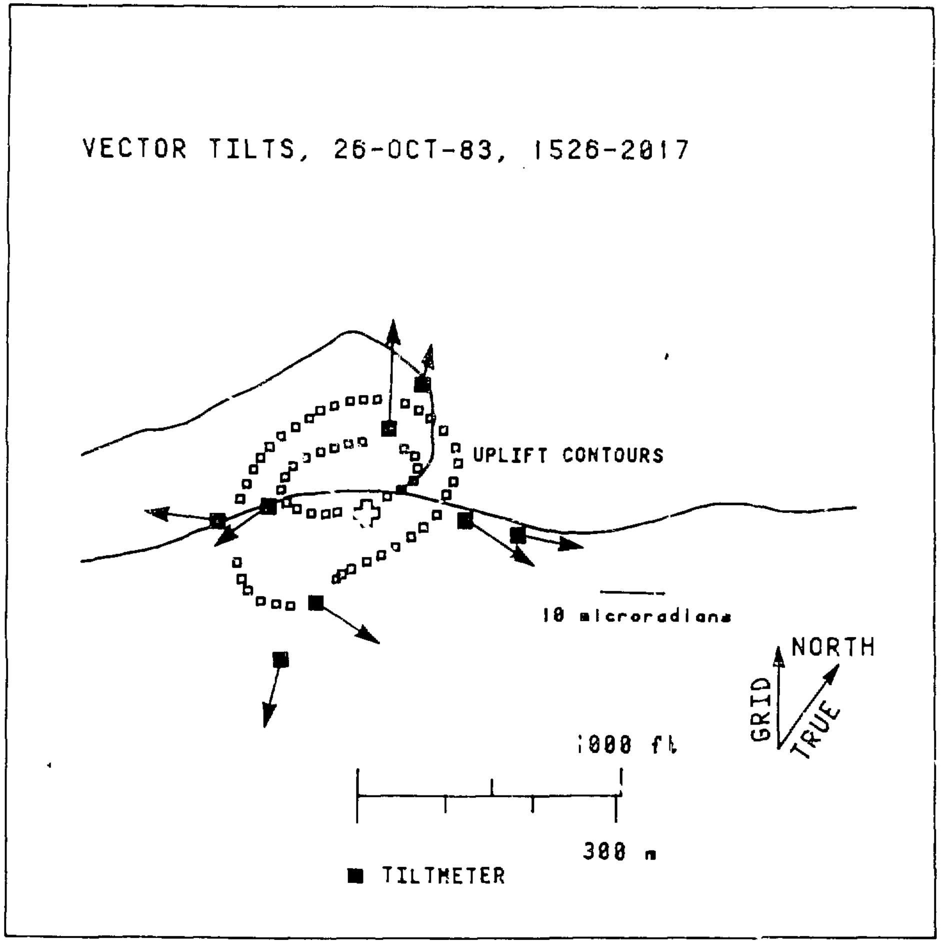
VECTOR TILTS, 26-OCT-83, 1526-2017
UPLIFT CONTOURS
10 microradians
NORTH
GRID
TRUE
1000 ft
300 m
■ TILTMETER

Figure 6

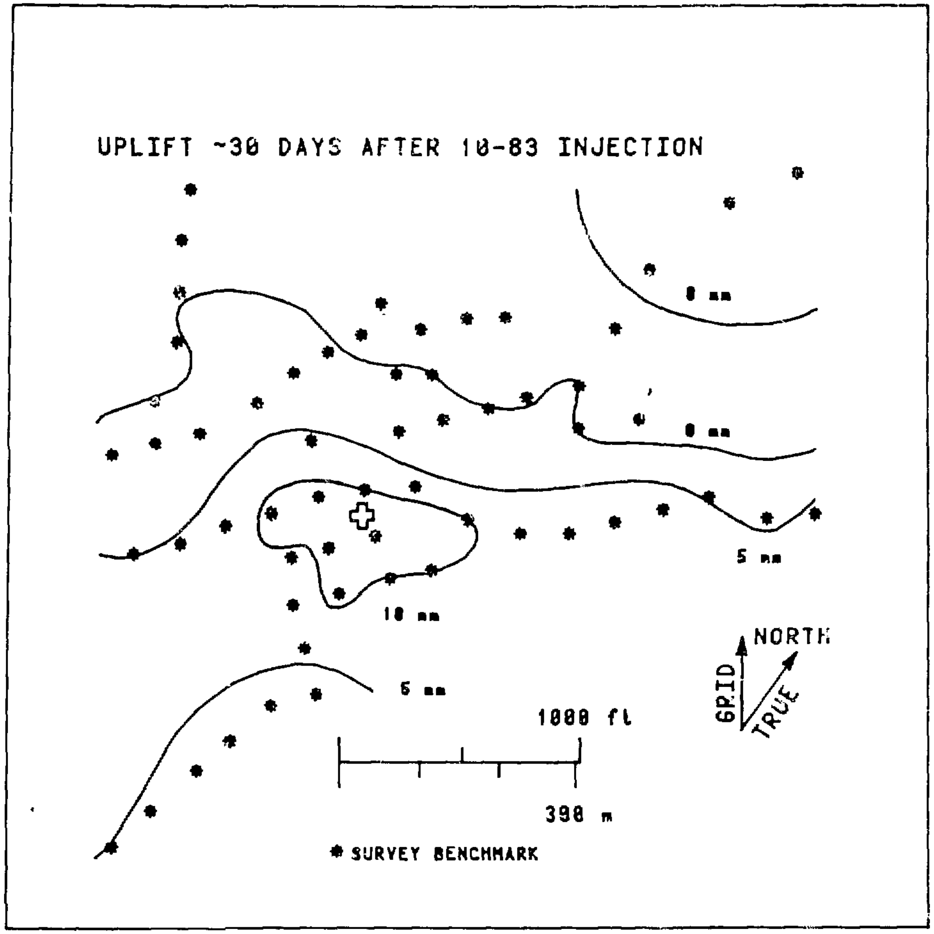
UPLIFT ~30 DAYS AFTER 10-83 INJECTION
0 mm
0 mm
5 mm
10 mm
5 mm
NORTH
GRID
TRUE
1000 ft
300 m
* SURVEY BENCHMARK

Figure 5

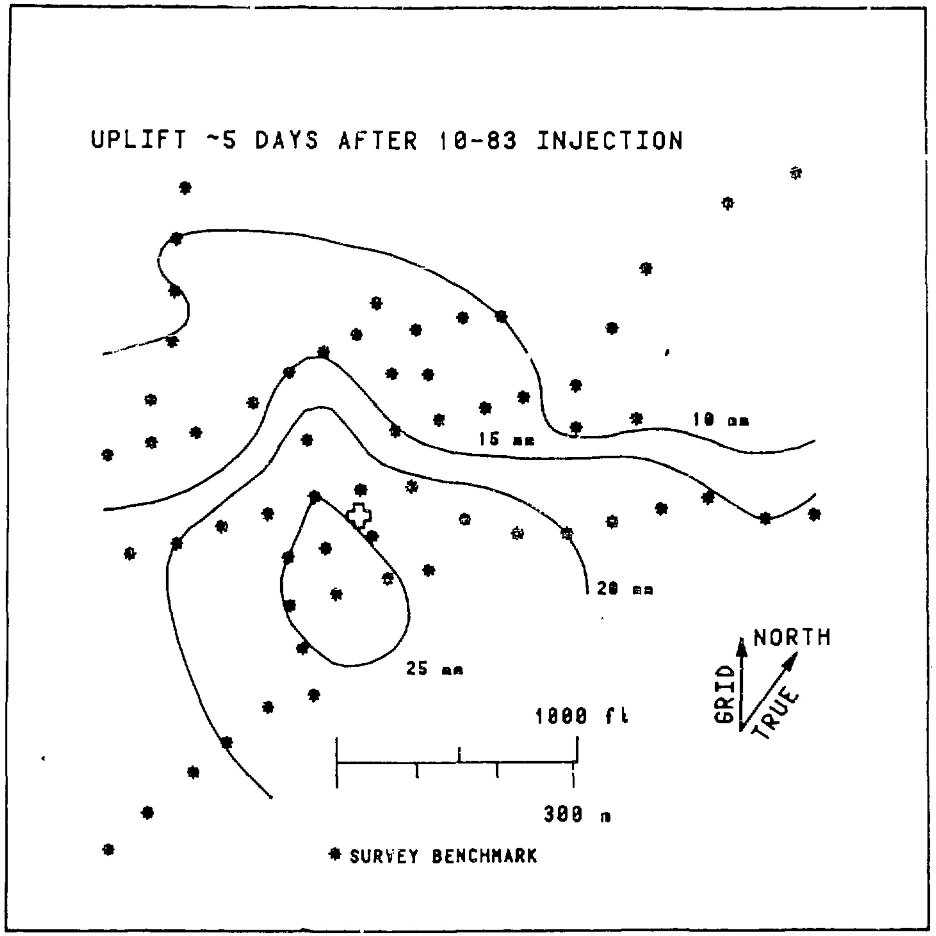
UPLIFT ~5 DAYS AFTER 10-83 INJECTION
10 mm
15 mm
20 mm
25 mm
NORTH
GRID
TRUE
1000 ft
300 m
✱ SURVEY BENCHMARK

Figure 4

ORNL-DWG 84-12900

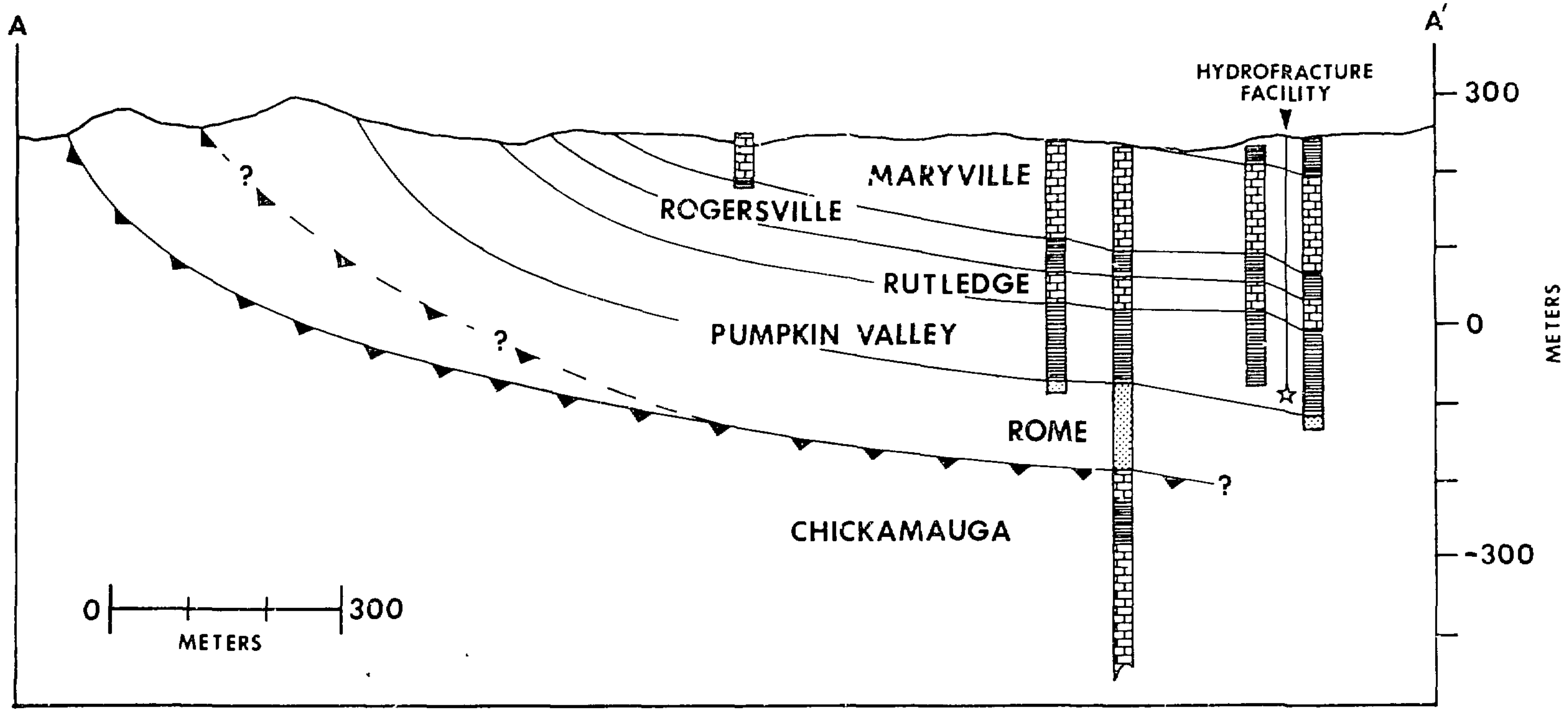

Figure 3

ORNL–DWG 67-7601R

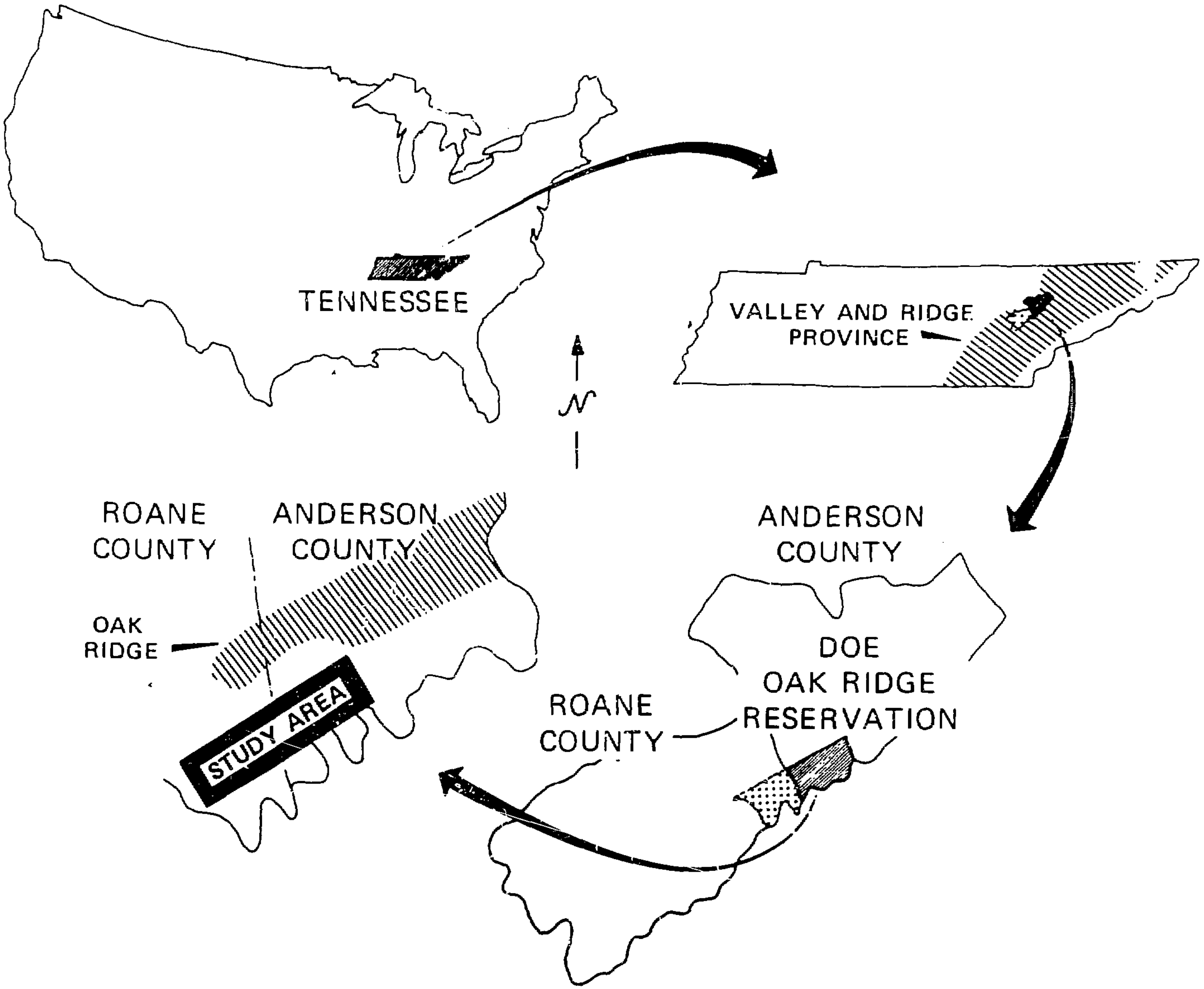

Figure 2

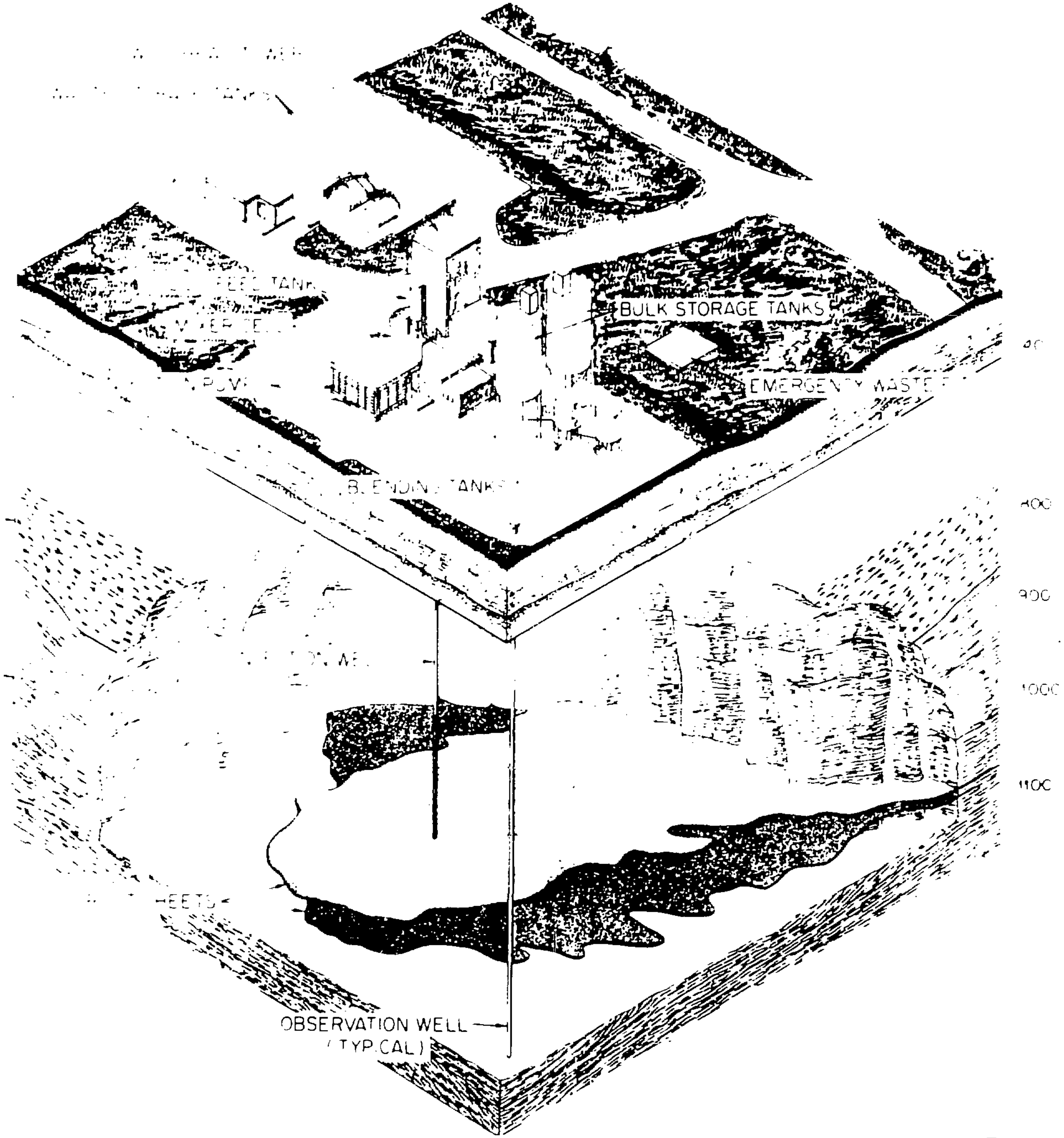
FEED TANK
BULK STORAGE TANKS
EMERGENCY WASTE
BLENDING TANKS
800
900
1000
1100
OBSERVATION WELL
(TYPICAL)

Figure 1

DISCLAIMER