A STUDY OF TRENCH COVERS TO MINIMIZE INFILTRATION AT WASTE DISPOSAL SITES

Task I Report
Review of Present Practices and
Annotated Bibliography

Beverly L. Herzog
Keros Cartwright
Thomas M. Johnson
Henry J.H. Harris

Illinois State Geological Survey

Prepared for
U.S. Nuclear Regulatory Commission
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September 30, 1981
Illinois State Geological Survey
Champaign, Illinois 61820

Prepared for
Division of Waste Management
U.S. Nuclear Regulatory Commission
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ABSTRACT

Failure of current trench covers in the humid eastern portion of the United States to prevent tritium and other radionuclide migration has prompted research into methods of reducing infiltration by modified trench covers. This report includes a discussion of present practices and a review of the relevant scientific literature. The main types of covers suggested are thicker clay covers of the current design, rigid and nonrigid man-made covers, covers employing clay sealants and covers using the wick effect. The two latter concepts are argued to offer the best long-term solution to the problem with the least maintenance. Optimal designs for clay and the wick effect have been proposed by SCS (1978) and Dragonette et al. (1979).
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ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. David Seifken, Project Officer for the Nuclear Regulatory Commission, for his guidance and support throughout the study. Also we thank Illinois State Geological Survey librarians, Mary P. Krick and Kristi A. Mercer, who gave invaluable help by acquiring the numerous documents discovered through computer searches made for the project.
INTRODUCTION

This report is the first of four tasks to be undertaken in a 42-month study of trench covers designed to minimize infiltration at waste disposal sites that utilize landfill methods. This report reviews both present practice in and scientific literature dealing with the design of trench covers. It includes an annotated bibliography of 208 references, prefaced by a summary review of the subject taken directly from the references. The annotations that accompany the references consist of a brief synopsis as well as an indication of relevance to trench cover design. The quality of the references is not discussed.

Most citations included in the bibliography were located by computer search in December, 1980, from the following data bases: NTIS, COMPENDEX, ENVIROLINE, Pollution Abstracts, CAS7376 (Chemical Abstracts), CAS77 and GEOREF. Because the initial search, which was limited to documents about trench covers, found little information, the search was then broadened to cover the general topic of low-level radioactive waste disposal. An attempt was made to obtain all relevant documents revealed by that search. One hundred and ninety-nine documents were received by August 11, 1981. Several documents that do not deal with trench covers are included in hopes that others can be spared the trouble of their relocation.

Many citations not found in the computer search were discovered among the references listed in the documents obtained. In addition, a limited search of literature on unsaturated groundwater flow produced a number of useful references. Other basic sources were University of Illinois library holdings, monthly reviews of "Water Resources Abstracts and Bibliography" and the American Geological Institute's "Bibliography and Index of Geology."

REVIEW OF EXISTING PRACTICES

Currently there are 11 major shallow land burial grounds for low-level radioactive wastes in the United States. Five of these are operated by the U.S. Department of Energy (DOE) and six are commercial sites. Of these, two DOE and four commercial sites are located in the humid eastern part of the country. Tritium migration has been observed at five of these sites (Murphy and Holter, 1980). The probable cause of migration is infiltration of precipitation through trench covers and damage through loss of control of the surface water (Battelle, 1976). The reduction of infiltration at low-level radioactive waste disposal sites appears essential to proper management in humid regions.
Current Trench Cover Designs

Of the eleven landfills for low-level radioactive waste in the United States, six are located in the humid eastern portion of the U.S. and five in the arid west (fig. 1).

Trench covers at all of the sites are basically the same; material excavated from the trenches is used for the cover. The material is mounded to a minimum depth of one to three meters, then vegetated for erosion control. At sites in the humid regions, covers are compacted by heavy earth-moving equipment or by temporarily placing excavated material from subsequent trenches on the mounds. The covers at the Barnwell and Maxey Flats sites and over the more recent trenches at the Sheffield site incorporate clay obtained from local sources.

Table 1 summarizes the characteristics of trench covers at the major low-level waste disposal sites.

A search was made for information about low-level waste disposal sites outside the United States. Few documents were located, and those that were indicate that, outside the U.S., shallow land burial is not used because of the shortage of land. The one exception is Canada, where five sites currently hold major amounts of low-level waste. These sites are the Whiteshell Nuclear Waste Establishment in south-eastern Manitoba, the Chalk River Nuclear Laboratories in east-central Ontario, the Bruce Nuclear Power Development in southwestern Ontario, the Gentilly Nuclear Power Development in southern Quebec, and a refinery of Eldorado Nuclear Limited on the north shore of Lake Ontario (Cherry et al., 1979). At Whiteshell, burial trenches are covered with compacted, excavated fill composed mainly of clay and till (Cherry et al., 1973). No descriptions of the trench covers at the other sites are available.

Environmental monitoring has been conducted at the U.S. sites. The data from the monitoring program are shown in table 2. Similar data are not available for Canadian sites.

A comparison of tables 1 and 2 shows that the eastern site with the fewest problems is Barnwell. It is one of the two sites that uses compacted clay for trench covers; it also has the thickest trench cover.
Figure 1. Locations of major low-level radioactive waste disposal sites in the United States.
Table 1. Characteristics of current trench covers in the U.S. (a)

<table>
<thead>
<tr>
<th>Site</th>
<th>Type of final cover</th>
<th>Thickness of final cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnwell, S. Carolina</td>
<td>0.6 m clay between waste and ground surface; additional mounded cover</td>
<td>3 m cover at center line; 1.5 m at trench edge</td>
</tr>
<tr>
<td>Beatty, Nevada</td>
<td>Excavated earth fill; no compaction; stones on top</td>
<td>Minimum 2 m total; mounded 0.6 m above grade</td>
</tr>
<tr>
<td>Maxey Flats, Kentucky</td>
<td>1 m compacted clay; mounded; reseeded</td>
<td>1 m cover; mounded 0.6 m above grade</td>
</tr>
<tr>
<td>Richland, Washington</td>
<td>Excavated earth fill; no compaction</td>
<td>Minimum 2 m total; mounded 1 m above grade</td>
</tr>
<tr>
<td>Sheffield, Illinois</td>
<td>Compacted clay cover; surface reseeded</td>
<td>Minimum of 1 m final cover; mounded</td>
</tr>
<tr>
<td>West Valley, New York</td>
<td>Excavated earth fill (reworked till) fill (b); compacted; topsoil added</td>
<td>Minimum of 3 m cover, mounded 1.5 m minimum above grade</td>
</tr>
<tr>
<td>Hanford, Washington</td>
<td>Excavated fill of gravel, fine sand and silt to surface (c); mounded as necessary</td>
<td>Minimum 2.5 m total, or that needed to reduce dose to less than 1 mR/hr at surface</td>
</tr>
<tr>
<td>Idaho National Engineering Laboratory, Idaho</td>
<td>Excavated soil fill; reseeded</td>
<td>Minimum 1 m to ground surface</td>
</tr>
<tr>
<td>Los Alamos Scientific Laboratory, New Mexico</td>
<td>Excavated tuff and soil fill (d); compacted by heavy earth moving equipment</td>
<td>Minimum 1.5 m total cover with mounding to 0.5-1 m above grade</td>
</tr>
<tr>
<td>Oak Ridge National Laboratory, Tennessee</td>
<td>Excavated material to ground surface (e); few experimentally sealed (e); reseeded</td>
<td>Minimum 1 m to ground surface</td>
</tr>
<tr>
<td>Savannah River Plant, South Carolina</td>
<td>Excavated till to ground surface, mounded as necessary</td>
<td>Minimum of 1.2 m cover, or that needed to reduce dose to less than 6 mR/hr at surface</td>
</tr>
</tbody>
</table>

(a) Adapted from Table 24-5, Battelle, 1976.
(b) From Prudic, 1979.
(c) From Barraclough, 1973.
(d) From National Research Council, 1976.
(e) The experimental seals were a mixture of soil and bentonite (Webster, 1979).
Table 2. Environmental Monitoring Results at the Major U.S. Low-Level Waste Disposal Sites(a)

<table>
<thead>
<tr>
<th></th>
<th>West Valley, New York</th>
<th>Maxey Flats, Kentucky</th>
<th>Barnwell, South Carolina</th>
<th>Sheffield, Illinois</th>
<th>Beatty, Nevada</th>
<th>Richland, Washington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent of tritium migration observed</td>
<td>On and offsite surface water; onsite ground water</td>
<td>On and offsite surface water; onsite ground water</td>
<td>None(b)</td>
<td>Onsite; Possible percolation of trench water</td>
<td>None(b)</td>
<td>None(b)</td>
</tr>
<tr>
<td>Extent of other radionuclide migration observed</td>
<td>On and offsite surface water</td>
<td>On and offsite surface water; on and offsite ground water</td>
<td>None observed</td>
<td>None observed</td>
<td>None observed</td>
<td>None observed</td>
</tr>
<tr>
<td>Transport media</td>
<td>1. Surface contamination carried by runoff. 2. Water infiltration of trenches and overflow. 3. Effluent from liquid waste treatment. 4. Possible ground water transport.</td>
<td>1. Surface contamination carried by runoff. 2. Effluent from liquid waste treatment. 3. Ground water transport.</td>
<td>None indicated</td>
<td>Ground water transport(d)</td>
<td>None indicated</td>
<td>None indicated</td>
</tr>
<tr>
<td>Solutions or preventions</td>
<td>1. Surface water control. 2. Possible engineered ground water control.</td>
<td>1. Surface water control. 2. Possible engineered ground water control.</td>
<td>Surface water control</td>
<td>Surface water control</td>
<td>Natural conditions sufficient.</td>
<td>Natural conditions sufficient.</td>
</tr>
</tbody>
</table>
Table 2. Continued

<table>
<thead>
<tr>
<th>Extent of tritium migration observed</th>
<th>Savannah River</th>
<th>Oak Ridge</th>
<th>Los Alamos</th>
<th>Idaho</th>
<th>Hanford</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onsite ground water</td>
<td>On and offsite surface water, onsite ground water</td>
<td>None detected</td>
<td>None detected</td>
<td>None detected</td>
<td>None from solid waste burial ground</td>
</tr>
</tbody>
</table>

| Extent of other radionuclide migration | None detected | On and offsite surface water, onsite ground water | None observed | None observed | Uptake by deep rooted plants (tumbleweed) |
| Transport mechanisms | None observed | 1. Overflow from water filled trenches. 2. Ground water 3. Surface water | None observed | None observed | Tumbling tumbleweeds |

| Potential causes for future problems | Surface water infiltrations of trenches | Continued uncontrolled surface and ground water | Dramatic climatic changes | Surface water infiltration and movement through fissured formations | Uncontrolled plant growth |
| Solutions or precautions | Surface water control | 1. Engineered surface and ground water control 2. Exhumation | None necessary | Surface water control | Plane species control |

(a) Mostly taken from tables 24.10 and 24.11, Baselle, 1976.
(b) Environmental surveillance program may be insufficient for detection of all modes of migration.
(c) Controversial data exist, further studies are being made to determine if migration or cross contamination has occurred.
(d) Data from USGS, 1978.
Murphy and Holter (1980) concluded that "effective management of surface water, through the application of improved capping techniques and surface water diversion, is a major factor in determining the success of operators in preventing water infiltration into burial trenches."

INFILTRATION-LIMITING TRENCH COVERS

In areas of high humidity, one of the biggest problems with current trench covers is that they permit the percolation of precipitation into the trenches. Commonly the waste-filled trench is more permeable than the original materials into which the trenches are dug. Consequently, despite compaction efforts, water can accumulate. Even where water does not accumulate in the trenches, it provides a mechanism for transport of radionuclides. Such has occurred at Oak Ridge (Duguid, 1976) and at Maxey Flats (Meyer and O'Connell, 1973). In addition, trenches can become full so that contaminated water seeps over the top, as has occurred at West Valley (Kelleher, 1979). In addition, erosion of trench covers can contribute to such problems.

Two general types of covers have been proposed: man-made "impermeable" covers (concrete, asphalt and impermeable membranes), and covers using natural materials (clay barriers or layered designs). Increasing the thickness of existing covers has also been suggested, but this alone may not solve the problem in humid regions. In a study at the West Valley site, Kelleher (1979) showed that, for erosion control, individual trench covers are superior to a single cover over the entire site.

SCS Engineers (1978) suggest that the uppermost one meter of all trenches should be filled with excavated material, followed by a compacted, mounded and sloped cover to reduce infiltration and the effects of waste decomposing and settling. Five percent is the recommended optimal slope.

The GAO (1976) reported that to compact material, it must be no thicker than 3 feet. Compaction of a thicker sequence results in a hard crust over softer material. The Brunner (1972) contradicts this figure, stating that in sanitary landfills the cover must be compacted in 6-inch layers. Matuszek et al. (1979) suggest that the permeability of the undisturbed material should be used to choose the specifications for hydraulic conductivity of the cover, and that a prediction of the amount of waste compaction should be used to choose the specifications for the cover strength.
Engineered Trench Covers

One method of reducing infiltration into trenches is to construct an impermeable cover of man-made materials. SCS Engineers conducted a study of this type in 1978. The results are given in table 3.

To the best of our knowledge, none of these materials have been used for final trench covers at low-level radioactive waste disposal sites. Concrete was used to separate alpha-contaminated wastes from beta-contaminated wastes at the Oak Ridge burial grounds three, four and five (Oakes and Shank, 1979); this practice has been discontinued.

At the Idaho and Hanford sites, concrete and asphalt and impervious membranes are used in storage schemes for transuranic wastes. There, transuranic wastes are placed on a concrete or asphalt pad and covered with an impermeable membrane and with earth to permit early retrieval.

Arora (1980) concluded that the use of rigid barriers, such as concrete, concrete asphalt, soil cement and metallic sheets is largely precluded by persistent subsidence such as has been observed in many trenches. (Flexible, synthetic membranes are excluded because of short expected lifetimes.)

Trench covers utilizing plastic membranes have been constructed at sanitary landfills, primarily as a remedial measure for sites with excessive groundwater migration (Farb, 1978 and Tolman et al., 1980). Preliminary results suggest significant reductions in infiltration. There are, however, no data on the long-term effectiveness or the possible life of such covers, or their ability to withstand consolidation of waste.

Clay seals

Clays currently used in trench covers are generally native clays, such as those at Maxey Flats and Barnwell. For a clay cover to be effective, the U.S. EPA (1978) has recommended a minimum of six inches of clay, with a hydraulic conductivity equal to, or less than $1 \times 10^{-7}$ cm/sec, covered by 18 inches of topsoil. SCS Engineers (1978) recommended a minimum of two feet of soil over the clay to prevent cracking and noted that clay can be combined with a plastic liner. Inexpensive soil sealants may also be used as a backup system for clay. Data indicate that the clay covers at Maxey Flats have not prevented tritium migration, whereas at Barnwell, where a
<table>
<thead>
<tr>
<th>Trench Cap Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Expected Longevity</th>
<th>Approximate Cost/Trench, Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (in general)</td>
<td>Longevity. Structural strength. Proven success as a water barrier and radwaste container.</td>
<td>Expense. Susceptible to cracking due to settling or frost heave of buried waste and/or soil cap in certain environments; chemical attack in acid, alkaline, and high-sulfate soils; erosion due to freeze/thaw cycles. Difficulty of access in the event that relocation of wastes becomes necessary.</td>
<td>40+ years</td>
<td></td>
</tr>
<tr>
<td>- 10 cm (4-in) layer</td>
<td>Cost, as compared to other concrete caps.</td>
<td></td>
<td></td>
<td>$16,200</td>
</tr>
<tr>
<td>- 100 cm (40-in) layer extending below the top of the trench</td>
<td>Less susceptible to cracking than the thin concrete layer.</td>
<td></td>
<td></td>
<td>$140,000</td>
</tr>
<tr>
<td>- Concrete encapsulation/trench filling/cover</td>
<td>Least damageable of the concrete caps.</td>
<td>Most expensive concrete cap. Wastes are least accessible</td>
<td></td>
<td>$500,000</td>
</tr>
<tr>
<td>Trench Cap Description</td>
<td>Advantages</td>
<td>Disadvantages</td>
<td>Expected Longevity</td>
<td>Approximate Cost/Trench, Installed $</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------</td>
<td>---------------</td>
<td>------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Asphaltics (in general)</td>
<td>Ease of placement. Cost. Proven worth as rad-waste encapsulation material. Versatility.</td>
<td>Susceptible to chemical degradation. Photosensitive. Susceptible to cracking due to settling or frost heave. Difficulty of access in the event that removal of the wastes becomes necessary.</td>
<td>15+ years</td>
<td></td>
</tr>
<tr>
<td>- Normal asphalt concrete, 4-in layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| - Hydraulic asphalt concrete, 4-in layer | Decreased permeability over normal asphalt concrete. | More difficult to apply than normal asphalt concrete. | | $5,400-
$7,600 |
| - Soil asphalt | Cost. Flexibility. | Increased permeability. Questionable quality control in installation. Temperature sensitive. | | $2,250 |
| - Catalytically blown bituminous seal (0.5-1 cm) | Flexibility. | Questionable homogeneity of cap. Become brittle at low temperatures. Little structural strength. | | $2,700-
$3,600b |
<table>
<thead>
<tr>
<th>Trench Cap Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Expected Longevity</th>
<th>Approximate Cost/Trench Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Cement</td>
<td>Costs.</td>
<td>Variable permeabilities.</td>
<td>25+ years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proven worth as a water barrier.</td>
<td>Susceptible to chemical attack and freeze/thaw erosion.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>More flexible than concrete.</td>
<td>Reduced longevity compared to concrete.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 15-20 cm (6-8 in)</td>
<td>Works better in heavy clay soils than normal soil cement.</td>
<td></td>
<td></td>
<td>$2,250</td>
</tr>
<tr>
<td>layer with a bituminous seal coat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Carbonate bonding</td>
<td>Very permeable.</td>
<td>Cost.</td>
<td>20+ years</td>
<td>$5,000-7,700c</td>
</tr>
<tr>
<td>(15 cm (6-in) layer)</td>
<td></td>
<td>Poor quality.</td>
<td></td>
<td>$1,800-3,400c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor weatherability.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Synthetic polymer</td>
<td></td>
<td>Poor puncture resistance.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>membranes</td>
<td></td>
<td>Stability.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Butyl rubber</td>
<td></td>
<td>Temperature sensitive.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Polyethylene</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Polyvinyl chloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trench Cap Description</td>
<td>Advantages</td>
<td>Disadvantages</td>
<td>Expected Longevity</td>
<td>Approximate Cost/Trench, Installed</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------</td>
<td>---------------</td>
<td>-------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Ethylene-propylene diene</td>
<td>Resistant to weathering and temperature deterioration.</td>
<td>Poor chemical resistance.</td>
<td>$4,900-7,600^c$</td>
<td></td>
</tr>
<tr>
<td>Chlorinated polyethylene</td>
<td>- see ethylene propylene diene -</td>
<td></td>
<td>$4,300-6,300^c$</td>
<td></td>
</tr>
<tr>
<td>Hylalon</td>
<td>Resistant to chemical attack, puncture, temperature deterioration.</td>
<td>Cost. Low Tensile Strength.</td>
<td>$4,300-6,300^c$</td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>Proven success as a water barrier. High impermeability. Self-sealing properties. Flexible.</td>
<td>Susceptibility to mechanical damage (animals, plant roots). Susceptibility to chemical deterioration. Must be kept wet.</td>
<td>1,000+ years</td>
<td>$1,300</td>
</tr>
<tr>
<td>Soil sealants</td>
<td>Relatively low cost. Ease of application.</td>
<td>Lack of control over polymerization or sealing process. Subject to chemical and biological attack.</td>
<td>unknown</td>
<td>$1,100+^c$</td>
</tr>
</tbody>
</table>

a This table is taken from Table 9, SCS Engineers, 1978.
b Approximate cost in 1978 dollars for a trench 100 m long by 15 m wide by 6 m deep. Includes only the materials and installation of the cap itself.
c Includes a 15 to 30 cm soil cover.
minimum of three meters of soil is placed over a clay barrier, no tritium migration has been noted.

Most of the sources that deal with clay barriers suggest that bentonite is superior to other clays. The EPA (1978) reported, however, that kaolinite and illite are superior to montmorillonite for resisting shrink/swell desiccation and cracking. Early work on the use of a bentonite barrier was performed by Hawkins and Horton (1967) at the Savannah River plant. They experimented with various thicknesses of Wyoming bentonite and soil covers to determine the minimum thickness that would prevent infiltration. They found that a one-inch layer of bentonite was sufficient and that a two-foot soil cover was all that was needed to prevent cracking during a prolonged drought. Caution must be taken, however, to prevent growth of deep-rooted plants. They also found that, whereas bentonite and concrete covers cost about the same, the bentonite withstood erosion better than concrete.

Volclay Soil Labs (1975) suggests that bentonite should be sandwiched between soil layers, at least in sanitary landfills, because contact between the waste and bentonite may cause reduction of the clay minerals. This would not cause difficulty at low-level radioactive waste sites, where it is common practice to fill the top meter of the trenches with excavated earth. A bentonite layer and soil cover could be added over existing trench covers. Das and Dakshinamurti (1975) have shown that the addition of bentonite to a soil can significantly decrease the infiltration rate. The addition of certain salts can decrease the infiltration rate even more. It has also been claimed that mixing bentonite with water-soluble polyacrylates will increase bentonite's oil sealing capabilities (Arora, 1980).

Bentonite covers are not yet in widespread use. The "few experimentally sealed" trenches at Oak Ridge (see table 1) use a thin layer of a native shale and bentonite (Webster, 1979; Arora, 1980). The long-term effectiveness of these experimental covers is being assessed. The effectiveness of the bentonite seal is a function of the type of bentonite used, preparation of the substrate, design and control of the sealing operation, and follow-up maintenance.

SCS Engineers (1978) suggest a design that incorporates a clay or membrane barrier as the optimal trench cover. Their design is different from other clay designs because it incorporates an upper gravel layer to direct water laterally away from the trench (fig. 2).
Figure 2. Conceptual completed low-level radwaste disposal trench. (After SCS Engineers, 1978)
Figure 3. Infiltration of 2-cm increments of rain.
(From Corey and Horton, 1969)
To the best of our knowledge, this design is not in use. A modified design using compacted clay covered by freely-draining sand has been approved for use at a sanitary landfill located in an environmentally sensitive site in Florida (Nelson et al., 1980). It will be many years before the performance of this cover will be known, however.

Layered Covers That Utilize the "Wick Effect"

The second suggested plan for construction of covers that limit filtration involves sandwiching coarse-grained material between fine-grained sediments. Early experiments by Horton and Hawkins (1965) showed that such layering can act as a barrier to infiltration. Corey and Horton (1969) illustrated the barrier mechanism by demonstrating that pore-water in fine-grained, unsaturated material will not flow into underlying gravel. The results of some of their experiments are shown in figure 3. They show that, the greater the contrast in the permeability between the two layers, the more effective the barrier. A second fine-grained layer below the gravel directs away from the wastes the water that horizontally enters the gravel layer under saturated conditions. The ideal wick soil is one which has a high moisture content at a significant negative pressure and a high hydraulic conductivity (Frind et al., 1977). Unfortunately, these characteristics are usually mutually exclusive.

Several researchers have suggested designs based on the wick effect. Farb (1978) suggested a sequence of topsoil, sand and clay as a means for upgrading hazardous waste disposal sites. Dragonette et al. (1979), suggested a wick cover over a series of trenches and suggested adding a drainage pipe in the coarse layer (fig. 4). The optimal design suggested by Dragonette et al. (1979) was a wick cover over a series of trenches, with or without perimeter drains around the site (fig. 5). Rojstaczer (1981) modeled a wick effect cover design and found that the cover's effectiveness depends on the hydraulic conductivity of the material used and the wetting scenario, and that the effectiveness of the moisture barrier may have been overrated by some authors. Cherry et al. (1973), Frind et al. (1977), and Rancon (1980), have suggested taking the wick concept one step further and using it around an entire trench (fig. 6). This, of course, cannot be used on trenches as a remedial measure. It is being tested (Cherry et al., 1973) at Chalk River in Canada. To the best of our knowledge, no other wick covers are being tested.
Figure 4. Design of an infiltration-limiting cover. (After Dragonette, et al., 1979)
Figure 5. Wick effect cover over a series of trenches with perimeter drains. (After Dragonette, et al., 1979)
Figure 6. Schematic diagram showing a hydrogeologic design for dry solid-waste burial zones. (After Cherry et al., 1973).
SUMMARY

Failure of current trench covers to prevent tritium and other radionuclide migration in the humid eastern portion of the United States has prompted research on designs for covers that limit infiltration. The mail types of covers suggested are thicker than current, rigid and nonrigid man-made covers or covers employing clay sealants as well as covers using the wick effect.

DISCUSSION AND CONCLUSIONS

This literature search located very little information dealing specifically with the design of covers for low-level radioactive waste sites. Most of the information relative to radioactive waste sites is site specific and contains little quantitative information. The generic cover improvements that have been suggested generally come from the disciplines of sanitary waste disposal and soil physics.

Although the literature is sparse, two problems are apparent. The first problem is that present trench covering techniques (i.e., backfilling with one to three meters of soil) have not been totally effective. The second problem is that no criteria have been established to determine cover effectiveness. In most cases, the trench cover was determined to have failed only if the trench overflowed or if radioactive material migrated offsite or further than predicted. The criteria become more important when the cover failure is less evident. An evaluation of cover performance should be based on its effectiveness in limiting infiltration. Reasonable criteria must be determined before potential designs can be evaluated.

With these limitations in mind, three general design concepts appear to have demonstrated potential as infiltration limiting cover for radioactive waste trenches. These include making the covers substantially thicker, using the layered cover proposed by Dragonette, et al. (1979), and installing a clay cap beneath compacted soil as proposed by SCS Engineers (1978). While these designs may be effective over compacted waste, no designs that have been proposed appear to be able to withstand subsidence caused by differential settlement of waste.
APPENDIX A

Annotated Bibliography for the Design of Infiltration Limiting Trench Covers for Low-Level Radioactive Waste
# Cross Index of Bibliography by Subject

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Ridge National Laboratory" in SANITARY ENGINEERING ASPECTS
OF THE ATOMIC ENERGY INDUSTRY—A SEMINAR SPONSORED BY THE
AEC AND THE PUBLIC HEALTH SERVICE, HELD AT THE ROBERT A.
TAFT ENGINEERING CENTER, CINCINNATI, OHIO, DECEMBER 6-9,

SUMMARY: Radioactive contaminated solid wastes at Oak Ridge National
Laboratory have been disposed of by burial since the beginning of op-
erations. The main problems associated with collecting, handling, and
transporting wastes to the burial site are the prevention of personnel
exposure and the spread of contamination. At present, there are 25 or
more outside agencies using ORNL facilities for waste disposal, with
an annual burial rate of approximately 5 acres per year. Burial has
provided a safe, economical, convenient method for disposal of these
wastes.

ANNOTATION: The waste is buried in trenches dug in soft Conasauga
shale and backfilled with the shale. Trench covers are not discussed
in detail.
ABSTRACT: In the scope of the European Research and Development Program (R & D Program) for the final disposal of radioactive wastes, the German Federal Republic and the Netherlands are following the so-called "Saltline."

Since 1967, low-level wastes, and since 1972, intermediate-level wastes have been deposited in the Asse Pilot Repository near Wolfenbüttel in the Federal Republic of Germany.

On the basis of knowledge gained up till now, the prerequisites for the planning and construction of a new, final mine repository on a salt diapire in Gorleben (North Germany) primarily for low-level and then for intermediate-level wastes, was accomplished within the scope of the planned nuclear fuel-cycle centre to be provided for by the German Federal Government.

The first results of practical heating-tests with electric heaters in halite formations as well as theoretical calculations, are available for the future final disposal of high-level, heat-generating wastes.

A Development Group (Entwicklungsgemeinschaft Tieflagerung, EGT) was founded by the Gesellschaft fur Strahlen- und Umweltforschung (GSF) and the Kernforschungszentrum, Karlsruhe (KfK) for the purpose of the concentration of activities in this field.

The R & D Program provides mainly for further development and the optimization of procedures for the disposal of low-level and intermediate-level wastes, as well as for the planned advance-experiments for the disposal of high-level radioactive glasses (which can be retrieved at a later date) on a small scale.

The cavern technique is being developed and tested parallelly for the disposal of low-level and intermediate-level radioactive wastes.

Within the scope of future R & D Programs, not only the feasibility analysis for the disposal of low-level and possibly also intermediate-level radioactive wastes in the closed-down "Konrad" Iron Ore Mine are being considered, but also the disposal of waste water containing tritium in porous-reservoir rocks.

ANNOTATION: Germany disposes of its low-level radioactive wastes in salt mines; trench covers are not mentioned.
ABSTRACT: Scintillation probe profiles from 154 monitoring wells located in 200 East Area have been compiled for input into the Long-Term Management of Low-Level Waste Projects data base. A thallium activated sodium iodide scintillation system and the scintillation equipment and instrumentation used to log these monitoring wells are described. In addition, waste management applications of scintillation probe profiles are discussed including the determination of the distribution of gamma emitting radiocontaminants and the identification of stratigraphic units. Cross references for well number and associated crib facility designation are given in the appendices.

ANNOTATION: The profiles discussed are from Hanford's liquid radioactive waste disposal operations. No mention is made of trench covers. The bulk of the report is the profiles.
ABSTRACT: Non-Fuel-Bearing Component (NFBC) waste from nuclear facilities is not a voluminous waste; however, for a commercial burial site, it is a much more hazardous waste by nature of the significantly higher radiation levels. Burial is presently done in excavated silt trenches and a modified form in use at the CNSI Barnwell facility. This disposal technique creates considerable problems in the handling efficiency, site utilization and personnel exposure. An engineered transport and burial system to reduce the problems and the exposure are discussed. Currently, non-fuel-bearing components and irradiated hardware coming from the reactor core are sheared, crushed, containerized, and transported to the waste burial site in a top-loading and untop-loading transport cask. At the site, this cask must be removed from the trailer and placed in a vertical position to remove the waste container. The process of removing a highly radioactive container from the cask with site equipment, in the open air, and transferring this container to a silt trench, creates handling problems and excessive exposure. A top-loading bottom-unloading transport cask and trailer unit has been designed so that in combination with an engineered waste disposal will simplify handling, minimize exposure, maximize site utilization and reduce burial site selection problems. The integrated technique discussed sets forth the interfaces, the logic of the transport device, the canister transfer from the cask to the disposal sleeve in a concrete vault with minimal exposure to personnel. Site utilization, cask handling efficiency and exposure control is the motivation for this presentation.

ANNOTATION: Trench burial is mentioned but the burial part is not the main focus of this paper. The trench cover is not discussed.

ABSTRACT: The primary mode of radionuclide transport from shallow land-disposal sites for low-level wastes can be traced to infiltration of precipitation. This report examines the factors that affect surface water entry and movement in the ground and assesses available infiltration-control technology for solid-waste-disposal sites in the humid eastern portion of the United States.

A survey of the literature suggests that a variety of flexible and rigid liner systems are available as barriers for the stored waste and would be effective in preventing water infiltration. Installation of near-surface seals of bentonite clay admixed with dispersive chemicals seem to offer the required durability and low permeability at a reasonable cost. The infiltration rate in a bentonitesealed area may be further retarded by the application of dispersive chemicals that can be easily admixed with the surface soil. Because the effectiveness of a dispersive chemical for infiltration reduction is influenced by the physico-chemical properties of soil, appropriate laboratory tests should be conducted prior to field investigation.

ANNOTATION: The document is one of the most recent works to deal directly with the design of trench covers. Fifty-seven references are given, many of which discuss the properties of soils in or the engineering details of specific covers. Natural barriers (mostly single layers of clay, but multiple layers are mentioned) and engineered controls (rigid barriers, flexible barriers and soil additives) are discussed.
ABSTRACT: We evaluated the influence of crushed agricultural limestone, placed in a layer over six soils, on the rate of migration of beryllium, cadmium, iron, nickel, and zinc contained in municipal, solid-waste, landfill leachate. The limestone was highly effective in slowing the rate of migration of beryllium, cadmium, nickel, and zinc in all six soils, which represent five major soil orders of the United States. Not only breakthrough (C/Co = 0.5) but also final breakthrough (C/Co = 1) values were significantly delayed (twofold to threefold) over soil alone. The limestone effect was considerably more than additive, i.e., several times more than the sum of soil alone plus limestone alone. The limestone effects were not the same for the individual metals. Attenuation effects were greatest for beryllium and least for cadmium. The migration rate of iron, indigenous to the landfill leachate, also was favorably slowed by the limestone barrier layered over the soils.

ANNOTATION: No mention is made of trench covers. Crushed limestone, which can slow the migration of cation- and anion-forming metals through soil may possibly have applicability for use as a low-level radioactive waste trench liner.
ABSTRACT: The first part (Part I) of the paper deals with the principles and regulations for discharging radioactive waste waters into main canals. Based on IGRP-recommendations and Euratom Radiation Protection Standards, the First Radiation Protection Ordinance of the Federal Republic of Germany applies the concept of maximum permissible concentrations of radionuclides in water. As a rule, the "maximum permissible concentrations of radionuclides in drinking water of radiation workers" may not be exceeded in discharged waste water. Experience has shown that these regulations have led to the installation of expensive equipment, which is unnecessary by safety considerations. On the other hand, nuclear power stations, having a very large throughput of cooling water, could, if following this policy, release large amounts of radionuclides. Therefore, regulations have been formulated which allow greater flexibility in the case of radioisotope users and which limit the total activity to be discharged from nuclear power stations. The license states that radioisotope users, according to the activity level and the radiotoxicity of the isotopes handled, have either to control the discharge by simple book-keeping, or to measure in a holdup tank, or to decontaminate the waste water. The license of nuclear power plants states a concentration limit, so that liquid wastes of high concentrations must be decontaminated before discharge, whereas liquid wastes with a lower concentration may be discharged together with the cooling water. Furthermore the total activity to be discharged is restricted.

The second part (Part II) deals with the management of low- and intermediate-level radioactive wastes. Liquid and solid radioactive waste-treatment methods employed by the different nuclear installations in the Federal Republic of Germany are outlined briefly and the experience gathered from their operation is summarized. New trends of development are indicated. The solidified radioactive residues are stored in an abandoned salt mine. Since 1967 low-level wastes have been stored there, within the framework of an experimental program. Preparations are being made to store intermediate- and high-level wastes. The storage volume of the mine is sufficient to accommodate the radioactive wastes expected to arise in the Federal Republic of Germany up to the year 2000, after further development of the technical facilities.

ANNOTATION: Two methods of disposal are discussed: controlled discharge to surface waters and storage in salt mines. No mention is made of trench covers.
ABSTRACT: Because of serious risks of contaminating water supplies, bulky low and medium active solid wastes cannot be buried or stored in mines in the Netherlands. Since long-term above-ground storage is costly and inconvenient, we have chosen sea-dumping as our ultimate disposal method. This decision was governed mainly by safety and economic criteria that were considered between the Government and RCN. A licensing system exists for the use and disposal of all fissionable and radioactive substances. This system applies to all categories of users—industry, laboratories, research, hospitals, etc. It is based on the Nuclear Energy Act, which also regulates waste storage and treatment. Licenses are granted by the Minister of Social Affairs and Public Health, sometimes together with or after consultation with other Ministers. A license imposes a number of special rules, e.g., restrictions of the quantity of radioactive nuclides used, and always on the storage of radioactive materials. Radioactive wastes must be stored and later disposed of by an officially recognized waste-disposal service. This service is organized by the Reactor Centre at Petten. In the second part of the paper details are given of new installations built at RCN for treatment of these wastes and their preparation for sea-dumping. The installations mainly consist of a baling facility, using a 90-tonne press mounted in a controlled area for pressurized-suit operation. Very recently the facilities were improved and the operations further mechanized to increase efficiency. The services of the central waste-treatment station can now be extended since a simple method of treating carcasses from tracer experiments with small animals has been found. This method is described in the paper.

ANNOTATION: The Netherlands uses ocean dumping to dispose of low-level radioactive waste. Trench covers are not mentioned.
ABSTRACT: This paper describes a study of the geohydrologic and geochemical conditions which may control subsurface migration of radionuclides from a semiarid burial site for solid radioactive wastes. Field investigation involved drilling 10 observation wells around and within an 88-acre (36-ha) area at the Idaho National Engineering Laboratory; 1,700 sediment, rock, and water samples were collected for mineralogic, chemical, physical, and radioactive analysis. The subsurface rocks are chiefly basalt with two principal sedimentary beds occurring at depths of about 110 and 240 feet (34 and 73 m). The water table in the underlying Snake River Plain aquifer (basalt) is at a depth of 580 feet (177 m) at the site.

Statistically significant trace amounts of radioactivity were found in about one-half of the 44 sediment samples from six shallow core holes down to depths of 240 feet (73 m), and in water samples from a small perched zone beneath the burial site. The levels of radioactivity detected were generally less than the amounts resulting from worldwide fallout found in surface soils in this region. The observed trace amounts of radioactivity may have been derived from the downward migration of radionuclides from the buried wastes, from artificial contamination of the cores during drilling and sample handling, or from a combination of these processes. Available data indicate that waste radionuclides have not migrated from this site into the Snake River Plain aquifer in detectable concentrations. Such downward migration appears unlikely, provided that water can be prevented from coming in contact with the buried wastes.

ANNOTATION: This semi-arid site has been flooded twice. Improvements since 1970 to reduce infiltration include increasing the thickness of and compacting the soil cover.

ABSTRACT: None.

ANNOTATION: Deep burial of wastes is discussed; and their covers are not mentioned.

ABSTRACT: None.

ANNOTATION: Photographic copies of slides shown at the meeting are given. The slides deal with deep disposal of high-level wastes and concentrate on salt deposits.
INTRODUCTION: This volume describes alternatives for operations designed to remove radioactive wastes from man's environment. Such operations are conventionally called "disposal;" in this document that term is used specifically for concepts that offer little or no chance for reversibility. Some concepts do permit reversibility, i.e., retrieval; these are described as "storage" operations. Storage and disposal alternatives that leave the wastes in existence but remove them from man's environment are "isolation" concepts. Some disposal alternatives would eliminate the wastes from existence on earth.

Discussion of the isolation and disposal alternatives is structured under five major headings. Section 23, Basic Concepts for Geologic Isolation, describes generic principles and factors common to all geologic storage and disposal systems. Section 24, Geologic Storage Alternative, describes options for retrievable emplacement of wastes into burial grounds or deep continental geologic formations. Section 25, Geologic Disposal Alternatives, describes options for irretreivable emplacement of wastes into deep continental geologic formations, seabeds and ice sheets. Section 26 describes alternatives for extraterrestrial disposal. Section 27 describes alternatives for disposal by transmutation.

ANNOTATION: Current covering techniques on commercial burial grounds are described as follows: "One to 3 m of soil is mounded over the top of the waste, the mound being 1 to 2 m high over the centerline of the trench. At the more arid western sites no special attempts are made to further compact the fill or seal the trenches. Efforts at the other four sites involve more impermeable soils such as clay in construction the cover, reseeding the mound, and construction of drainage fields around the mounded trenches." Similar procedures have been followed at the ERDA sites; however, no dewatering techniques are applied at any of the ERDA sites. Problems and potential problems at the sites are noted. This source gives an excellent overview of shallow land burial as it was in 1976.

ABSTRACT (from NTIS); Volume 3 contains eight appendices: a reference environment for assessing environmental impacts associated with construction and operation of waste treatment, interim storage and/or final disposition facilities; dose calculations and radiologically related health effects; socioeconomic impact assessment; release/dose factors and dose in 5-year intervals to regional and worldwide population from reference integrated systems; resource availability; environmental monitoring; detailed dose results for radionuclide migration groundwater from a waste repository; and annual average dispersion factors for selected release points.

ANNOTATION: Low-level site environments are discussed; trench covers are not discussed.
ABSTRACT: Ground disposal practices currently in use at Hanford for the disposal of low- and intermediate-level liquid and solid wastes are discussed.

Low-level liquid wastes are routed to artificial swamps and intermediate-level liquid wastes to underground tile fields which rely on the ion-exchange properties of the soil to retain the radioactivity while returning the water to the environment after a delay of several years. Intermediate-level wastes which contain radioactivity that would not be efficiently adsorbed by the soil are released to trenches in limited quantity so that the soil retains the contaminated liquid by adsorption. Typical liquid waste disposal costs are $1.40, $700 and $7400 per million litres for swamp, crib and trench disposal, respectively. Waste solids are packaged in cardboard, wood, steel or concrete burial boxes depending on size, weight and radiation intensity. These packages are then buried in disposal trenches. Small size, high-activity solid wastes are packaged in steel drums and placed in underground caissons, while equipment too large to be conveniently disposed of by these methods is loaded on expendable railroad cars and stored in railroad tunnels. Costs for solid waste disposal range from $20 to $3000/m$^3$ depending on the relative complexity of the disposal. The bases for determining the type of disposal method used and the physical features of the disposal systems are reviewed.

ANNOTATION: The trenches are backfilled using bulldozers. The weight of the soil is expected to compact the waste.
ABSTRACT: Since the 1965 IAEA Symposium on the Treatment of Low- and Intermediate-Level Radioactive Wastes, radioactive waste management and effluent control have become the subjects of increasing public interest and concern in the United States of America. The entire nation has become pollution conscious and environmental problems are being considered as the challenge of the 1970s. Recent United States developments in power reactor waste management, land burial, sea disposal, and deep-well injection, are summarized, principally as they relate to the establishment and modification of existing or new waste-management policies and procedures. Many public criticisms have been directed at the effluent control operations of the expanding United States nuclear power industry, such as the discharge of heated effluents and their potential effect or impact on our environment. Much controversy has also centered on the discharge of very low quantities of radioactivity from the normal operation of United States nuclear power plants, which has been generally at levels of less than a few percent of internationally accepted radiation protection standards. Power-reactor waste-management experience is described, including the significance of tritium and noble gas releases in these operations. While the release of heat from nuclear power plants is not unique, nevertheless, because of a lower thermal efficiency, light-water nuclear plants of current design discharge more waste heat to the environment than a conventionally fired plant of the same size. The radiological effects of low-level releases and the problem of heated effluents from nuclear power plants are interrelated factors when one considers the potential total impact of these operations on the environment. An expanded thermal effects research and development program is being developed by the United States Atomic Energy Commission in concert with other Federal and State government agencies and the utility industry to provide the technical basis for the safe development and public acceptance of nuclear energy. The scope of this emerging program is described. Because of the rapid growth of nuclear power and increasing uses of radioactive materials and other sources of radiation, the USAEC has proposed amendments to its regulations on radioactive effluents from light-water-cooled nuclear power reactors, to help ensure that total radiation exposures to the public from licensed atomic energy activities remain low. Bases for the amendments to the AEC regulations are discussed with their possible significance indicated.

With the growth of the United States nuclear energy industry, disposal of solid radioactive waste materials by commercial land burial has also continued to increase. The magnitude of radioactive waste land burial, including the AEC and industrial operations, is summarized.
In this connection, during the past several years the volumes of waste materials contaminated with transuranium nuclides has also shown a marked increase. Technical studies on the segregation and retrievability of these solid wastes from other waste materials in AEC operations are discussed. The disposal of solid waste materials by sea burial, has essentially ceased, primarily because of the availability of commercial land burial services. Developments in this area since the 1965 IAEA conference are summarized. Deep-well injection has become increasingly popular for the disposal of all types of industrial wastes, principally from the chemical, petrochemical and steel industries. However, the technique has essentially not been used for the disposal of radioactive waste materials. The limitation of this waste disposal method and recent actions which have been initiated by the U.S. Department of the Interior to regulate and control these underground disposal operations are described. During the 1960s, an extensive research, development and demonstration program was carried out on the treatment and disposal of all types of gaseous, liquid and solid waste effluents. Waste-management technology is now available for the removal of radioactivity down to small fractions of authorized radiation protection guides. During the 1970s, major emphasis in the radioactive waste-management program will be placed on industrial application and the obtaining of public acceptance of this control technology.

ANNOTATION: Although burial of radioactive wastes is discussed, the discussion focuses on the burial of transuranic wastes in such a way that they can later be retrieved and on deep burial of high-level wastes.
ABSTRACT: In August, 1967, the first radioactive waste was buried at the Sheffield Nuclear Waste Disposal site. Ten years later, a total of 2,558,000 cubic feet containing over 49,000 curies of by-product material, 202,000 pounds of source material, and 48,000 grams of special nuclear material have been buried.

Our experience with this site has taught us much about the importance of an adequate criteria for the site: the interactions between the State as the owner and the Federal Government as the licensing agency; the need for extensive environmental surveillance data; and the necessity for maintaining an impartial and unbiased relationship between the contractor and the general public.

Several changes would be instituted if Illinois were to undertake such a project today rather than ten years ago. These changes would involve such items as land acquisition, site monitoring and environmental surveillance, funding of the State operations and perpetual care, and public relations. The adequacy of criteria regarding the solidification as well as sections of the Transportation Regulations should also be examined.

ANNOTATION: The management of a disposal site is discussed. All waste is solid and contains less than 1 curie of radiation per cubic foot. No mention is made of trench covers.

ABSTRACT: None.

ANNOTATION: Disposal of high-level wastes in deposits of bedded salt is discussed.
(18) "Disposal of Low-Level Radioactive Wastes from Pilot Plants:
CHEMICAL ENGINEERING PROGRESS, v. 67, no. 4. P. 81-86.

ABSTRACT: (From Compenpex) Technical details of the treatment of
liquid and solid radioactive wastes from uranium and thorium processing
operations at the National Lead Co.

ANNOTATION: No mention is made of trenches for low-level waste.


ANNOTATION: Most of the papers do not deal with low-level radioactive wastes. Three pertinent articles—those by Cherry, Grisak and Clister, by Meyer and O'Conner, and by Robertson and Barraclough—are listed separately in this bibliography.

FOREWORD: Sanitary Landfill Design and Operation is a state-of-the-art treatise. It not only describes the known in sanitary landfill technology, it also indicates areas in which research is needed.

This publication represents the combined efforts of many individuals within the Federal solid waste management program, other Federal agencies, State and local governments, private industry, and universities.

It is the hope of the U.S. Environmental Protection Agency that planners, designers, operators, and government officials will use this document as a tool to help overcome the poor land disposal practices that are evident today.

ANNOTATION: Although the publication deals with sanitary wastes, it contains information that can be applied to trench covers for low-level radioactive waste. Sanitary landfills require a cover only two feet thick; the cover must be compacted in six-inch layers. The density of well-compacted coarse- and fine-grained material is defined.
ABSTRACT: The incentives for separating and eliminating various elements from radioactive waste prior to final geologic storage have been examined. The study required evaluation of numerous parameters concerning the transport of radioactivity from the geologic storage repository to man. Available data were used whenever possible, but many of the study parameters had to be estimated. The values used were either consistent with current knowledge or were selected to maximize the calculated potential radiation doses; thus incentives for removing various elements from the waste were greatly increased. In addition, incentives were greatly overestimated by neglecting all short-term risks and by assuming that elements removed from the waste could be eliminated from the earth without risk. The conclusion that the incentives for removal of any elements, including the transuranics, from high-level waste are vanishingly small was based on comparison of the predicted potential radiation doses with routine doses from natural sources. The study found that there are reasonable conditions of geologic emplacement where the predicted incremental dose to man is calculated to be at least as low as one-tenth of "background." Additional investigation can reduce the uncertainties present in the study. Such investigation should be the major focus of future research related to partitioning, if any is undertaken.

ANNOTATION: Trench covers are not mentioned.
Carter, M. W., A. A. Moghissi and B. Kahn (eds.). 1979. MANAGEMENT
1211 p.

ABSTRACT: None.

ANNOTATION: The volumes contain several pertinent articles, many of
which are listed separately in this bibliography.
INTRODUCTION: The report summarizes presentations, critiques and recommendations for the disposal of commercial radioactive wastes based upon an analysis of the information presented at the Rock Mechanics Review/Workshop, Denver, Colorado, December 16-17, 1976. The workshop, comprised of both formal and informal sessions, with about 50 participants, was hosted by RE/SPEC Inc. and Dr. Paul Gnirk, President, and was sponsored by the Office of Waste Isolation (OWI).

Despite the rather preliminary nature of the results presented and the youth of the program itself, it is clear that the essential ingredients for a successful program are at hand, especially as regards disposal in natural salt formations. These include laboratory studies of appropriate rock deformation, numerical analyses of thermal and mechanical stresses around openings, and in situ field tests.

ANNOTATION: This article discusses salt repositories for radioactive wastes, not trenches.

ABSTRACT: This review of Canadian development work related to the disposal of non-fuel radioactive wastes arising at nuclear generating stations was presented at the Canadian Nuclear Association Symposium on the Management of Radioactive Wastes in Canada, Toronto, 1979 April 10-11. Current programs relate primarily to the conditioning of the wastes into a form suitable for disposal and the definition of criteria for the design and siting of the repository.

ANNOTATION: Disposal of high-level waste in plutons is recommended. Only minor mention is made of low-level wastes.
ABSTRACT: All of the existing low-level radioactive waste management sites in Canada and in the non-arid region of the United States have shallow burial zones that are in or very near the zone of water-table fluctuation. In this zone groundwater flow generally occurs at significant rates. Processes of physical and chemical weathering are normally quite active. At most of these sites it is unlikely that the wastes can remain in the burial zones for the duration of the period of hazardous radioactivity levels without causing contamination of groundwater beyond the site boundaries. At some of the sites contamination has already occurred. All the sites require continual monitoring and maintenance and as such can be regarded as sites for temporary waste storage rather than long-term waste isolation. To avoid the difficulties that arise when wastes are buried in or near the water-table, various investigators have recommended that future low-level radioactive waste management sites be located in areas where the upper limit of the zone of water-table fluctuation is well below the bottom of the burial zone. In humid and semi-humid regions, areas with this hydrologic characteristic are very rare. The probability of sites of this type existing in areas that are also suitable in terms of social, economic, and transportation criteria is extremely small.

As an alternative to the 'bury above the water-table' approach, we propose that solid low-level radioactive wastes be buried at the bottom of large holes augured to depths of many meters below the water-table in fine-grained deposits. In southern Canada the best deposits in this regard are dense relatively unfractured clayey till and glaciolacustrine clay. Below the zone of water-table fluctuation the mechanism of radionuclide transport will be molecular diffusion. Diffusion is a process that is so slow that radionuclides such as $^{90}$Sr, $^{137}$Cs, and $^{3}$H will decay to levels that are very near background before migration to the biosphere. Long lived isotopes such as $^{14}$C and $^{226}$Ra will eventually diffuse to the biosphere, but only after many thousands of years. The emission flux will be very low. In hydrogeologic studies of prospective sites for below-water-table disposal in clayey deposits, determination of the age of the groundwater by means of the naturally occurring isotopes, $^{3}$H, $^{18}$O, D, and $^{14}$C is a key factor. The burial zones must be shown to have pore water that is very old, thereby indicating extremely small groundwater velocities.

ANNOTATION: Waste should be buried in clay below the water table where groundwater velocity is low and molecular diffusion is the primary mechanism of transport. There is no mention of trench covers. Deep boreholes at the site have bentonite seals under a compacted mixture of bentonite and backfill material.

ABSTRACT: One of Canada's two main subsurface radioactive-waste-management sites is located at the Whiteshell Nuclear Research Establishment in southeastern Manitoba. The area receives low-, medium-, and high-level solid wastes and small amounts of liquid waste. The wastes are buried at depths as great as 15 ft (5 m) below ground surface and are below the water table, which is normally within a few feet (about 1 m) of the ground surface. Only low-level solid wastes are not protected by metal and/or concrete containers. No significant groundwater contamination has occurred since use began in 1964.

Hydrogeologic studies of the area were conducted during a 5-year period. The methods of investigation included geologic test drilling, surface geophysics, installation and monitoring of an extensive piezometer and well network, short- and long-term pumping tests, single-well response tests, tracer-injection experiments, hydrochemical studies, and mathematical simulations of the groundwater flow pattern. This study resulted in an integrated interpretation of the groundwater flow system which was used to evaluate the waste-management properties of the existing site and adjacent terrain.

The waste-management operations are carried out in deposits of Pleistocene clay and clay-loam till. The deposits have significant secondary hydraulic conductivity resulting from numerous fractures. Because of high hydraulic head in a sandy deposit below the burial zone, the direction of natural groundwater flow is upward through the till and clay into the water-table zone.

The high water table is not a serious limitation at the site. Leaching of solid wastes eventually may produce contaminated groundwater, but the natural groundwater flow system will localize the contaminants in or near the soil zone. Monitoring and removal, if necessary, would be relatively simple. In the unlikely event of leakage of liquid wastes into the groundwater zone, the natural groundwater flow system will minimize the hazard by localizing the contamination at shallow depths in the waste-management area or by transporting the radionuclides at very slow rates in an underlying sandy deposit. The hydrogeologic studies show that contaminants in the sand could be effectively controlled or removed by a combination of natural sorption processes and well pumping.

ANNOTATION: A description and diagram of a "layered" design for dry solid-waste burial zones are given. A few other options, such as clay and asphalt covers, are briefly described.
ABSTRACT: The Kentucky radioactive waste disposal site, operated by the Nuclear Engineering Company, Incorporated, has been in operation since March 1963. As of January 1, 1972, approximately 0.71 million cubic meters of waste, containing 1,153,333 curies of byproduct material, 208,903 grams of special nuclear material, and 39,493 kilograms of source material, have been disposed of at this facility. Due to the relatively long period of operation and the large quantities of radioactive material involved, a detailed inventory of two of the largest pits at the site was made, based on available disposal records. This report contains a brief history of this facility and a summary of the inventory results.

ANNOTATION: The trenches were filled from the high end and backfilled to keep radiation at the ground surface below 2mr/h. Completed trenches were backfilled with a minimum of 1 meter of earth material, which was mounded and compacted to reduce infiltration. After settling of the cover, shallow-rooted plants were to be planted for erosion control.

ABSTRACT: A series of models has been developed for evaluating dispersion of radionuclides in groundwater. These models have been used to predict the migration of radionuclides released to the groundwater under normal and accidental circumstances. They are part of a larger set of radionuclide dispersion models that are used for both groundwater and surface water.

The groundwater models are based on the solution of the three-dimensional equation for the conservation of mass in uniform media with simple geometries. The models account for advection with groundwater flow, dispersion in the aquifer, radioactive decay, and the sorption of chemically active ions on the aquifer medium.

The point concentration model is used for calculating the concentration downgradient from the source in a three-dimensional aquifer of infinite lateral extent, and either constant or infinite thickness. The flux model is used to compute the rate of radioactive material which enters a surface water body that intercepts the groundwater flow. This flux can then be utilized as input to models describing dispersion of radionuclides in surface waters.

Limited confirmation has been performed with field data from deep well injections. Results are reasonably accurate considering the simplicity of the model.

These models have proven useful, when used with appropriate conservative coefficients, for routine licensing evaluations, as well as for generic studies of the liquid pathway.

ANNOTATION: Trench covers are not mentioned.
INTRODUCTION: The task of disposing of the radioactive wastes produced by nuclear power plants is often cited as one of the principal drawbacks to the continued expansion of this country's capacity to generate electricity by means of the nuclear-fission process. Actually the task is not nearly as difficult or as uncertain as many people seem to think it is. Since 1957, when a committee of the National Academy of Sciences first proposed the burial of such wastes in deep, geologically stable rock formations, a substantial body of evidence has accumulated pointing to the technical feasibility, economic practicality and comparative safety of this approach. In recent years a number of alternative schemes—some of them involving undersea burial—have also been put forward, but deep underground burial remains the best understood and most widely favored solution to the problem of nuclear-waste disposal.

In what follows I shall describe the nature of the wastes produced by nuclear power reactors, evaluate their potential impact on public health and the environment and outline current plans to dispose of them in secure underground repositories.

ANNOTATION: Deep burial of high-level wastes is discussed in detail.
FOREWORD: ... Successful application of the underground waste disposal are numerous. They did not in the past, nor will they in the future, occur accidentally. They require knowledgeable personnel, a background of research and planning of the entire project, a dedication to execute each step as skillfully as possible, a determination to observe and monitor results and a commitment to alter or halt a program which presents possible dangers to man and his environment.

It is clear that this method is not the final answer to society's waste problems. It will be useful to us until our studies devise better ways of treating wastes and rendering them harmless. The problem is great—and it is growing. This symposium clearly documents an awareness and a dedication to meet the problem head on.

ANNOTATION: The volume contains three pertinent articles—by J. G. Ferris, by J. E. Galley, and by T. P. Harrison—which are listed separately in this bibliography.

ABSTRACT: Calculations and experimental measurements indicated gravel lenses are unsuitable for diverting water around large burial trenches. The calculations suggest that leaching of radionuclides from the interior of process equipment is unlikely until the soil is saturated near the equipment.

ANNOTATION: A good discussion of the wick effect is given. The diversion of water from a waste burial trench by layers in the trench cover is also discussed.
ABSTRACT: Low-level radioactive wastes generated at the Savannah River Plant and Laboratory are stored at the Savannah River burial ground. These wastes have accumulated from 20 years of reprocessing nuclear fuels and materials for defense programs at the Savannah River Plant. Burial in earthen trenches and above ground storage for transuranic materials are the principal modes of storage.

The infrequent operating incidents that have occurred during the 20-year period have been analyzed. The incidents can be categorized as those causing airborne contamination, waterborne contamination, or vegetation contamination through penetration of plant roots into contaminated soil. Contamination was generally confined to the immediate area of the burial ground. Several incidents occurred because of unintentional burial or exhumation of material. The frequency of operating incidents decreased with operating experience of the burial ground, averaging only about two incidents per year during the last six years of operation.

ANNOTATION: The trenches are 20' wide by 20' deep. Below the waste is approximately 1000' of unconsolidated sand, clayey sand, sandy clay, and clay. The water table is 30-50' below the land surface. The cover is at least 4' of dirt, as required by regulations. Pensacola Bahia grass is used for erosion control.
INTRODUCTION: Assessment of risk from man-made radiation requires the development of mathematical models capable of accurately describing the complex relationships existing among all pertinent physical and biological factors.

ANNOTATION: An overview of the problem is given, with specific discussion of the problems associated with the tailings from a uranium mine. No mention is made of trench covers.

ABSTRACT: Sandy loam soils were treated with bentonite separately and in conjunction with sodium chloride and sodium carbonate in varying proportions to study the changes in soil physical properties and their effect on water harvesting and reduction in percolation losses. Laboratory measurements revealed that the apparent contact angle value increased from $72^\circ 04'$ in the control to $87^\circ 56'$ in soil treated with a combination of 2% bentonite and 0.75% each of sodium chloride and sodium carbonate salts. The capillary rise of water in 24 hours decreased from 41.50 cm to 5.75 cm. Similarly, the infiltration rate was reduced from 18.0 mm/hour to 1.5 mm/hour and the hydraulic conductivity decreased from $4.92 \times 10^{-1}$ cm/hour to $1.02 \times 10^{-3}$ cm/hour in the above treatment. The horizontal infiltration as well as the diffusivity were also very much reduced in the treated soils. Treatment of a similar soil under field conditions with bentonite and sodium chloride resulted in a runoff of 65.5% of the rainfall against 45.7% in the control. Water requirements of a 100-day rice crop (Oryza sativa) was reduced from 346 cm to 255 cm by the application of bentonite with salts. Percolation losses in irrigation taks were also successfully controlled by using the same technique in tank beds.

ANNOTATION: Trench covers are not specifically discussed. The addition of bentonite to soil cover materials is suggested to reduce infiltration.

ABSTRACT: Nongaseous radioactive wastes occur as liquids containing high-level concentrations of radionuclides, liquids containing low concentrations of radionuclides, and solids contaminated by radioactivity. Whether released by accident or design into the earth or onto the earth's surface, only water is capable of transporting significant quantities of radionuclides away from burial sites. Geohydrologic information that must be determined to predict the velocity and direction of waste movement from a site include climate, hydrology, detailed subsurface geology, permeability, porosity, sorptive potential, seismic potential, and geologic history of the area.

Since the late 1960s mathematical models have been used to make predictions of waste transport in some hydrologic systems. Intensive field investigations at each site are needed before these models can be used.

ANNOTATION: Criteria for the safe disposal of both high- and low-level wastes are discussed. Covers should contain "sufficient soil to achieve shielding."

ABSTRACT: None.

ANNOTATION: The hydrogeology of materials having low permeabilities is important in any discussion of their use for waste isolation. The importance of better trench caps is emphasized, but no designs are given.
INTRODUCTION: The Los Alamos Experimental Engineered Waste Burial Facility is a part of the National Low-Level Waste Management Program on Shallow-Land Burial Technology. In this test facility, basic information can be obtained on the processes that occur in shallow-land burial operations, and new concepts for shallow-land burial can be tested on an accelerated basis and on an appropriate scale. This paper will present some of the factors considered in the design of the facility and a description of the experiments that are initially planned. This will be done by discussing the purposes of the experimental facility, and how the initial experiments planned for the facility fit into the overall plan to understand the basic processes that occur in shallow-land burial and to try out new concepts.

ANNOTATION: Various wick systems will be tested in the cover experiments. Caps designed to prevent "biological intrusion" will also be tested.

ABSTRACT: None.

ANNOTATION: Descriptions of nine types of possible trench covers and diagrams for many of the alternatives are given. A cover which has a highly permeable layer between two layers of low permeability is recommended to limit infiltration.

ABSTRACT: None.

ANNOTATION: The trench covers at West Valley, New York, consist of soil excavated from the trench and compacted to a depth of at least 8 feet.
ABSTRACT: The offsite radioactivity releases in the Clinch River are less than 1% of the amount allowable for unrestricted use of the water by a population. However, in keeping with ERDA's objective to maintain releases to "as low as practicable," studies have been conducted to locate sources of radioactivity release and to seek methods of reducing or eliminating them. The study, begun in 1973, is concerned with determining the radioactivity contributions to the Clinch River from the buried waste at ORNL and with implementing corrective measures.

The $^{60}$Co-organic complexes present in the ground water near trench 7 have been identified to be present in two molecular weight fractions, one greater than 700 and one less than 700. Approximately 85% of the $^{60}$Co is being transported with the lighter organic fraction. The chemical composition of this fraction has not been identified, but may be composed of natural organics or EDTA (ethylene-diamine-tetracetic acid).

The calculated discharge of $^{89}$Sr from burial ground 4 to White Oak Creek showed a decrease in the discharge corresponding to a decrease in precipitation. The calculated discharge does not agree with stream-monitoring data, and it is believed that the stream-monitoring data are in error or that a new source of $^{89}$Sr is present in the drainage. Drainage improvements for the burial ground have been installed, but as yet no data are available to show their effectiveness.

Alpha radioactivity has been found in water samples from burial ground 5. More detailed analyses of the water from one seep indicated that both $^{244}$Cm and $^{238}$Pu were present in the water. Because of the presence of these radionuclides, corrective measures were applied to reduce the amount of water moving through the buried waste. Four trenches were sealed with a near-surface plastic membrane; however, as yet no data are available to show its effectiveness.

The procedures for the design of a bentonite-shale mixture have been developed, and enough data have been obtained to show that an adequate sealing material can be made using 10% bentonite. The procedure will be used for near-surface sealing of both past and current burial grounds.
Two computer codes for calculation of water movement and radionuclide transport have been completed. These models are currently being applied to seepage through trench 7 to predict the future behavior of the waste.

ANNOTATION: The trenches at ORNL are in unlined shale and covered with 2 feet of soil, which allows infiltration and radionuclide transport. As of 1975 no migration had been observed from the current solid waste disposal area. One suggestion to improve the burial ground is to make a bentonite-shale seal three inches thick and cover it with 2 feet of soil material. The upper 2 feet would be vegetated to decrease erosion. The design of the seal is discussed.
SUMMARY: Recent reports and Congressional hearings have indicated that performance of waste disposal operations "is not uniformly good" and that radionuclide migration in ground water has occurred at some sites. While releases into the environment have not resulted in injury to the public, they have raised questions concerning the adequacy of the concept of shallow land disposal of low-level radioactive waste. In view of these questions and because the predicted future waste volume/available disposal are questioned, DOE has initiated a program to develop improved technology for shallow land burial.

In February 1977, ERDA (now DOE) requested that burial sites prepare an assessment of their disposal/storage activities for low-level solid waste. The operators were to assess the current operations based on existing information or short-term improvement needs; long-term needs will be addressed in the land burial technology program.

ANNOTATION: Trench cover thickness is dependent upon the radiation level of the waste. In all cases, the cover is at least 1 m thick. The importance of a good trench cover is mentioned as is the need for research in this, and other, aspect of low-level radioactive waste disposal.

ABSTRACT: The physical characteristics of the virgin site and of the disturbed site after burial drastically affect the transport of radionuclides from buried waste. The disturbance of the land surface during the waste burial operation causes changes in the local ground-water regimen. These changes can increase the water table elevation and cause the occurrence of perched water in burial trenches. The combination of these changes may lead to submersion of the waste and to increased radionuclide transport from the burial site in both surface and ground water.

Factors such as ion exchange can retard or in some cases, with competing ions, can also mobilize radionuclides and increase their discharge into ground and surface water. Because of complexing agents (organics) contained in the waste, increased mobility of some radionuclides can be expected. The chemical form of radionuclides in the water, the ground-water quality, and the chemistry of the geologic formation in which the waste is buried all influence the movement of radionuclides in the hydrologic system.

For the assessment of the environmental impact of low-level waste burial, models capable of simulating both the chemical and the physical factors that affect hydrologic transport must be available. Several models for conducting such simulation are presently available. However, the input parameters used in these models are highly variable, and the accuracy of parameter measurement must be considered in evaluating the reliability of simulated results.

The results of this study show that isotopic and concentration limitations, with one or two possible exceptions, do not limit the usability of existing or proposed shallow land burial sites. The limiting mode for the operation of a site is more apt to be the annual spillage of materials as they are received and handled at the site rather than the escape of the buried activity from the site.

ANNOTATION: Waste burial at Oak Ridge National Laboratory is described. The bathtub effect, mobilization of radionuclides by complexing, and transport via fractures are discussed.
ABSTRACT: Chem-Nuclear's low level burial ground located in Barnwell, SC, with primary licensing by the state of South Carolina, has seen a substantial increase in volume of waste and presently serves the majority of fuel and nonfuel cycle radwaste generators in the country. The waste, upon receipt, is monitored and disposed of in one of our engineered trenches. The packaging requirements, trench design, and surface management minimize the possibility of release through the water pathway. The Health Physics practices and the environmental programs evaluate and monitor the personnel and population exposure pathways.

ANNOTATION: The trench covers at Barnwell consist of a minimum of 2 feet of clay, which acts as a moisture barrier, covered by a minimum of 3 feet of earth. In practice, the total earth cover is usually 5-10 feet thick. The cover is contoured and seeded to inhibit erosion.

ABSTRACT: This paper describes the methods used at Los Alamos for the disposal of solid radioactive waste material. It is a resumé of ten years of experience at the Los Alamos Laboratory. Collection, transportation and burial of solid wastes as well as cost data are presented. Radiological safety aspects are also discussed.

ANNOTATION: Waste disposal pits are described. When waste reaches 1 m below ground surface, a final cover of earth is added. This cover, which is 1 m thick, is graded to promote drainage away from the pit.

ABSTRACT: None.

ANNOTATION: This citation is for three summary articles: "Radon-222 Releases Associated with Cultivation of Agricultural Land" by C. C. Travis and S. J. Cotter; "Organic Compounds Identified in Trench Leachates from Low-Level Radioactive Waste Disposal Sites" by A. J. Francis, C. Iden, B. Nine and P. Colombo; and "Shallow Land Disposal of Low-Level Radioactive Waste: Radionuclide Sorption" by R. F. Pietrzak, G. Galdi and P. Colombo. None of these articles deals with trench construction.

ABSTRACT: Low-level radioactive wastes produced by users of radionuclides are generally disposed of by shallow land burial. Reliance for containment is placed on characteristics of shallow geologic formations or soils; thus, effective waste management requires a knowledge of radioactive waste/soil interactions.

Because of the wide variations in soil and waste characteristics, the degree of radionuclide retention would be expected to vary; knowledge of that variation may be of value in predicting radionuclide mobility. This report discusses results of investigations of radioactive waste/soil interactions as they relate to radionuclide retention and its variability among soils and radionuclides. . .

ANNOTATION: The waste was placed on top of the soil in the experiments described; therefore, trench covers were not discussed.
ABSTRACT: Groundwater contamination problems, resulting from the indiscriminate disposal of potentially hazardous wastes, are seldom so uncomplicated that one site restoration technique will adequately serve to correct the contamination problem. Such contamination is typically the result of waste disposal practices which have led to an accumulation of solids, liquids, sludges, discarded containers, and miscellaneous debris. Therefore, more than one remedial procedure may be required to abate a groundwater contamination problem.

ANNOTATION: Sanitary landfills should be covered with synthetic or layered natural materials. The physical integrity of the synthetics is still in question. The optimal layered design is topsoil, sand, clay and waste set on a slope to speed lateral movement through the sand.

ABSTRACT: Since the initial land burial of solid radioactive waste in 1952 at the Savannah River Plant, 577,000 c of fission products and induced radioactivity has been buried. Routine surveillance of thirteen test and observation wells has indicated no migration of radioactive material. Geologic and hydrologic studies, radioassays of soil samples, and measurements of ground water velocity using tritium as a tracer, indicate little possibility of introducing this buried radioactivity into public zones. Maximum movement detected by radioassay of soil was 2 ft, with one exception.

ANNOTATION: Operations during 1953-1962 are described. The trench covers consisted of soil with a minimum thickness of 5 feet.
INTRODUCTION AND SUMMARY: Solid radioactive waste burial at the Savannah River Plant between 1955 and 1972 filled a 76-acre site. Burial operations then were shifted to an adjacent site, and a program was begun to develop a land cover that would 1) minimize soil erosion and 2) protect the buried waste from deep-rooted plants, since radionuclides can be recycled by uptake through root systems.

In anticipation of the need for a suitable soil cover, five grass species were planted on 20 plots (4 plots of each species) at the burial ground (Facility 643-G) in 1969. The grass plots were planted for evaluation of viability, root depth, and erosion protection existing under conditions of low fertility and minimum care. In addition, 16 different artificial soil covers were installed on 32 plots (each cover on two plots) to evaluate 1) resistance of cover to deterioration from weathering, 2) resistance of cover to encroachment by deep-rooted plants, and 3) soil erosion protection provided by the cover.

All test plots were observed and photographed in 1970 and in 1974. After both grass and artificial soil covers were tested five years, the following results were observed:

Pensacoal Bahia grass was the best of the five cover grasses tested and

Fifteen of the sixteen artificial covers that were tested controlled vegetation growth and soil erosion.

ANNOTATION: This paper concerns covers that will limit erosion and protect waste from deep-rooted plants. It approaches the problem from the point of the plants used as opposed to the earth design used.
ABSTRACT: To detect leaching and migration of radionuclides from low-level radioactive waste buried in the Savannah River Plant burial ground, eleven dry wells are monitored annually. These wells were installed through backfilled waste trenches in 1964. Radiation profiles are obtained by plotting radiation levels at various depths.

Twelve years of radiation profile measurements in these dry wells show that most photon-emitting radionuclides buried with waste remain in place after burial. Radiation intensities in half of the monitored wells have decreased considerably in 12 years.

ANNOTATION: The trench covers at the site are at least 1.2 meters thick. Several radiation profiles and the construction of monitoring wells are included.

ABSTRACT: The increasing tempo of ecologic crusades for the cleanup of lakes and streams is literally driving pollution underground. There is in prospect a veritable explosion in the use of sanitary landfills for disposal of solid wastes, in the use of spray irrigation for disposal of partly treated sewage effluent, and in the use of deep-well injection for disposal of certain industrial wastes.

Citations of the astronomical volume of storage space within the earth's crust, the very small velocity of groundwater motion, the evidence of entrapment of hydrocarbons and brines, and the presence of very fine-grained confining rocks all intrigue proponents of subsurface storage with the potential for resolving our waste-disposal problems. What gives cause for concern is the recognition that groundwater reservoirs or aquifers are not static environments, but represent dynamic flow systems that undergo change whenever a new stress is imposed.

Attendant upon the injection of fluid into an aquifer is a consequent increase in hydraulic head which ultimately influences the hydrologic regime throughout the entire flow system, however distant its boundaries may be. Disposal to shallow aquifers, which are generally sources of water supply, poses a threat not only to present and future well developments, but also to lakes and streams that are sustained by groundwater seepage. In deep-lying confined aquifers, where overburden pressures are large, the hydraulic transmissivity is generally small; consequently, the pressures required for significant rates of injection are large. In marked contrast to the very slow migration of the cylinder of injected waste, a transient increase is propagated outward in a confined aquifer with the velocity of sound in the medium. Thus, evaluation of the consequences of waste injection requires not only consideration of the effects of the advancing cylinder of waste, but also the far-reaching effects of the cone-of-pressure increase.

ANNOTATION: The siting of sanitary landfills is discussed in detail. Radioactive wastes are mentioned briefly. Covers are not mentioned.

ABSTRACT: This publication is the first in a series of annotated bibliographies jointly compiled by the staffs of the Ecological Sciences Information Center of the Information Center Complex at Oak Ridge National Laboratory and of Dames & Moore, White Plains, New York. The data file was built to provide information support to Department of Energy researchers in the field of low-level radioactive waste disposal and management. The scope of the data base emphasizes studies which deal with the "old" Manhattan sites, commercial disposal sites, and the specific parameters which affect the soil and geologic migration of radionuclides. Specialized data fields have been incorporated into the data base to improve the ease and accuracy of locating pertinent references. Specific radionuclides for which data are presented are listed in the "Measured Radionuclides" field, and specific parameters which affect the migration of these radionuclides are presented in the "Measured Parameters" field. In addition, each document referenced in this bibliography has been assigned a "relevance" number to facilitate sorting the documents according to their pertinence to shallow land burial technology. The documents are rated 1, 2, 3, or 4, with 1 indicating direct applicability to shallow land burial technology and 4 indicating that a considerable amount of interpretation is required for the information presented to be applied. The references are arranged by the representing affiliation (i.e., government, industry, academic, or foreign). Subheadings are also included where two or more contributing organizations are listed. Within each of the affiliation sections, the references are arranged alphabetically by the organization responsible for the research (corporate author). Indexes are provided for author, geographic location, title, measured parameters, measured radionuclides, keywords, subject categories, and publication description.

ANNOTATION: The volume cites many of the references included in this bibliography. All aspects of the burial of low-level wastes are considered.

ABSTRACT: The citation is for an abstract only.

ANNOTATION: Trench covers are not mentioned.

ABSTRACT: Trench leachate samples collected anoxically from shallow-land, low-level radioactive waste disposal sites were analyzed for total aerobic and anaerobic populations, sulfate reducers, deitrifiers, and methanogens. Among the several aerobic and anaerobic bacteria isolated, only Bacillus sp., Pseudomonas sp., Citrobacter sp., and Clostridium sp. were identified. Mixed bacterial cultures isolated from the trench leachates were able to grow anaerobically in trench leachates, which indicates that the radionuclides and organic chemicals present were not toxic to these bacteria. Changes in concentrations of several of the organic constituents of the waste leachate samples were observed due to anaerobic microbial activity. Growth of a mixed culture of trench-water bacteria in media containing a mixture of radionuclides, $^{60}$Co, $^{85}$Sr, and $^{134}$, $^{137}$Cs, was not affected at total activity concentrations of $2.6 \times 10^2$ and $2.7 \times 10^3$ pCi/ml.

ANNOTATION: Trench covers are not discussed in detail.

ABSTRACT: The feasibility of using the unsaturated hydraulic properties of granular soils in the design of geologic environments for radioactive waste storage facilities in the shallow subsurface is investigated. The essential parts of the geologic environment are a gravel layer surrounding the buried waste container, and a fine-grained soil layer overlying and surrounding the gravel. As long as the pressure at the soil-gravel interface remains negative, water infiltrating into the soil layer will not cross the interface but will flow laterally within the soil layer and around the container. Thus the buried container is kept dry, deterioration of the container is minimized, and potential contaminants are effectively contained. The use of manmade moisture barriers, which tend to deteriorate over longer periods, is avoided.

A transient, saturated-unsaturated finite element flow model is used in the simulation. The results show relationships between the design parameters and the performance of the system, expressed by the pressure head at the soil-gravel interface, for various storm conditions. According to these relationships, the concept is valid and more detailed investigations are warranted.

ANNOTATION: The wick effect is examined in detail. The ideal wick has a high moisture content at a high negative pressure and high hydraulic conductivity. Since these properties are usually mutually exclusive, middle range soils may be best. Fine sand and silty loam were investigated using the finite element model.

ABSTRACT: Insoluble solid wastes can be buried at shallow depths in locations where they are safe from exhumation. If any parts are soluble, the solution must be managed as with any similar liquid waste. Programs for the management of waste liquids must be tailored to the chemical and physical characteristics of the liquids.

Geologic requisites for successful underground management of liquid wastes include: (1) porous and permeable reservoir rocks, in which the storage space may be caverns, intergranular pores, or fracture crevices; (2) impermeable seals to prevent escape of fluid wastes; (3) adequate understanding of hydrologic parameters and planning to prevent undesirable migration of fluids; (4) compatibility between waste materials and the reservoir rocks and their natural fluids.

Layered sedimentary rocks, rather than igneous or metamorphic rocks, provide the most suitable reservoir space, for both geologic and hydrologic reasons. If the wastes are hazardous to the biosphere, objective reservoir formations must be deep enough to provide permanent protection to groundwater aquifers.

The site must be reasonably stable seismically and not actively moving along, or broken by, faults.

Choice of a suitable underground disposal site can be made only after a thorough investigation of available subsurface data, supplemented by drilling and various other processes of subsurface exploration if sufficient data are not already available. Preliminary investigations and later subsurface operations will be expensive, but they cannot be avoided. Public insistence on an end to pollution must be accompanied by public understanding that a clean environment can be purchased only by higher taxes, if government managed, or by higher prices for consumer goods, if industry managed, plus individual awareness and practices.

As waste-management costs rise, it will become more economical to convert wastes into usable products, in effect eliminating, rather than managing, wastes.

ANNOTATION: Landfill covers and radioactive wastes are not discussed.
ABSTRACT: For the past years, the Nuclear Fuel Service, Inc. (NFS) site located in West Valley, N.Y., has been the subject of state and federal efforts to determine decontamination and decommissioning options. In 1978, the U. S. Environmental Protection Agency (EPA) issued Criteria for Radioactive Wastes for storage and disposal of all forms of radioactive wastes. Under an Atomic Energy Commission (AEC) license, NFS operated the only commercial fuel reprocessing facility in the United States. As a result of the reprocessing activities, the site contains liquid high-level radioactive waste, buried cladding hulls and defective fuel elements, a spent for storage pool and a low-level burial ground. Low-level radioactive material contained therein also comes from sources other than NFS's operations. The site received a license from the State of New York to perform low-level burial operations and radioactive material was buried until 1975. Studies of the low-level burial area show radioactive gases have leaked through the trench caps and the caps are more permeable than the surrounding soil allowing water infiltration into the trenches. Active site maintenance is used to prevent trench water overflow through the trench caps. Other remedial actions have been described for the site and are undergoing implementation. The West Valley site will be examined to determine the extent of remedial action and decommissioning activities which may be necessary based on the proposed EPA environmental criteria for radioactive wastes.

ANNOTATION: Modified trench caps were used on later trenches, according to this paper, to decrease infiltration. These modifications are not specified. Remedial action on the early trenches included making the caps 8 feet thick. This is now the standard for all trenches, newer and older, at the site.

ABSTRACT: Fractures in glacial till and glaciolacustrine clay were observed in excavations up to 20 ft (6.1 m) in depth and in drill cores at the Whiteshell Nuclear Research Establishment (WNRE) in southeastern Manitoba. The fractures are characteristically coated with carbonate and oxide precipitates, which indicate groundwater movement through the fractures. The fractures impart an effective bulk hydraulic conductivity to the clay-loam till and lacustrine clay, as evidenced by tritium tracer experiments and piezometer response in the till and clay to pumping of an underlying sandy aquifer.

The intergranular hydraulic conductivity of clay-loam till and glaciolacustrine clay in the Interior Plains, as determined from laboratory considerations test data, is in the range of \(2 \times 10^{-10}\) to \(9 \times 10^{-11}\) ft s\(^{-1}\) (6 \(\times\) 10\(^{-9}\) to 2.7 \(\times\) 10\(^{-9}\) cm s\(^{-1}\)). The bulk hydraulic conductivity of the fractured clay-loam till at WNRE, as determined from finite-element mathematical modeling, is about 6 \(\times\) 10\(^{-9}\) ft s\(^{-1}\) (1.8 \(\times\) 10\(^{-7}\) cm s\(^{-1}\)). The model value represents the effective hydraulic conductivity imparted to the till by the fractures.

Seven pumping tests, ranging in duration from 8.75 to 120 h, were conducted on the sandy aquifer and drawdown data in the aquifer were analyzed to obtain the hydraulic conductivity and storativity of the aquifer.

A 32-day pumping test on the aquifer showed that many of the piezometers in the till and clay respond quickly and strongly to the aquifer drawdown, while others show no noticeable response. The responding piezometers intersect open fractures whereas the others do not. Analysis of the piezometer drawdowns during the long-term pumping test using the Neuman and Witherspoon 'ratio' method indicates that the rapid piezometer drawdowns in the confining layers can be accounted for the assigning specific storativity values in the range of \(1 \times 10^{-5}\) to \(5 \times 10^{-6}\) ft s\(^{-1}\) (3 \(\times\) 10\(^{-5}\) to 1.5 \(\times\) 10\(^{-5}\) m s\(^{-1}\)) to the clay-loam till and lacustrine clay. These values are typical of fractured rock. If intergranular specific storage values are used, the calculated piezometer drawdowns are very small or negligible.

ANNOTATION: Trenches and covers are not discussed.
ABSTRACT: The basic authority for federal enforcement in water pollution is the Federal Water Pollution Control Act (P.L. 84-660, as amended, 33 USC, sec. 1151-1175). The Environmental Protection Agency has been charged with the administration and enforcement of this act, which declares the policy of Congress "to recognize, preserve and protect the primary responsibilities and rights of the states in preventing and controlling water pollution."

By use of three enforcement tools—the "Enforcement Conference," the "180-Day Notice," and the "Permit Program"—the EPA is to see that water pollution is prevented and controlled. Although these statutory authorities apply to surface waters, the Federal Water Quality Administration, EPA's predecessor, recognized the increasing use of the subsurface for disposal and storage of liquid wastes and thus announced a policy on disposal of wastes by subsurface injection. The EPA has followed the FWQA policy but has required clear demonstration that subsurface disposal of wastes will not interfere with present or potential use of subsurface water supplies and/or will not contaminate interconnected surface waters or otherwise damage the environment.

The President, by E.O. 11574, ordered the implementation of the Refuse Act Permit Program, under the authority of the 1899 Refuse Act. This act prohibits putting almost anything, by any means, into a navigable water or its tributaries.

The enforcement tools of EPA initially will be used to focus on the most serious cases of pollution. However, it appears obvious that substantial changes will take place in the near future. The Senate has passed the Federal Water Pollution Control Act Amendment of 1971, which calls for the elimination of the discharge of all pollutants by 1985. The states are given the prime responsibility for achieving this goal, but the bill grants EPA broad powers regarding enforcement if the state takes no action. At this date, the bill has not been passed by the House.

ANNOTATION: Trench covers are not mentioned.

INTRODUCTION: The current program of the waste management group at the Savannah River Plant includes the selection and evaluation of a material which will prevent leaching of buried solid waste. Routine sampling of monitoring wells and surface streams has indicated no significant migration of radionuclides from the SRP burial ground during the 8 years it has been in use. Nevertheless, the potential problem justifies improved protection of buried solid radioactive waste from ground water which could cause movement of radioactivity.

ANNOTATION: An experimental cover design which incorporates a thin bentonite layer is described. The results of the experiment are not presented.
ABSTRACT: Wyoming bentonite clay prevented infiltration of rainwater into radioactive waste buried above the water table in a humid region. A lysimeter study showed that a 1-in.-thick bentonite layer was adequate and that drying and cracking of the bentonite during prolonged drought could be prevented with 2 ft. of soil cover. A large subsurface bentonite structure built in the field demonstrated the feasibility of applying a continuous bentonite layer over extensive vertical and horizontal areas. The test was evaluated by D₂O tracing of soil moisture both outside and under the bentonite structure. Structures must be maintained free of all plant growth because bentonite is easily penetrated by roots.

ANNOTATION: Tests of layered covers were performed at the Savannah River Plant to determine the best combination of bentonite and soil. One inch of bentonite was found to cost about the same as concrete but to withstand erosion better.
ABSTRACT: To assess the long-term hazard potential associated with the burial of partially decontaminated process equipment, burial emplacements of equipment from an irradiated-fuel separations building (canyon) are being exhumed and examined. One piece of equipment, a Purex feed adjustment tank that was retired in 1957 from service in a hot canyon at the Savannah River Plant, has been exhumed and studied.

Assays of the tank and soil show that only 1 mCi of $^{137}$Cs and 0.4 mCi (7 mg) of $^{239}$Pu remain on the surfaces of the tank; amounts of these radionuclides in neighboring soil are substantially less. Radionuclides from the contaminated surface of the tank migrated into neighboring soil. Of the three nuclides studied, $^{90}$Sr migrated most extensively, as observed previously. $^{239}$Pu contents of the tank and neighboring soil were less than the 10 mCi/g total transuranic nuclide content allowed under ERDA standards for burial of nonretrievable waste.

This paper also describes plans for future studies including: (1) exhumation of other equipment, and (2) in-place lysimeter and laboratory-column tests for studying radionuclidic migration in soil.

ANNOTATION: No mention is made of the cover material.

ANNOTATION: Although this article does not deal with trench covers, it is included in this bibliography because it is a source several authors have referred to on the principles of the wick effect which these other authors base the layered trench cover design on.

ABSTRACT: This report presents observations during the excavation of low-level waste buried for 14 years in the humid environment of the Savannah River Plant. The waste was buried in sandy clay soil trenches more than 20 feet above the water table and covered with soil soon after burial. The waste uncovered included wood, steel, plastics, cotton cloth, rubber, and paper. Cardboard boxes not enclosed in plastic were the only materials that deteriorated visibly.

ANNOTATION: Fifteen of the 47 inches of annual rainfall becomes infiltration. The average depth to the water table is 45 feet. A minimum of 4 feet of soil is placed over the wastes as soon as possible after burial.

ABSTRACT: Windscale and Calder Works of the UKAEA is situated in Cumberland on the northwest coast of England. Large volumes of low-activity and suspect active solid wastes arise both from process and laboratory operations. The total quantity is about 1000 tons/yr with an uncompressed volume of about 6000 m³. It is impracticable to use monitoring as a method of segregation into active and inactive fractions. Consequently, all the material must be treated as radioactive waste and disposed of correspondingly. A study of the relative cost of disposal methods has emphasized the expense of pretreatment such as incineration or baling and shown that local burial without treatment is by far the cheapest method of disposal. This method is possible only if a suitable burial site is available close to the origin of the wastes. If this is not the case, pretreatment becomes necessary to ease the transport problems. Such a site exists near Windscale and the wastes are collected in transportable containers designed for dumping operations. These containers are picked up by a special vehicle, taken to the burial site and emptied into a trench. The material is covered with earth as dumping proceeds. Monitoring of water from the site shows negligible activity.

ANNOTATION: Waste is piled to the top of the trench. At least 3 feet of dirt is piled on the waste and then compacted to form a flat surface.
ABSTRACT: The field of ground-water flow and contaminant transport has grown rapidly in recent years. This growth has been in response to an increasing need for ground-water supplies, a need for the evaluation of ground-water resources as input to regional planning and interest on the part of environmental groups and government in protecting these ground-water resources from contamination.

Concern for ground-water contamination has become a major obstacle to many waste disposal projects in Ontario; in particular to sanitary landfiling. Much of this is due to a lack of understanding of this subject by lay people and even by professionals. In this presentation I would therefore like to review some of the basics of ground-water flow, describe how contaminants are introduced into and move with the ground water, give some examples of ground-water contamination problems in Ontario, and suggest some solutions to these problems.

ANNOTATION: The best solution to ground-water contamination from landfills is to prevent the contamination from occurring. No details are given on trench covers.
A SELECTED, ANNOTATED BIBLIOGRAPHY OF STUDIES RELEVANT
TO THE ISOLATION OF NUCLEAR WASTES, v. 1, Oak Ridge Na-
tional Laboratory (ORNL/EIS-156/V1). 450 p.

HIGHLIGHTS: This annotated bibliography of 705 references repre-
sents the first in a series to be published by the Ecological Sci-
ences Information Center (ESIC) containing scientific, technical, eco-
omic, and regulatory information relevant to nuclear waste iso-
lation. Most references discuss deep geologic disposal, with fewer
studies of deep seabed disposal; space disposal is also included.
The publication covers both domestic and foreign literature for the
period 1954 to 1980. Major chapters selected are Chemical and Physi-
cal Aspects; Container Design and Performance; Disposal Site; En-
vironmental Transport; General Studies and Reviews; Geology, Hy-
drology and Site Resources; Regulatory and Economic Aspects; Re-
pository Design and Engineering; Transportation Technology; Waste
Production; and Waste Treatment. Specialized data fields have been
incorporated to improve the ease and accuracy of locating pertinent
references. Specific radionuclides for which data are presented
are listed in the "Measured Radionuclides" field, and specific
parameters which affect the migration of these radionuclides are
presented in the "Measured Parameters" field. The references
within each chapter are arranged alphabetically by leading author,
corporate affiliation, or title of the document. When the author
is not given, the corporate affiliation appears first. If these
two levels of authorship are not given, the title of the document
is used as the identifying level. Indexes are provided for (1)
author(s), (2) keywords, (3) subject category, (4) title, (5) geo-
graphic location, (6) measured parameters, (7) measured radionu-
clides, and (8) publication description.

ANNOTATION: Most citations in this volume deal with deep geologi-
cal disposal and high level waste.

ABSTRACT: Radioactive wastes produced by radioisotope users all over the country are being collected by Japan Radioisotope Association to be forwarded to Japan Atomic Energy Research Institute for final treatment. Low- and intermediate-level liquid wastes from fuel reprocessing plant, which will be constructed in the near future, would be released into coastal sea-water under appropriate control regulations. Many nuclear power plants are under construction and are planned for the near future throughout Japan because of the rapid increase of energy demand for several decades to come. In view of this, it is expected that radioactive solid wastes from the plants will accumulate year by year and exceed the storage capacity at these sites. The final disposal of these wastes is the most important problem to be solved in Japan. The feasibility of both terrestrial and marine disposal is being investigated under the specific conditions of Japan by the committee on radioactive solid waste management of Nuclear Safety Research Association. The problem involves many factors concerning waste treatment and packaging techniques, transportation, ground water, oceanography, fisheries, environmental radiation safety, etc. The land burial of the wastes should not be allowed without careful consideration of the small land area and the high population density and also of the utilization of land by future generations. On the other hand, deep sea disposal should not be considered as an easy solution, because of the high utilization of marine products. To establish a national policy for radioactive solid waste management, the present study was concentrated on various weak points to be overcome, and individual technical questions to be investigated in the light of present knowledge.

ANNOTATION: Land burial is not used extensively in Japan because of a shortage of suitable land. Land burial is discussed in this article, but no details are included on trench covers.
ABSTRACT: None.

ANNOTATION: A test at the Savannah River Plant is discussed in which a bentonite "umbrella" was placed over the top and sides of a trench. The soil was subjected to drying, cracking and shrinkage. The decrease in infiltration was significant.

ABSTRACT: None.

ANNOTATION: Fifty-three papers are grouped under the following headings: general management in the treatment of low- and intermediate-level radioactive wastes, operating experience with existing facilities, and treatment of solid wastes and special wastes. Two of these papers, "Waste Management Practices at Lawrence Radiation Laboratory, Livermore" by Kvam and "The Degree of Treatment Required for Low- and Intermediate-Level Radioactive Wastes to Prevent the Hazardous Pollution of the Environment" by Kenny are cited in this bibliography.

ABSTRACT: None.

ANNOTATION: This document contains 43 papers in the following categories: operation, experience, uptake and migration, site selection, buried solidified wastes, and salt disposal and disposal into deep or porous formations. The 5 papers by Howells, Enders, Merritt and Mawson, Marter, and Beard and Godfrey are listed separately in this bibliography.
ABSTRACT (from COMPENDEX): Fifty-three papers are grouped under the following headings—national waste management policies and experience, operational experience and site policies and developments. The need for standards governing sea disposal and thermal stream pollution is stressed.

ANNOTATION: The five papers in this volume which relate to the problem are cited separately in this bibliography.
ABSTRACT: None.

ANNOTATION: Volume I contains 30 papers in the following categories: policy and planning, removal of gaseous radionuclides, treatment of low-level waste, treatment of hulls and solvent, and solidification of high-level wastes. The paper by Perge, Trice and Walton is listed separately in this bibliography. Volume II contains 31 papers under the following headings: evaluation of solidified, high-level waste products, conditioning medium-level waste, management of alpha-bearing waste, geologic disposal, sea disposal, and burial of radioactive wastes. The three papers by Andrew, Meyer, and Matuszek, Strnisa and Baxter are listed separately in this bibliography.
INTRODUCTION: Early in 1943 the United States Army Corps of Engineers located the Hanford Engineering Works of the Manhattan Project in an isolated portion of the Pasco Basin on the Columbia River Plateau. The successful project launched the United States into the atomic era with its attendant risks and potential rewards of bountiful energy. An early recognized risk was the potential ill effects of exposure of people to excessive levels of ionizing radiation. Therefore, emphasis was placed on isolating radioactive materials.

An early decision was made to isolate radioactive dry wastes and industrial wastes by packaging the wastes and burying them in a trench with at least one to three meters of earth cover. While this method has successfully isolated the dry wastes at Hanford, the adequacy of this method has been subjected to debate. Concern for release of radioactivity into the environment has led to a number of reviews. As a consequence, considerable effort has been expended to assess the environmental impact of burying Hanford radioactive wastes. The results of that assessment are summarized in this paper.

ANNOTATION: The standard cover procedure at Hanford was backfilling the trenches with soil that had been removed from the trenches. Problems occurred from waste compaction, erosion, burrowing animals and deep-rooted plants. Additional backfilling and adding heavy gravel to the covers have decreased the problems.

ABSTRACT: The use of vermiculite columns for the decontamination of low- and intermediate-level waste streams has received considerable attention, primarily because of the good physical properties of vermiculite, its inexpensiveness, and its sorptive properties for cesium and strontium.

The cesium-exchange properties of various grades of commercially available vermiculite were investigated. Elucidation of the reaction mechanism has led to improvement of the cesium-sorptive properties, either by treatment of the vermiculite or by addition of potassium salts to the waste stream.

Studies of the kinetics and thermodynamics of the exchange reaction permit extrapolation of the data for consideration of the extended use of vermiculite columns for decontaminating other waste streams.

ANNOTATION: The use of vermiculite columns for cleaning up radioactive waste streams is discussed. Trenches are not mentioned; however, the use of vermiculite to decontaminate radioactive wastes may have applicability to trench liners.
ABSTRACT: The entry is for an abstract only.

ANNOTATION: No specific mention is made of trench covers.

ABSTRACT: None.

ANNOTATION: This volume of selected papers does not deal with trench cover design.

INTRODUCTION: Nuclear Fuel Services, Inc., has operated a commercial low level radioactive waste burial ground at West Valley, N.Y., since 1963. The NFS facility is one of six commercial burial sites in the United States. Nuclear Engineering Company operates burial sites at Morehead, Ky., Sheffield, Ill., Beatty, Nev., and Richland, Wash. Chem-Nuclear Services operates a burial facility at Barnwell, S.C.

The paper by Daly and Gormly (see this volume), which presented a forecast of solid radioactive waste generation rates, clearly indicates the need for burial sites. Therefore, this presentation will not dwell upon projected waste burial requirements. Rather, it will be restricted to a description of the NFS West Valley, N.Y., waste burial facility, current practices for burial, a summary of NFS's operating experience, and some of the results of testing and monitoring performed to confirm the safety of the operation.

ANNOTATION: This article describes the design of the trenches of the West Valley, N.Y., low level radioactive waste disposal site. Covers include at least 4 feet of backfill under a final cover at least 4 feet thick.
INTRODUCTION: The United States Environmental Protection Agency requested that the New York State Department of Environmental Conservation make an inventory of the radioactive materials buried in the West Valley Site, Cattaraugus County, N.Y. The inventory will be used along with similar inventories of disposal sites in other states to determine volumes, types of radioactive wastes, and the originators of the wastes so that better predictions can be made as to future requirements for low-level burial sites. In addition, an assessment can be made of the potential for future problems from long-lived radioactive materials buried at the site. The inventory was made of over 1,700,000 cubic feet of wastes buried at the commercial site from October 1963 through December 1972. An inventory was also made of over 87,000 cubic feet of wastes from the Nuclear Fuel Services reprocessing plant, licensed by the USAEC, buried in an adjacent area, from 1966-1972.

The greatest volume of waste comes from waste disposal firms and most of these wastes were associated with hospital, institutional and industrial activities. The use of the burial site by nuclear power plants was less than ten percent of the total volume, however, such use is increasing. $^{238}$Pu was the most important isotope buried in terms of quantity and toxicity.

ANNOTATION: A section on the operation of the site is included. It indicates that the wastes were not compacted or covered daily. When the waste reached the original ground surface, four feet of backfill was placed over it. After the trench was filled, an additional 4-foot-thick mounded cover was provided for the entire trench. The mounded surfaces were smoothed periodically to fill in settlement holes and cracks.
ABSTRACT: A history of the water problems encountered at the West Valley, New York, burial site is presented with recommendations concerning operation at this site to prevent migration of radioactivity off site. When a permit to bury wastes was first issued in 1963, the possibility of water ponding in trenches because of relatively impermeable soil was recognized. Water rose persistently in 3 completed trenches in the north burial area, so the permit was revised in 1968 to be more explicit on how the trenches should be constructed to minimize the entrance of water into completed trenches. Water has not risen in the 7 trenches in the south burial area, which were completed in accordance with the revised permit. Water continued to rise in the 4 trenches in the north burial area and in early 1975 water from 2 of these trenches began to seep out through the cover. Three of the trenches were pumped to halt this seepage.

Monitoring of surface streams has indicated no large-scale migration of radioisotopes away from the burial site. However, extraneous sources of radioactivity made it impossible to detect small amounts of seepage. Soil samples taken in 1973 near the trenches confirmed that there was no large-scale underground migration. The borings did indicate the existence of perched ground water near the problem trenches in the north burial area that could result in the horizontal migration of water in or out of trenches. The USGS is now making a detailed hydrogeological study of the burial area. Erosion control and prevention of water from entering completed trenches are the main environmental problems at the West Valley burial site.

ANNOTATION: The West Valley site had problems with cover erosion and water infiltrating into the trenches. This article examines schemes to mitigate the water problems. It was found that the 1.2 m of cover required was insufficient and that a 2.7 to 3.4 m cover (assuming no waste compaction) was needed. In addition, the study found that a single umbrella cover over all the trenches led to more ponding and erosion than did individual covers.

ABSTRACT: This paper reports on a recent survey of the major ocean disposal site for radioactive wastes on the Pacific coast. This site, located near the Farallon Islands (59 km west of San Francisco), was used from 1946 to 1966 for the disposal of containerized, low-level radioactive waste materials. On the order of 47,000 containers were dumped in three areas within the site during its period of activity.

In August of 1974, a survey was conducted by a joint team, Interstate Electronics Corporation and Naval Undersea Center, for the U.S. Environmental Protection Agency. It was performed for the Ocean Disposal Program and the Office of Radiation Programs under a contract to study criteria for the control of ocean dumping. The purpose of the survey was to locate the cannisters and investigate their condition and the condition of surrounding sediments.

The paper addresses the technical and operational problems faced by the combined team and the methods used to solve them. An analysis of the significance of the findings and their implications on the future use of the oceans for disposal of low-level radioactive wastes is provided.

ANNOTATION: This article deals with disposal of low-level radioactive waste by ocean dumping rather than land burial.
ABSTRACT: The Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory is a site for shallow land disposal and storage of solid radioactive waste. It is currently operated for ERDA by EG&G Idaho, Inc. The facility has accepted radioactive waste since July 1952. Both transuranic and non-transuranic wastes are handled at the complex.

This document describes the operational and engineering developments in waste handling and storage practices that have been developed during the 25 years of waste handling operations. Emphasis is placed on above-ground transuranic waste storage, subsurface transuranic waste retrieval, and beta/gamma compaction disposal.

ANNOTATION: Only one page of this article deals with trench disposal. The covers are described as a "minimum of 0.9 m (3 ft) of earth."

ABSTRACT: The recommendations of the International Commission of Radiological Protection are taken as a basis for a general discussion of permissible levels for the disposal of liquid and solid radioactive wastes to the environment.

For the relatively small number of major radioactive disposals, an experimental approach based on the measurement of environmental pollution, which results from preliminary disposals at lower levels than those ultimately envisaged, is recommended. Firm levels are ultimately set in the light of calculated values of irradiation of the public.

For smaller disposals where so elaborate an approach cannot be justified, permissible levels can be calculated from broad general considerations of the dispersal of the waste and the habits of the public. Tentative conservative levels are suggested for the disposal of liquid radioactive waste to sewers and rivers, and for disposal of solid radioactive waste by tipping.

The broad discussion of these methods of the disposal of liquid radioactive wastes to the ground and of incineration of solid radioactive wastes gives some guidance on how these levels may be relaxed in less restrictive conditions. Conversely, where the radioactive content of waste may ultimately appear in articles handled by the public, as when radioactive waste is salvaged, a more restrictive approach is considered essential.

It is emphasized that the strict approach to radioactive health hazards and the painstaking evaluation of irradiation of the public constitute a degree of control not remotely approached with other industrial hazards; and that our knowledge of the effects of ionizing radiation, limited though it may be, enables us to assess the hazards with an accuracy not generally attainable in other fields.

ANNOTATION: A section on burial is included; covers for burial trenches are not mentioned.
ABSTRACT: The aims of United Kingdom radioactive waste-management policy are to ensure that nobody receives a dose of radiation in excess of the appropriate limits recommended from time to time by ICRP, and to reduce the doses as far below those limits as is reasonably practicable. The legal powers to control waste discharges in accordance with these aims are described. For important wastes, the principle of the critical path approach guides the setting of limits for disposal; some examples are described in detail. For small users, a more general approach based on guiding limits deduced from hypothetical worst cases is followed; the limits are given. A few remarks are made on future waste-disposal problems and on the United Kingdom contribution to global problems in this field.

ANNOTATION: This article focused on the laws covering the wastes, especially as they pertain to dosage from a site. Land burial is discussed; trenches are not.
ABSTRACT: The U.S. Geological Survey is conducting research on borehole geophysics, including the application of well logging to the investigation of radioactive waste disposal sites. During the past 14 years, eight such sites have been studied.

Geophysical well logging provides in situ measuring techniques which can be used to supplement conventional coring and water sampling techniques in both site-selection studies and in the monitoring of operating disposal sites. Some of the advantages of well logging over conventional techniques include the relatively large volume of rock investigated and the ability to measure temporal changes. Logging also reduces the amount of expensive coring required. Logs provide a continuous record of data that can be correlated from hole to hole. Data from geophysical logs can be interpreted in terms of lithology, elastic moduli, bulk density, porosity, moisture content, water quality, and the location and orientation of fractures. After a site is in use, borehole geophysics provides a means to monitor changes in moisture content, water level, and radionuclide concentration in either cased or open holes. Water samples, usually taken by conventional methods through wells, provide data only on the permeable intervals below the water table. Gamma spectral logging techniques provide data on the vertical and lateral distribution of contaminants.

Radionuclides that have migrated have been identified at several sites. Detection limits on the order of 0.2 picocuries per gram have been attained for $^{60}$Co and $^{137}$Cs. A number of their gamma-emitting radioisotopes can be identified using in-hole gamma spectrometry.

ANNOTATION: For an open site, boreholes can be used to measure moisture content changes, water table depth, and radionuclide concentration. There is no discussion of trench covers.
ABSTRACT: Five main geological mediums were discussed in detail at the Helsinki International Symposium. Rock salt is best understood, although brine migration theory needs clarification. Research in Swedish granite has usefully defined the probable limit for canister heat output at less than 5 kW, to avoid borehole cavitation. Disposal of intermediate-level wastes by deep hydraulic fracturing of shales is practiced successfully. Principles for selecting disposal sites are being clarified but the prediction of long-term waste behavior and defining what is acceptably safe require further study.

ANNOTATION: This article contains only one paragraph on low-level wastes, and no significant information that is not found elsewhere.

ABSTRACT: This publication describes a mathematical model developed to evaluate non-point source pollution from field-sized areas. CREAMS consists of three components: hydrology, erosion/sedimentation, and chemistry. The publication is presented in 3 volumes: Vol. I, model documentation, describes the concepts of each of the model components; Vol. II, user manual, describes the model application and selection of parameter values; Vol. III, supporting documentation, provides additional data and parameter information.

ANNOTATION: This article does not deal directly with low-level radioactive waste. However, a modified version of the hydrologic model was used for Perrier's and Gibson's model (HSSWDS) which is cited in this bibliography.

INTRODUCTION: Waste concentrates must be disposed of in such a way that any reentry of radionuclides into the biocycle is safely excluded until the radioactivity has decayed to negligible levels. Only in rare cases, a few weeks or months are sufficient for this decay. Usually, many years, sometimes even several hundreds of years and more are necessary for this purpose. Today, several methods exist for the safe final disposal of solid radioactive wastes.

ANNOTATION: Low-level wastes are just dumped in trenches and covered with dirt. Wastes with higher radioactivity are dumped in concrete lined trenches and covered with concrete and dirt.

ABSTRACT: This paper describes the facilities and practices currently involved in medium- and low-level radioactive-waste management at the University of California Lawrence Radiation Laboratory, Livermore. The research programmes of the Lawrence Radiation Laboratory are such that waste disposal includes a complete variety of problems ranging from mixed fission products to transuranic elements.

At a cost of 6-10¢ gal, up to 200,000 gal of liquid waste ranging from $10^4$-$10^8$ dpm/l (5 $x$ $10^{-6}$ to 5 $x$ $10^{-2}$ uCi/ml) are decontaminated annually in the $250,000$ coagulation facility. After breaking emulsions and centrifuging the waste when necessary, the pH is adjusted to 2.5 and an oxidizing environment is provided. Addition of Fe$^{+++}$ and elevation of the pH to 9.0 results in a floc capable of enmeshing or combining with contaminants. Decontamination factors of 10,000 are obtained routinely in batch sizes ranging from 500-30,000 gal.

Although most polyvalent cations respond favourably to co-precipitation, the presence of alkali metals, alkaline earths, and the complex, ninevalence states of ruthenium in the waste require further ion-exchange polishing. After precipitation, the hydroxide floc is partially de-watered with the aid of a rotary-drum filter, giving an overall volume reduction greater than 99.5%. Other liquid disposal techniques in use at LRL, Livermore Laboratory, include phosphate and sulphide flocs, solidification, and solar evaporation.

Over 25,000 ft$^3$ of packaged dry waste are consigned to off-site land burial annually. Packages range from 55-gal drums to waste encapsulated in 20-t concrete coffins. A variety of special Livermore containers, utilizing wood, lead, steel, polyurethane and concrete, are described, together with techniques for their use. A detailed account is offered of the design and operation of a 5-t hydraulic ram for compressing drummed dry waste. Costing only $1500, the press achieves a four-to-one volume reduction and offers significant savings.

ANNOTATION: No wastes are buried at Lawrence Livermore Laboratory. Trenches are not described.
INTRODUCTION: The continuing accumulation of nuclear wastes in temporary storage has become a key element in the arguments for a moratorium by those who oppose nuclear power in the United States. The resolution of this issue and the permanent disposal of nuclear wastes must be the highest priority of our national nuclear energy program.

There are two principal elements of the U.S. nuclear waste management program. The first is the commercial waste disposal program. . . The second element . . . is the effort to dispose of the Department of Energy's nuclear wastes.

ANNOTATION: The paper discusses a Waste Isolation Pilot Plant (WIPP) for disposal of DOE low-level wastes in bedded slats and experiments on high-level wastes. It does not deal with trenches or their covers.
ABSTRACT: The increasing public attitudes and actions against shallow land burial of radioactive waste from commercial power reactors are beginning to be of much concern to the nuclear industry. In order to develop an industry position in regard to these public concerns, an analysis has been made of the geological, areal, and managerial aspects of a typical but hypothetical shallow land burial site.

Our premise has been that there should be two isotopic limits, i.e., inventory and concentration, associated with the shallow land burial of low-level waste from LWR. The study considers several mechanisms whereby the "escape rate of the radioactivity from the waste trench itself" has been estimated. These lead to inventory limitations and are based on such parameters as soil-water equilibrium, time for ion exchange equilibrium to be established, isotope decay in the water-course, rate of ground water flow, and operational spillages.

Our approach to the study of concentration mechanisms includes a consideration of any calculations for potential exposure pathways that involve personal intrusion (excavation, inhalation, ingestion) natural intrusion (wind and water erosion of the burial site) and abnormal events (earthquakes and direct meteor hits). All of these assume institutional control will be lifted after 100 years. From these calculations it has been possible to determine acceptable concentrations for key isotopes by the most limiting pathways.

ANNOTATION: The article looks at various contamination pathways and suggests decommissioning concentrations. The main problem is spill out the top of the trenches, not migration from the trenches. No mention is made of trench cover material or construction.

ABSTRACT: A radioactive waste burial site is operated at the University of Missouri under the conditions of 10 CFR 20.304. Over 90% of the radioactive wastes generated by the laboratories and clients, exclusive of the Research Reactor Facility, are economically disposed of at this site. During the 7-year operation about 200 cubic meters of low-level wastes containing about $1.5 \times 10^6$ becquerels have been buried in 3.6 meter deep by 0.6 meter wide trenches. A radiation surveillance program confirms that radiation levels in the vicinity of the burial site are well within accepted limits.

ANNOTATION: The trench design discussion in this paper does not include the trench covers.

ABSTRACT: The geological and hydrological conditions that exist at Burial Ground 4, now abandoned, are described, and findings with respect to surface- and ground-water contamination at the site are reported. The site was opened in February 1951 and closed to routine burial operations in July 1959. The average rate of burial during this period was about 2-1/2 acres per year. Approximately 50% of the buried waste at the site originated at Oak Ridge National Laboratory, while the remainder was contributed by more than 50 off-site agencies.

The burial ground is underlain by the Conasauga shale of Cambrian age. At the site the formation consists mostly of maroon and gray shales interbedded with a few thin limestone lenses. Water-level measurements indicate that the buried waste is in contact with ground water during most periods of the year. Activity was detected in water samples from a number of wells located in areas of low topography where ground-water contact with the waste is greatest. Radionuclides were also found in seeps and streams within the area. Identifiable contaminants include Ru-106, Co-60, Cs-137, Sr-90, Zr-Nb-95, Po-210, Pu-239-240, and the trivalent rare earths. The contribution of activity from the burial ground to nearby White Oak Creek has been insignificant.

The criteria employed in selecting Burial Ground 5, the methods used in evaluating the site, and a preliminary analysis of a new burial trench are discussed. Forty-five auger wells were drilled to determine the character of the residual cover, the depth of the water table, and the chemical and radionuclide composition of the ground water. Five deep wells were drilled to define the occurrence and circulation of ground water at greater depth. Pressure tests of the deep wells showed that the most permeable zones or fractures occur within the first 100 ft of depth below ground surface. The new burial trench, including a gravel underdrain, collecting sump, observation well, and asphalt cap, was designed to improve monitoring and restrict ground-water and surface-water contact of the waste.

ANNOTATION: The original trenches were covered by backfilling. For burial ground number 5, a new cap design was used which included an asphalt cap. Reports of the new design's effectiveness were not available when this report was published.

ABSTRACT: None.

ANNOTATION: This document includes several summary articles related to its title. The articles include: "The Nuclear Regulatory Commission's Low-Level Waste Management Program" by Michael J. Bell; "ERDA's Role in Low-Level Waste Management" by G. H. Daly; "EPA Activities in Radioactive Waste Management" by David S. Smith; and "Goals and Projects of U.S. Geological Survey for the Study of Solid Low-Level Radioactive Wastes" by Warren W. Wood and George D. DeBuchananne. None of these articles contains any specific information on trenches.
ABSTRACT: A simplified mathematical model for analyzing the migration of leachate and radioactive material contained in radioactive waste burial trenches is presented. A differential equation describing the distribution and movements of radioisotopes is analytically solved, assuming a constant flux of trench water infiltrating into a saturated porous medium which is not an aquifer. The calculated lateral migration for tritium as titrated water agrees well with field measurements, using a realistic value of the water velocity and an adjusted dispersion coefficient. For strontium, however, the fit results in an inordinately small distribution coefficient. Migration in silty till appears to be insignificant relative to the projected 1000-year storage time due to low permeability and radioactive decay.

ANNOTATION: At the West Valley, New York, site there is 28 m of silty till which is a very fine-grained, heterogeneous mixture of clay and silt with minimal amounts of sand and stone. The till is dense, compact, moist and water-saturated. The model assumes constant flux and saturated conditions. This article deals mostly with the model development and results.

ABSTRACT: Selection and design of cover for solid/hazardous waste landfills usually require engineering planning for efficient accommodation of the volume of incoming waste within certain moderate to severe constraints. The foremost constraints are usually the amount and characteristics of cover material available in the immediate vicinity. Local soils available in adequate amounts seldom have the best characteristics for the several cover functions, e.g., they are too clayey or sandy.

Several steps are recommended for effective planning of cover. First, identify the primary and secondary functions to be served by the cover and establish relative importances, e.g., impeding water percolation is more important than supporting vegetation, etc. Second, use data on soil properties in terms on the Unified Soil Classification or the U.S. Department of Agriculture systems to rate available soil for effectiveness in the various functions. Third, specify certain design procedures in the disposal operation for circumventing the deficiencies of the selected cover soil. Placement procedures, such as compaction, will improve the soil for certain functions. Elsewhere, the soil properties favorable for one function are unfavorable for another, e.g., a clayey cover soil impeding water percolation will prevent leakage of decomposition gases that may be desired. Fourth, where a single soil cannot serve contrasting cover functions, the designer may incorporate features, such as layering, or can resort to the use of special non-soil materials and additives.

ANNOTATION: The study was directed toward municipal, industrial and hazardous wastes, and does not cover radioactive wastes. The study does not include examples of final covers, but discusses soil tests for picking cover soil, slope stability, cover cracking, etc.
ABSTRACT: A critical part of the sequence of designing, constructing, and maintaining an effective cover over solid and hazardous waste is the evaluation of engineering plans. Such evaluation is an important function of regulating agencies, and accompanying documentation can form one basis for issuing or denying a permit to the owner/operator of the waste disposal facility. This manual describes 36 steps in evaluation of plans submitted for approval. Generally, the evaluator considers available soils, site conditions, details of cover design, and post-closure maintenance and contingencies.

ANNOTATION: The manual is written for use by persons evaluating sites, not operators. It suggests what information to look for but does not generally include design specifications.
INTRODUCTION: The Hanford Reservation occupies about 570 square miles of the southeastern part of the state of Washington. In early 1943, the United States Army Corps of Engineers selected the Hanford site as the site for reactor and chemical-separation facilities for the production and purification of plutonium. The separation and waste-management facilities are located on the 200 Area plateau about seven miles from the Columbia River. The area is semi-arid, receiving less than seven inches of precipitation annually, and the water table is 150 to 300 feet below the ground surface. Favorable ion-exchange properties of the soil aid in the retention of radionuclides.

ANNOTATION: This paper describes a planned program and results were not yet available at the time the paper was presented.

ABSTRACT: Solid radioactive waste has been buried at the Savannah River Plant since 1953. The waste, consisting of equipment and material contaminated with fission products, activation products, and transuranic isotopes, has been buried in unlined earthen trenches above the water table. A total of 1,500,000 Ci of fission and activation products and 9000 Ci of transuranic elements have been buried through 1966. Materials containing long-lived transuranic isotopes such as $^{239}$Pu are encapsulated in concrete to permit retrieval for more permanent storage. The average cost of all land burial is $35.00/m^3$, but burial of transuranic isotopes is higher because of concrete encapsulation. Disposal of high-activity gamma waste is also more costly because of increased handling problems. In thirteen years, no radioactive materials have been detected in ground water underlying the burial trenches, and no significant amounts are expected to outcrop at the surface on the flood plain of a Savannah River tributary.

Low-level liquid wastes, mainly from chemical separation areas, are discharged to connected earthen seepage basins. Water level in these basins remains essentially constant because seepage and evaporation are about equal to the volume of rainfall and the influent liquid waste. Liquid wastes are analysed both before and after disposal in seepage basins. Procedural release guides limit the amount of each isotope discharged because certain long-lived isotopes, such as $^{90}$Sr and $^{137}$Cs, could eventually outcrop at a Savannah River tributary. A total of 1500 Ci of fission products (exclusive of tritium) and 13 Ci of transuranic elements have been committed to seepage basins. Only tritium oxide (a ternary fission product) has been detected in a surface stream. This occurred where the seepage basins were close to a stream. The soil surrounding the basins has an ion-exchange capacity that delays the movement of radioactive materials other than tritium oxide. The long travel time to reach a stream, and limits on amounts discharged to the basins, limit the amount of radioactive material in the off-site environment to levels that will result in exposures far below those set by the Federal Radiation Council. Seepage basins cost about $0.25/m^3$ to construct, and experience indicates that the useful life of a basin is greater than 10 years.

ANNOTATION: Alpha waste is covered with earth immediately after burial; low-level beta-gamma wastes are covered with earth as needed. All wastes receive a final cover of about 2 meters.

INTRODUCTION: Much attention is being focused at this time, both in Government and private sectors, on the management and disposal of commercial high-level radioactive wastes, including spent fuel. While past interim storage techniques for high-level waste appeared adequate at the time, and do not seem to have caused any significant health hazards to date, efforts are needed to develop and implement disposal methods to assure environmental protection from radioactive wastes.

Resolving the problem of disposal of radioactive wastes requires satisfactory execution of three important programs: (1) statement of requirements for protection of the environment and public health; (2) development of technologies and sites, and the conduct of operations for disposal of radioactive wastes that can satisfy environmental and public health requirements; and (3) regulation of activities at specific sites to assure overall safety, including environmental and public health protection. The responsibility for the first program lies with EPA; the latter two are the responsibility of the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC), respectively, and are the larger parts of the overall process. Although EPA's job is the smallest of the three, it may well be the most difficult and important part because the statement of environmental and public health requirements can greatly influence the development of both the technology and the regulation of sites and operations. For this reason, promulgation of environmental standards, among all the activities scheduled in the President's Nuclear Policy Statement of October 27, 1976, was set for very early completion.

The public is apprehensive about radioactive wastes, primarily we believe, because of their concern about possible impacts on the environment and public health over long periods of time, and the fact that there are as yet no stated requirements to limit such impacts. Any apprehensions about developing technical approaches or regulating their application do not appear to be nearly as strong as the environmental and public health impacts.

ANNOTATION: Only minor reference is made to low-level waste and that concerns development of a model to determine radioactive pathways. No mention is made of trench covers.
ABSTRACT: A commercial radioactive waste burial site has operated since 1963 at the Western New York Nuclear Service Center. Solid low-level radioactive wastes are buried in trenches excavated from a very fine-grained heterogeneous mixture of silt and clay (silty till) and are then covered with the excavated material. Despite many operational precautions, water levels in three burial trenches rose to within a few centimetres of the covering material by late 1973. Activity levels of HTO, \(^{90}\)Sr, and \(^{137}\)Cs in trench water and core samples were measured to obtain preliminary information on the degree of subsurface radionuclide migration from the burial trenches into the surrounding soil. Tritium concentrations measured in void-space water from vertical cores appeared to peak in the cover material 1.5 to 2 m below the ground surface. Concentrations of \(^{90}\)Sr and \(^{137}\)Cs in the silty till were greatest near the surface of the cover material. Concentrations of HTO and \(^{90}\)Sr, measured in a series of slant-hole core samples collected until the trench was intercepted, showed tritium migration to have progressed less than 0.3 m, while \(^{90}\)Sr migration appeared to be somewhat less. The preliminary data suggest that: (a) radionuclide migration from the burial trenches into the undisturbed silty till is slight; (b) radioactivity in the surface soil is not necessarily caused by migration of trench water; (c) groundwater movement is not massive; (d) rainwater infiltration, with settlement and compaction of buried wastes, is the most likely cause of rising trench water levels; and (e) surface contamination may occur from spills during burial operations, from trench digging, and from deposition of stack effluents from a nearby nuclear fuel reprocessing plant. By January 1975 the steadily rising water levels in three trenches were approximately 1 m above the undisturbed soil from which the trenches were excavated, resulting in increased radioactivity levels in local streams draining the site. To lower the trench water levels below that of the undisturbed soil, water was removed from the trenches, treated to reduce activity levels, and released to local streams. The estimated maximum individual total body dose for the release was \(3 \times 10^{-4}\) mrem for an individual served by the nearest public water supply. The total-body population dose, integrated for an estimated population of \(2 \times 10^6\), was \(3 \times 10^{-1}\) person-rem. Statistically, according to the BEIR Committee risk estimates, less than \(10^{-4}\) deaths would be expected to occur from this discharge. Dose estimates indicate that continuous discharge of untreated trench water from the low-level radioactive waste burial site would not produce a statistically significant health effect.
ANNOTATION: After each 30 m segment of trench was filled, it was covered with one meter of excavated earth (silty till). When the trench was filled, the excavated till was redistributed over the trench and compacted to a depth of 2.5 meters. This was graded and seeded to reduce infiltration.
ABSTRACT: Offsite release of relatively small amounts of radioactivity from waste burial sites has conflicted with public expectations of "zero release," resulting in efforts toward development of more rigorous management and site selection criteria. The studies at the commercial burial facility at West Valley, New York, are aimed at developing a generic, predictive pathways model which may be used for the selection of future sites and for the development of remedial measures at existing sites.

In order to define radionuclide transport to the environment from the burial trenches via groundwater, surface-water, atmospheric, and biological pathways, comprehensive field and laboratory investigations were begun in 1975 at the West Valley site. Groundwater circulation in the clayey, silty till that underlies this site appears to be very slow with the possible exception of the circulation in weathered, fractured till near land surface. The most significant pathway for uncontrolled releases of radioactivity to the environment appears to be overflow of the trenches and emanation of gaseous $^3$H and $^{14}$C through the trench cover.

A simplified, one-dimensional mathematical model has been developed for preliminary analysis of the subsurface migration of leachate and radioisotopes from a trench. Calculated rates of migration of $^3$H and $^{90}$Sr agree reasonably well with data from one test hole. Prediction of long-term water transport of long-lived radionuclides, such as $^{14}$C and $^{239,240}$Pu requires further data.

ANNOTATION: The authors state that "for management in the short term, improved trench cover design and precompaction of waste deserves attention." There is currently a problem with infiltration and gas relief through the covers. A model has been made for the West Valley site which uses the permeability of undisturbed material to set the specification for the hydraulic conductivity of the trench cap. Waste compaction is estimated so that the specification for the strength of the cap can be set.
ABSTRACT: The nuclear industry is faced with serious problems in the transportation and burial of low-level radioactive wastes. Soaring burial costs, state regulations regarding transportation routes, and lack of direction from regulatory agencies are problems that must be resolved.

In order to gain control of this situation, four major steps must be taken. First, states must accept their share of responsibility in the "waste" problem. Regulatory agencies must recognize the seriousness of the problem and develop a schedule for action. The nuclear industry must assert in a positive manner regarding the safety of nuclear power, and the low-level waste burial ground situation must improve.

ANNOTATION: The need for more low-level waste disposal sites is discussed. No mention is made of infiltration problems or trench covers.

ABSTRACT (from COMPENDEX): Current problems in the management of residual fuel structural material, high level waste, low-level solid waste, slightly contaminated process wastewater, loaded process off-gas and ventilation filters, and discarded process equipment, are discussed. Disposal of spent fuel as waste and factors relating to a federal repository for either storage or disposal of solids and other wastes are also examined.

ANNOTATION: There is little mention of low-level radioactive waste and no mention of trenches.

ABSTRACT: The citation is for an abstract only.

ANNOTATION: The paper presented a general method that can be applied to determine disposition criteria for any decommissioned low-level waste burial ground.
ABSTRACT: The ultimate disposition of decommissioned low-level waste (LLW) burial grounds depends upon the degree and type of waste inventory remaining and the containment of the waste. Examination of existing guidelines and regulations has led us to the conclusion that there is a need for a general method that can be applied to determine disposition criteria for any decommissioned LLW burial ground. This method should be sufficiently flexible to accommodate various radionuclide mixtures and site-specific features unique to any burial ground. The term "disposition criteria" for buildings or sites with surface deposits is defined as residual radioactive contamination levels acceptable for public use of the decommissioned facility. For a burial ground where subsurface radioactive inventories remain, the disposition criteria consist of a combination of institutional controls, stabilization techniques, and property use restrictions for the general public. The acceptability of the disposition criteria is determined based on a maximum annual dose limit. All important potential exposure pathways are considered for a maximum-exposed individual residing at a burial site in determining the disposition criteria. Four potential release agents are considered for a decommissioned LLW burial ground: geomorphological, hydrological, biological, and human activity. The major geomorphological process addressed is surface erosion. The hydrological release agents include ground water migration and surface water runoff. Transfer of the waste via biological mechanisms is accounted for in the food pathways, and an excavation scenario is devised to examine the importance of human activity. Example disposition criteria for a generic LLW burial ground located at two reference sites are presented. The two locations are representative of an arid western and a humid eastern site.

ANNOTATION: The disposition criteria is based on a "maximum annual dose" approach, using numerous computer runs and many assumptions. The trench covers are assumed to be 1 or 2 meters thick.

ABSTRACT: Ion exchange, gel filtration chromatography, and gas chromatography-mass spectrometry analyses have demonstrated that ethylenediaminetetraacetic acid (EDTA), an extremely strong complexing agent commonly used in decontamination operations at nuclear facilities, is causing the low-level migration of cobalt-60 from intermediate-level liquid waste disposal pits and trenches in the Oak Ridge National Laboratory burial grounds. Because it forms extremely strong complexes with rare earths and actinides, EDTA or similar chelates may also be contributing to the mobilization of these radionuclides from various terrestrial radioactive waste burial sites around the country.

ANNOTATION: This study describes the burial trenches and pits at Oak Ridge National Laboratory where the bedrock is shale and precipitation is the highest of any low-level radioactive waste burial ground. No specific information is given on the trenches or their covers.

ABSTRACT: The soil at Chalk River is quite shallow and consists mainly of sand. It has a low exchange capacity, but is very permeable. Large disposals of radioactive wastes have been made into this soil, in solid and liquid form, both experimentally and as part of the normal waste management programme. The experiments included the pumping of cilocurie amounts of mixed fission products, dissolved in nitric acid, into soil pits. An emergency disposal of mixed fission products suspended and dissolved in water, resulting from a reactor accident, was also made directly into the sand. The geology and soil structure are known in considerable detail, and the hydrology of the region around the waste management areas has been studied intensively. A description is given of the rate and direction of movement of radionuclides through the soil, and particularly in the ground water. It will be shown that, even under the difficult conditions at Chalk River, direct disposal into the ground has been both convenient and safe. The amount of ground used has been small, and movement of radionuclides through the soil has been extremely limited. Decay of radionuclides during their slow movement makes ground disposal a safe operation if ground conditions are adequately known.

ANNOTATION: At Chalk River, low-level wastes were compressed in a trench and covered with sand. High-level wastes and liquid wastes are also discussed.

ABSTRACT: This entry is for an abstract only.

ANNOTATION: The six commercial low level radioactive waste disposal sites are discussed. The data and conclusions based on the data are not given in the abstract. There is no indication whether trench covers are discussed in the paper.

ABSTRACT: Low-level nuclear fuel cycle wastes are being disposed of at six commercially operated sites in the United States of America. Similar wastes resulting from Federal activities are being disposed of at five Federally operated sites. The hydrology, geology, climate and operational practices at these sites vary greatly. At three sites in the wetter eastern United States which have low-permeability burial media, it is difficult to keep water from getting into the trenches. Two commercial burial sites in New York and Kentucky have not performed as planned. Authorization to operate these facilities was based on site analyses which, it was believed, demonstrated that the buried radioactive wastes would not migrate from the site during their hazardous lifetime (i.e., for hundreds of years). In ten years or less, however, radioactivity has been detected off-site from these two sites. Radioactivity has migrated offsite from the Federal burial site at Oak Ridge National Laboratory, also State and Federal authorities have stated that the radioactivity in the environment around the site was not a health hazard at this time. Information is presented on recent disposal practices and experience at these three low-level burial facilities. Based on this experience, the paper (1) briefly describes operations and problems at the sites; (2) suggests factors which led to the problems; (3) identifies problems which appear to be generic to disposal in humid climates; (4) identifies specific problems which could either reduce the ability to predict the impact of disposal operations or reduce the retention capability of the site; and (5) recommends improvements which can be made in site selection, development, and operation to reduce the environmental impact of the site.

ANNOTATION: At Maxey Flats, West Valley and Oak Ridge, a common operational practice has been to cover the waste with earthen material to form a cap. The caps were usually of higher permeability than the trench material and allow infiltration. The author concludes that changes must be made in site operation to avoid the types of problems that have occurred in the past. New cover designs are not discussed.

ABSTRACT: The EPA is evaluating the potential environmental impact and risk to man from disposing of low-level radioactive waste (LLW) in the ground. A generic model is being developed to simulate the interaction of a variety of LLW types and land disposal methods and operations with the natural characteristics of the site and their potential impact on the environment. Shallow land burial will be used as a base case. This model will be an important tool in EPA's work to develop environmental standards for LLW. This paper presents the general objectives, information requirements, components and pathways considered in the environmental assessment model and some considerations in developing the model.

ANNOTATION: This paper focuses on the development of the model. Hydrogeological characteristics of the trench cover are included in the data required by the generic model. Conventional and improved shallow land burial schemes are considered. The conventional scheme assumes a cover 1 m thick while a 2-3 m cover is assumed for the improved design.

ABSTRACT: Although alternative methods may be developed for disposal or management of some low-level radioactive wastes, shallow land burial will probably remain a primary management method for these wastes for the next ten to twenty years. This paper, which is oriented toward the technical and philosophical aspects of land burial, discusses today's sites, reviews projections for quantities of new wastes, and identifies technical problems and basic management issues which may influence the future development of land burial techniques and sites.

Specific information is presented on the general performance of selected burial sites, projections of the availability of burial space to the year 2000, problems associated with present and future wastes, problems encountered at burial sites, and research and development work being conducted by the U.S. Environmental Protection Agency (EPA) at burial sites. The relation of EPA's work on the ground disposal of low-level radioactive waste to research and development being conducted by other Federal agencies is also discussed.

Finally, a listing is given of certain basic management issues which should be resolved before shallow land burial can be fully implemented at the level needed to support the growth of nuclear power expected during the last quarter of this century.

ANNOTATION: Trench caps are usually more permeable than the original soil and rock, causing increased infiltration and ponding. No suggestion for a solution is given.
ABSTRACT: None.

ANNOTATION: At Sheffield, trenches are 200-500 feet long, 50-60 feet wide and 20-25 feet deep and are spaced at least 10 feet apart. Material excavated to build the trenches forms the immediate and final cover. The final cover is composed of at least 3 feet of clay compacted to 90% of its original density. Additional soil is placed on top to get the desired height and contour and to provide material for reseeding.

ABSTRACT: None.

ANNOTATION: This document includes four summary articles: "Overview of the Migration Problem" by Donald Jacobs; "Physical Migration of Radionuclides in Soil" by A. R. Jarrett and J. S. Brenizer; "Chemical Migration of Radionuclides in Soil" by Frank L. Parker and James L. Grant; and "Radionuclide Migration Resulting from Site Intrusion" by Vern C. Rogers. The first two articles do not mention trench covers. The second two are annotated separately in this document.
INTRODUCTION: It is paradoxical to consider that, whereas the prime object of waste or tailings disposal methods is to store SOLIDS and to confine them, our problems are largely caused by WATER. In Canada, this factor is compounded by our relatively humid climate.

Consequently, the main emphasis in geotechnical engineering design must be directed to control of possible water impoundment, to control of possible seepage, and to confinement of such seepage to designated local areas. The management of seepage is especially important with uranium tailings since radioactive matter, such as radium 226, is normally leached out of the waste due to the action of precipitation and ground water.

Placing emphasis on seepage necessitates an appreciation, not just of the environment in regulatory terms, but of the local engineering geology; definition of the potential problems of the waste disposal site area; engineering design to accommodate and treat the potential problems and to allow for future abandonment; management and monitoring of construction in keeping with the design.

The principles noted above are examined by reference to the hazards and to concepts of the design and construction of tailings disposal areas.

ANNOTATION: This article deals with uranium tailings which are disposed of in ponds; trench covers are not mentioned.

ABSTRACT: The results of environmental monitoring of radioactivity levels near the Maxey Flats Radioactive Burial Site are reported. Radioactivity measurements were made to identify and quantify radionuclides released to the environment from the site and to identify the exposure pathways to people in the immediate area. Environmental media that were sampled for analysis included surface water, stream sediment, well water, milk, and vegetables. Specific analyses were for $^3$H, gamma-ray emitters, $^{90}$Sr, $^{226}$Ra, and $^{238,239}$Pu.

Radionuclide levels in the vicinity of the site were quite low. Tritium from surface runoff and the site evaporator was the most abundant radionuclide and was the major source of exposure to people in the area. The potential dose to individuals ingesting water, milk, and vegetables at the observed $^3$H concentrations was estimated to be less than 0.5 mrem/jr.

ANNOTATION: No mention is made of trench covers.

PREFACE: As an integral part of the overall Atomic Energy Commission waste disposal development program, working meetings are held from time to time to provide workers in the field an opportunity to discuss first-hand new developments and problems in a specific area of the field. . . . Approximately 50 people, including representatives from England, France, Italy, Belgium, India, and the International Atomic Energy Agency, participated in technical discussions related to ground disposal of various types of radioactive wastes in the United States and other countries.

Detailed panel discussions were held on hydrogeology, geochemistry, waste injection and solid waste disposal. Operating data from ground disposal operations at Hanford, Oak Ridge, National Reactor Testing Station, Broodhaven and Chalk River, Canada were also presented.

ANNOTATION: This is a collection of 43 papers, seven of which are listed separately in this bibliography.

INTRODUCTION: More than 7,000,000 cubic feet of low hazard potential solid radioactive waste from the 15-year-old nuclear energy industry have been buried in the continental United States in shallow trenches at government-controlled Atomic Energy Commission installations. Throughout the atomic industry today, there are over four thousand establishments—ranging in size from the largest Commission production sites through modest commercial and industrial isotope users to small hospital and university research laboratories—performing operations that result in the generation of increasingly large amounts of solid radioactive materials that must be painstakingly handled, safely packaged and often transported long distances. The wastes are characterized by a wide variety of chemical content and toxic types, and generally by low concentrations of activity.

The management and disposal of this large volume of useless material, of varying activity, from the nation-wide nuclear energy and radioisotope program poses no single problem with a single solution. The problems vary widely depending upon the nature, concentration and quantity of radioactivity involved, and on the specific environment in which the material will ultimately repose. Safety factors and hazards must be carefully considered at each step in the disposal system which involves packaging, shipping, handling, monitoring and burial.

ANNOTATION: A good history of early U.S. low-level waste disposal sites and activity is included. Trenches are mentioned many times; trench covers are not discussed.
ABSTRACT: Safety and cost information are developed for the conceptual decommissioning of commercial low-level waste (LLW) burial grounds. Two generic burial grounds, one located on an arid western site and the other located on a humid eastern site, are used as reference facilities for the study. The two burial grounds are assumed to have the same site capacity for waste, the same radioactive waste inventory, and similar trench characteristics and operating procedures. The climate, geology, and hydrology of the two sites are chosen to be typical of real western and eastern sites...

The basic decommissioning options considered in the study are site/waste stabilization followed by long-term care of the site, and waste relocation.

Site/waste stabilization involves the use of engineered procedures to reduce the rate and extent of radionuclide release from buried wastes left in place after site closure. Three stabilization plans are evaluated for each reference site. The plans correspond to varying levels of effort that may be required to properly stabilize a site. The minimal plan assumes that stabilization has been an integral part of normal site procedures during burial ground operations and, therefore, only minor effort is required to prepare the site for long-term care. The modest and complex plans correspond to increasingly greater needs for site/waste stabilization before the site is turned over to a government agency for long-term care.

ANNOTATION: For the generic burial ground described, the trench is assumed to be filled with waste to within 1 meter of the surface. The top meter is filled with soil and a cap is mounded to 1 meter above grade. The final cover is of low permeable material and seeded with shallow rooted plants. The dominant release mechanisms for the western site are human activities and wind erosion. At the eastern site the mechanisms are human activities, hydrological releases (infiltration and overflow) and wind erosion. The modification of trench covers suggested for stabilization of the site is to thicken the cap. A good summary of existing sites is included. Several stabilization techniques are outlined that would interfere with the transport mechanisms.

ABSTRACT: None.

ANNOTATION: A very small part of this report deals with low-level wastes; it indicates only that solid low-level wastes are buried.
ABSTRACT: No regular abstract was given.

ABSTRACT OF PRINCIPAL FINDINGS: 1. The Panel on Land Burial believes no measurable harm to human health has resulted from the past and present practices in the land burial of solid low-level radioactive waste at the sites managed by the U.S. Atomic Energy Commission (AEC) (now the U.S. Energy Research and Development Administration, or ERDA). 2. The Panel is not satisfied that the plan to exhume and rebury the presently buried solid low-level transuranium radioactive waste can be accomplished without a measurable degree of hazard to the employees so engaged. We see no merit in the concept. As a consequence of our concern, we urge a reexamination and a reevaluation of the possible risks and possible benefits to be obtained before such a project is undertaken. 3. While the Panel believes that there has been, and will be, no measurable harm to man from past and present practices of land burial of solid low-level radioactive waste, we are not convinced that current practices should be continued indefinitely into the future. As a consequence of the large volume of such waste anticipated in the near future from the commercial nuclear industry, we believe that a strong effort should be directed toward improving old, or developing new volume reduction technique prior to final disposal. These efforts are essential, because the amount of available land suitable for use for waste burial is limited in many parts of the United States. Otherwise, it may be impossible to meet future demands for space. Additional study and improvement of the transportation system for waste is also basic to this concept. 4. This Panel also urges that there be an economic and technical reassessment of and research into the methods for recovery of useful fissile and non-fissile materials that can be recycled into the energy chain or used otherwise. 5. The comments of this Panel, in accord with our charter, are primarily directed at the past and present practices of the U.S. Energy Research and Development Administration. However, they must also be construed as pertaining to other governmental agencies at all levels. These include not only federal agencies, but also those of state and local governments. 6. This Panel is seriously concerned with the land burial problem that will present itself with the dismantling of present commercial nuclear power reactors as they become obsolete and are replaced. We believe much more thought must be given to the design of the fabric or basic structure of the buildings housing future commercial power-generating reactors, in order that their useful life can be extended even though their internal operational parts are replaced.

In other words, the Panel believes that reactors and other nuclear facilities should be specifically designed so that the radioactive
parts of the power plant or other functional parts of the system could be removed and replaced at the end of their useful life without having to destroy or abandon the shielding, building walls, and other portions of the total facility. In this way, the future need for the disposal of solid low-level radioactive waste may be substantially reduced. Safe dismantling of the present monolithic, nearly indestructible structures of contemporary commercial nuclear power-generating stations presents a most difficult task. The methods for separation of the radioactive fraction of the debris from these structures for disposal cannot be considered lightly. This problem includes the dismantling and decommissioning of commercial nuclear power reactors, as well as of other commercial and ERDA nuclear facilities. The problem has not been discussed or presented in the body of this report, but is a general concern of the Panel.

7. The Panel is aware of ERDA's policy of not establishing any unnecessary additional land burial sites for solid low-level radioactive waste. Because of the anticipated volume of such waste to be produced in the foreseeable future, the Panel believes that this policy should be reconsidered in connection with current and long-term needs of the nuclear industry and in view of all other recommendations of this report and other current developments. 8. At present, ERDA has set an upper limit of 10 nanocuries of transuranium nuclides per gram of waste; above this level, waste cannot be buried. This limit was empirically established by referring to a range of radioactivity produced by natural radium in the earth's crust. The Panel believes that this criterion needs further careful study and evaluation, because the original assumptions may be modified by more recent data on the biological and ecological effects of low levels of radiation for occasional or long-term exposure. The Panel understands that ERDA initiated a study of this question in September 1975, which should be completed in early 1977. The results of this study should be reviewed critically by outside experts at that time. 9. The Panel believes that a permanent final repository for solid waste contaminated with transuranium nuclides must be established without delay. This will obviate the undesirable "20-year retrievability" program for such waste and will materially reduce hazards to the handlers and operators. 10. The Panel believes that the amount of all radioactive material that escapes from burial sites to the public domain must be monitored continually and reported periodically and frequently to the public. The Panel also believes that such reporting of leaks to the public needs to be accompanied by better public education or information on the nature of the potential hazards involved. 11. The Panel believes that a careful study should be made of the actual rate of migration of transuranium nuclides under a wide range of field conditions (e.g., humidity, soil type, concentration, type of effluent, etc.). 12. The Panel has noted that in the past, not enough thought or study has been given to the selection of sites for the near-surface burial of solid low-level radioactive waste.
It has given a list of types of information needed for complete characterization of potential sites before introduction of radioactive waste should be permitted. 13. The Panel notes that the present annual rate of production of solid low-level radioactive waste at ERDA sites (measured by volume) is approximately equivalent to the volume of solid waste produced annually by a representative town in the United States with a population of 55,000. The amount of commercial solid radioactive waste now being produced (1976) is about the same, but will increase dramatically. 14. The Panel has made a series of recommended general principles for the burial of radioactively contaminated solid waste.

ANNOTATION: This volume describes most of the government-owned low-level radioactive waste sites. Little specific information is given on the covers; most were simply backfilled and compacted. At Los Alamos, the covers are made of crushed tuff and soil, while at Hanford the cover is a mixture of gravel, fine sand and silt, which reduces the radiation level.

ABSTRACT: One of the few sites available to Escambia County, Florida, for use as a sanitary landfill has a good supply of soil resource materials but is in a sensitive environmental setting requiring non-degradation of a nearby body of water. Special engineering features are needed to meet these stringent environmental requirements. These features include:

- A drainage of the shallow (perched) groundwater,
- A clay-rich liner to act as a filter for contaminants in the landfill leachate, and
- An infiltration limiting cover to reduce the volume of leachate produced.

The proposed design uses resource materials available on the site to construct a layered cover system incorporating subsurface drainage and extensive erosion control measures to limit infiltration through the cover to less than 1.6 cm (0.6 inches) of water per year. Other available materials from the site are proposed for a liner/filter designed to transmit the small quantity of leachate produced and to attenuate contaminants in the leachate. Hydrogeologic and geochemical calculations develop expected concentrations of 19 parameters at various points in the hydrologic system. These calculations show that the sensitive body of water will not be degraded.

ANNOTATION: The cover design uses a minimum of 6 inches of topsoil over at least 2 feet of sand and 2 feet of compacted clay. Peripheral drains are used between the sand and clay layers. This cover has not been used long enough to be evaluated.

ABSTRACT: The centralized treatment and disposal of radioactive wastes in Norway is carried out at the national nuclear research institute, which was established in 1948 at Kjeller, near Oslo. At present, approximately 500 people are employed at Kjeller and Halden. Although the quantities of wastes generated are small compared with countries with an extensive nuclear energy program, wastes of varied composition and activity levels are procured from the operation of hot laboratories, pilot-plant processing and radioactive materials, reactor-operation (2 and 20 MW), and isotope production. The developments in waste management and treatment from 1948 to 1965 was presented at the IAEA Symposium in Vienna, in December 1965.

In the last five-year period the increased activities on projects concerned with prototype fuel testing, post-irradiation examination, reprocessing pilot plant and isotope production necessitated improvements in waste treatment and disposal. The authorized maximum permissible discharge of low-level liquid waste to the River Nitelva was increased to 2 Ci (weighted) 30 d after the installation of an effluent pipeline, which improves the dilution and dispersal of the activity. Safety assessments show that solidified wastes can be disposed of by shallow land burial within the Institute site, and permission has been granted to dispose of one thousand drums containing approximately 250 Ci. The plant for waste processing and storage has been modified and improved. Shielding has been reinforced, and new equipment installed for remote operation, decontamination, and ion-exchange resin transport and storage. Wastes with contact dose rates of 10 R/h are now satisfactorily processed, compared with the 1-R/h level for which the plant was originally designed. Although the waste-treatment plant is relatively simple in design, it has proved to be flexible and reliable in operation. The cost of modifications and new plant equipment amounts to approximately N.Kr. 200 000 ($28 000) which corresponds to 25% of the initial plant capital cost.

ANNOTATION: This article concentrates on treatment of waste rather than final disposal. The waste was buried in a dense clay that had "good shielding properties."
Nuclear Regulatory Commission. 1977. "PUBLIC COMMENTS AND TASK
FORCE RESPONSES REGARDING THE ENVIRONMENTAL SAFETY OF
THE REPROCESSING AND WASTE MANAGEMENT PORTIONS OF THE
LWR FUEL CYCLE." NUREG-0216. 425 p.

FORWARD: On October 18, 1976, the Nuclear Regulatory Commission
published in the Federal Register a notice of a proposed revision
to Table 5-3 of 10 CFR Part 51 and announced at the same time the
availability of the document on which the proposed revision would
be based—"Environmental Survey of the Reprocessing and Waste
Management Portions of the LWR Fuel Cycle" (NUREG-0116). This
notice solicited comments on the proposed rule change and on the
accompanying impact analysis in NUREG-0116. December 2, 1976,
was set as the end of the comment period, but comments were re-
ceived as late as January 20, 1977.

This present document contains responses by the NRC Task Force to
the comments received. These responses are directed at all com-
ments, including those received after the close of the comment
period. The Task Force also provides herein additional informa-
tion on the environmental impacts of reprocessing and waste man-
agement which has either become available since the publication
of NUREG-0116 or which adds requested clarification to the
information in that document.

This document (NUREG-0216) is intended as a part of the record in
support of the proposed rule, and taken together with the original
survey (WASH-1248) and the additional analyses published in NUREG-
0116, it provides the record upon which the Commission bases its
decision with regard to the proposed rule.

ANNOTATION: The comment was made in this document that in prac-
tice waste trenches are sometimes filled to ground surface level,
while in theory approximately the top 5 feet of the trenches are
not filled with waste. The problem of upkeep of trench covers and
infiltration through covers is mentioned by one commenter.
ABSTRACT: White Oak Creek and Melton Branch tributary surface streams flow through the Oak Ridge National Laboratory (ORNL) reservation and receive treated low-level radioactive liquid waste which originates from various Laboratory operations. The streams receive additional low-level liquid waste generated by seepage of radioactive materials from solid-waste burial grounds, hydrofracture sites, and intermediate-level liquid-waste sites. Over the years, various liquid-waste treatment and disposal processes have been employed at ORNL; some of these processes have included: settling basins, impoundment, storage tanks, evaporation, ground disposal in trenches and pits, and hydrofracture. Burial of solid radioactive waste was initiated in the early 1940s, and there are six burial grounds at ORNL with two currently in use. Monitoring at White Oak Dam, the last liquid control point for the Laboratory, was started in the late 1940s and is continuing. Presently, a network of five environmental monitoring stations is in operation to monitor the radionuclide content of surface waters in the White Oak watershed. In this paper, the solid waste burial grounds will be described in detail, and the environmental data tabulated over the past 29 years will be presented. The various monitoring systems used during the years will also be reviewed, the liquid effluent discharge trends at ORNL from the radioactive waste operations will be discussed.

ANNOTATION: Trenches in burial ground 1 were backfilled with dirt after being filled with wastes. Burial ground 2 was exhumed and re-buried in burial ground 3. In burial ground 3 alpha-contaminated wastes were placed in the bottom of the trenches and covered with concrete. The beta-gamma wastes were placed on top of this and were covered with native soil (weathered shale). These practices were continued in area 4 and the early trenches in area 5. This segregation procedure was later discontinued.
INTRODUCTION: This newsletter represents the eighth in a series of quarterly newsletters that have been published by the Ecological Sciences Information Center on subject areas relevant to low-level radioactive technology. In order to present the selected information more effectively, this issue has been divided into the following chapters: low-level radioactive waste, decontamination and decommissioning; milling tailings; legislation; related news; meetings; current literature of interest; and translations.

ANNOTATION: No mention is made of trench covers.
ABSTRACT: None.

ANNOTATION: This is a collection of 19 papers on industrial wastes. Two of these papers "Groundwater Contamination and Its Control" by Hughes and "Geotechnical Aspects of Disposal and Containment of Low-Level Radioactive Wastes" by Milligan, Seychuk and Turton, are listed in this volume.

INTRODUCTION: The authors have undertaken a study to identify advanced low-level radwaste treatment systems that are commercially available or expected to be in the near future; collect engineering and performance data on these systems; and assess these systems in a manner that will be useful as a planning aid to the electric power generating industry.

The systems considered in this study are mainly those referred to as volume reduction (VR) systems, and can be conveniently classified, with few exceptions, into one or more of the following process categories: dehydration, incineration, crystallization, and compaction.

ANNOTATION: Volume reduction before burial to reduce burial costs for the power plant is discussed. Trenches and their covers are not mentioned.

ABSTRACT (from Environline): Since 1970, nuclear power plant designs have been modified to improve their capability for handling low-level radioactive wastes. Design alterations have stressed greater capacity, safety, and reliability. Volume reduction methods are used extensively to minimize overall disposal costs for both liquid and solid wastes. Also discussed are: gaseous waste design improvements; liquid segregation; evaporator processes; filter performances; and water management strategies. Volume reduction methods considered include: dehydration, evaporation, crystallization, compaction, and incineration. Ways of controlling operating costs are reviewed. The merits and problems of waste burial vs. storage are examined.

ANNOTATION: No mention is made of trenches or covers. The authors argue in favor of storing low-level wastes on power plant grounds due to cost and possible unavailability of burial sites.
ABSTRACT: Hydrogeologic criteria presented by Cherry and others (1973) are adopted as a guideline to define the hydrogeologic and hydrochemical data needs for the evaluation of the suitability of proposed or existing low-level radioactive waste burial sites. Evaluation of the suitability of a site requires the prediction of flow patterns and of rates of nuclide transport in the regional hydrogeologic system. Such predictions can be made through mathematical simulation of flow and solute transport in porous media. The status of mathematical simulation techniques, as they apply to radioactive waste burial sites, is briefly reviewed, and hydrogeologic and hydrochemical data needs are listed in order of increasing difficulty and cost of acquisition.

Predictive modeling, monitoring, and management of radionuclides dissolved and transported by ground water can best be done for sites in relatively simple hydrogeologic settings; namely, in unfaul ted relatively flat-lying strata of intermediate permeability such as silt, siltstone and silty sandstone. In compact, dense, fractured, or soluble media, and poorly permeable porous media (aquitards) are not suitable for use as burial sites first because of media heterogeneity and difficulties of sampling, and consequently of predictive modeling, and second, because in humid zones burial trenches in aquitards may overflow. A buffer zone several thousands of feet to perhaps several miles around existing or proposed sites is a mandatory consequence of the site selection criteria. As a specific example, the Maxey Flats, Kentucky, low-level waste disposal site is examined.

ANNOTATION: The authors suggest that in the future, burial should be in soils with intermediate hydraulic conductivities because aquitards aggravate the bathtub effect in humid zones. A list of data needed to properly evaluate proposed sites is given. Trench covers are not specifically dealt with.

ABSTRACT: None.

ANNOTATION: At Oak Ridge National Laboratory, it was shown that "lining the trenches with manganese oxide would tend to absorb some of the most potentially hazardous material such as strontium and the actinides." High pH and Eh environments enhance the absorption. The authors suggest that relatively impermeable, sloped covers are needed to keep water out of the burial ground, and that it appears more water movement is through the fissures and cracks than the uniform soil.

ABSTRACT: None.

ANNOTATION: This document has four main chapters: pertinent legislation, solid waste characteristics, hazardous waste management, and impacts of RCRA on Illinois. No details are given on landfills.
INTRODUCTION: The material in this paper represents the thoughts and deliberations of a number of engineers and scientists engaged in the research and development aspects of a radioactive waste disposal, including several of you here today from Oak Ridge, Savannah River, the AEC and the Geological Survey. Because of many complex environmental variables and the amount of engineering judgment involved, the AEC has not seen fit to establish at the present time any official site criteria or guides for the disposal of solid packaged wastes.

While there may appear to be a lack of unanimity on some of the points discussed, we believe this represents only a certain degree of professional differences of opinion. It is evident that each site environment has inherent characteristics which must be studied and evaluated in its own context. Continued operating experience, observation, analysis and evaluation are required to obtain more quantitative data on questions raised herein.

ANNOTATION: The authors suggest backfilling as the standard cover technique and indicate that sometimes modifications may be needed to make the cover more impermeable.

ABSTRACT: This paper presents an overview of the ERDA's major program for the long-term waste management of radioactive waste and provides a perspective for symposium participants with regard to the interrelationship of specific components of the program that are discussed in detail in other ERDA-sponsored papers. Needs, goals, and plans are reviewed for ERDA's management of the commercially generated wastes which are expected to be delivered to ERDA in accordance with Federal regulations. At present, ERDA responsibilities include long-term management of commercial-level wastes. Possible future regulations may give ERDA responsibility for the long-term management of commercial low-level solid wastes contaminated with transuranic nuclides. Primary planning goals and programs for the development of terminal storage facilities and waste processing technology to produce acceptable waste forms for long-term management are reviewed for each of the waste types identified above. The status of development programs for the long-term management of airborne radionuclides, which may be required at some time in the future, is also reviewed.

ANNOTATION: Low-level waste burial is mentioned briefly. Trench covers are not discussed.

ABSTRACT: The purpose of this research project was to provide an interactive computer program for simulating the hydrologic characteristics of a solid and hazardous waste disposal site operation. A large number of stations (cities) within the United States for which 5 years of climatic records exist have been put on tape for easy access and can be used in lieu of on-site measurements. In addition, to expedite model usage, the model stores may default values of parameter estimates which can be used when measured and existing data files are not available. The user must supply the geographic location, site area and hydrologic length, the characteristics of the final soil and vegetative cover, and default overrides where deemed necessary. From minimal input data, the model will simulate daily, monthly, and annual runoff, deep percolation, temperature, soil-water, and evapotranspiration.

The model, which is a modification of the SCS curve number runoff method and the hydrologic portion of the USDA-SEA hydrologic model (CREAMS), has been modified to conform to the design characteristics of solid and hazardous waste disposal sites. The model takes hydrologic parameter input data and operates sequentially as precipitation information is read. The user can request a final cover soil with a vegetative and a barrier layer or with a uniform final cover soil. The user can select an "impermeable liner" separating the final cover soil material from the solid waste cells and select the life expectancy of the liner. The model is designed for use in a conversational manner, that is, the user interacts directly with the program and receives output immediately. No prior experience with computer programming is required for model usage. All necessary commands to use the model are presented in the user's manual.

ANNOTATION: The authors suggest that loam has the ideal soil texture to minimize vegetative production and that runoff is significantly affected by soil type, vegetative cover and management practices. The model used a deterministic approach. No details on trench covers are discussed.

ABSTRACT: Radioactive wastes from the nuclear industry are classified into low, intermediate and high activity levels, and problems of their storage and release examined in detail. Current means of storage are considered with reference to processing of low and intermediate level liquid waste, processing of high level waste, processing of airborne waste, and ground disposal and processing of solid waste. Release is discussed in terms of effluent release limits, monitoring and the use of permanent records, impact of release to the human environment, and guides for preventing accidental release. Contamination of the shore of Lake Huron from radioactive fallout is discussed as a particular example.

Problems to be solved are identified in three main areas: gaseous wastes, actinide-contaminated wastes, and permanent disposal, and some specific suggestions for study are made.

ANNOTATION: All types of radioactive wastes and their processing are discussed. There is little discussion of trenches and ground disposal; no mention is made of trench covers. The authors suggest that leaching can be prevented by bituminization, proper solidification or modifying the subsurface environment.

ABSTRACT: None.

ANNOTATION: This volume contains 54 papers under the following headings: new perspectives, political, social, and public interactions; low level wastes, criteria, controls, and management; volume reduction techniques; waste management techniques; environmental considerations and risk assessment; and workshop reports. Four papers, those by Manry, Martine, Isaacson and Brown, and Albrecht and Perzel, are listed separately in this bibliography.
ABSTRACT: A technique was developed for collecting cores for radiometric analysis from beneath a low-level radioactive-waste landfill to determine the rates of downward radionuclide migration below the trenches. A closed pipe was driven through the buried waste, and a removable point withdrawn. The hole was then advanced by alternately pushing a coring device, then driving an inner casing to the depth reached by the coring device and cleaning out cuttings from within the casing. The effectiveness of the technique was limited by inability to predict the location of impenetrable objects within the waste in some parts of the burial ground and difficulty in detecting when the end of the pipe first penetrated undisturbed material beneath the trench floor. Geophysical logs of the completed hole were used to help determine the trench-floor depth.

ANNOTATION: No information is given on the trench covers.
ABSTRACT: Burial trenches for disposal of solid radioactive waste at West Valley, New York, are excavated in till that has a very low hydraulic conductivity (about $5 \times 10^{-8}$ centimeters per second). Fractures and root tubes with chemically oxidized and/or reduced soil in their walls extend 3 to 4.5 meters below natural land surface. Preliminary simulations of pressure heads with a digital model suggest that hydraulic conductivity is an order of magnitude greater in the fractured till near land surface than at greater depth. Hydraulic gradients are predominantly downward, even beneath small valleys. The upper part of a body of underlying lacustrine silts is unsaturated; in the lower, saturated part, slow lateral flow may occur.

In the older trenches, water began to build up in 1971, overflowed briefly in 1975, and was pumped out in 1975-76. Water levels rose abruptly during major rainstorms in mid-1975, indicating rapid infiltration through cracks in the cover material. The new trenches have maintained low, stable water levels, perhaps because of thicker, more compact cover and less waste settlement; pressure heads near these trenches are low, locally approaching zero, perhaps because of slight infiltration and limited near-surface storage.

Peak tritium concentrations in test-hole cores (generally $10^{-5}$ to $10^{-3}$ microcuries per milliliter) were found within 3 meters of land surface and are attributed to surface contamination. Concentrations declined rapidly with depth within the fractured till; secondary peaks found at about 9 meters in three holes are attributed to lateral migration from trenches. Other radioisotopes were detected only near land surface. Samples from the walls of shallow fractures revealed no accumulation of radioisotopes.

ANNOTATION: The burial ground is underlain by 27 m of silty, clay till with deformed, discontinuous sand lenses. The covers are re-worked till and are cracked. The cracks change in size with changes in moisture content. Compaction was accomplished by temporarily piling material from the next trench on the cover.
ABSTRACT: The capillary barrier technique, by which one can create dry structures in porous media relying simply on the differences of particle size distribution between two media, has been demonstrated by laboratory experiments on reduced-scale models. In order to test the applicability of this phenomenon to practical waste storage, an experiment trench was excavated in fine soil, filled two-thirds with gravel and then covered with argillaceous sand of fine texture which formed a dome above the soil surface. Moisture transport was observed by measuring the evolution of water profiles with a neutron moisture gauge and by noting the movement of radioactive tracers. Static measurements were also performed with a strainer pipe going down to the bottom of the trench. The influence of atmospheric precipitation was recorded during several seasonal cycles; experiments were also carried out with intensive water spraying on the trench surface. After five years of regular observations, in spite of the intensive irrigation conditions, no appreciable moisture transport was observed across the interface of the fine medium toward the coarse medium, which indeed remained a dry structure. Applied with certain precautions, this simple, sturdy and inexpensive method can considerably improve the safety of underground repositories for low- to medium-level wastes.

ANNOTATION: For the capillary barrier to work, the fine material must have a granular diameter of less than 0.25 mm, but not be either too consolidated or too powdery, and the interface must be clean.

INTRODUCTION: The ground disposal practices in effect at the Savannah River Plant are presented. This Plant, operated by E. E. du Pont de Nemours and Company, occupies an area of 320 sq. mi. along the Savannah River downstream from Augusta, Georgia. The Plant and its production facilities include: (1) a fuel preparation area, (2) five reactor areas, (3) two radiochemical separations areas, (H Area and F Area), and (4) a heavy water plant.

Within 40 miles of the center of the Plant there is a population of 400,000. The largest population center in this area is Augusta and its suburbs, with a total population of 150,000. Much of the area surrounding the Plant is farmland but in recent years several large industrial plants have been built.

ANNOTATION: A good description of the geology and hydrology of the Savannah River Plant is given. Burial of radioactive wastes is mentioned, but trench covers are not discussed.

INTRODUCTION: Much of the solid, radioactive waste currently produced by contractors and licensees of the AEC is at present disposed of by land burial at sites at Oak Ridge National Laboratory, Tennessee, and at the National Reactor Test Station, Idaho.

For a variety of reasons, economic, geographic, and environmental, it is desirable that one or more burial grounds be established to serve safely and economically the regions generating the largest quantities and volumes of these wastes. One such region is northeast United States.

ANNOTATION: This paper gives criteria that were used to select burial sites in 1961. It does not discuss trench covers.

ABSTRACT (from Environline): The underground disposal of nuclear wastes may be done at shallow depths. In rock caverns at various depths, and in deep continental rocks, national activities, waste disposal issues, and international activities and cooperation are discussed. Land burial of low and intermediate level radioactive wastes has been done for decades in many countries, including France, the U.S., the USSR, India, Canada, and Britain. International R&D and deep injection projects are reviewed. The U.S. Dept. of Energy National Waste Terminal Storage Program is assessed. IAEA plans to issue guidelines on safe underground disposal encompassing five areas: regulations; siting; waste acceptance criteria; design and construction; and operation and shutdown of depositories.

ANNOTATION: This article contains a summary of what individual nations are doing with their wastes. Low-level radioactive waste burial is mentioned, but no specifics on it are given.

ABSTRACT: None.

ANNOTATION: The findings of President Carter's Interagency Review Group on Radioactive Waste Management and the highlights of the President's Radioactive Waste Management policy statements are presented. High-level wastes are emphasized.
ABSTRACT: Industrial and low-level radioactive liquid wastes at the National Reactor Testing Station (NRTS) in Idaho have been discharged to the Snake River Plain aquifer since 1952. The movement and distribution of these wastes have been monitored. The aquifer is large and has a high transmissivity. The total waste discharge to the aquifer at NRTS, which has averaged about $1 \times 10^{9}$ l per year, contained small quantities of tritium, $\text{Sr}^{90}$, $\text{Cs}^{137}$, $\text{Co}^{60}$, chloride, hexavalent chromium, various acids and bases, and heat. Tritium and chloride have dispersed over a 15-sq mi (39 km$^2$) area of the aquifer in low but detectable concentrations and have migrated as much as 5 mi (8 km) downgradient from discharge points. A remarkable degree of lateral dispersion has diluted and spread the waste products rapidly. The movement of cationic waste solutes, particularly $\text{Sr}^{90}$ and $\text{Cs}^{137}$, has been significantly retarded owing to sorption phenomena, principally ion exchange. $\text{Cs}^{137}$ has shown detectable migration in the aquifer and the $\text{Sr}^{90}$ has migrated only about 1.5 mi (2 km) from a discharge well. The $\text{Sr}^{90}$ plume covers an area of only 1.5 sq mi (4 km$^2$) of the aquifer.

Digital modeling techniques have been applied successfully to the analysis of this complex waste-transport system by numerical solution of the coupled equations of groundwater motion and mass transport. The model includes the effects of convective transport, flow divergence, two-dimensional hydraulic dispersion, radioactive decay, and reversible sorption. The 20-year transport and distribution history of waste chloride and tritium has been successfully simulated by the model. The less conservative cationic solutes have also been successfully modeled. The modeling results indicate that hydraulic dispersion (especially transverse) is a much more significant influence than has been suggested by earlier studies. The model may be used to project future waste-migration patterns for varied hydrologic and waste conditions.

ANNOTATION: Various transfer mechanisms of radioactive isotopes through the aquifer are discussed. Trench covers are not discussed.
INTRODUCTION: The methodology developed for the Radioactive Waste Disposal Classification System" (RWDCS) can be used to establish guidelines such as criteria and performance objectives for the safe disposal of low-level radioactive waste (LLW). In the RWDCS, wastes are classified based on the requirements for their safe disposal, which was defined as adequate protection of the public in terms of the dose rate to persons receiving the maximum potential exposure. This health and safety requirement is an important initial input both to the development of the RWDCS and to the development of LLW disposal criteria and guidelines. Other requirements, such as site and waste form characteristics criteria can then become whatever is necessary to attenuate the waste concentration (or inventory, as appropriate) to meet the health and safety criteria.

ANNOTATION: This article discusses disposal concentration guidelines for low-level sites, but does not deal with the individual sites.

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ABSTRACT: None.

ANNOTATION: This article discusses various means of site intrusion by man, animals and vegetation. The mechanisms discussed include direct intrusion by man resulting in inhalation of radioactive material, isotope uptake by vegetation, drilling wells on the site, erosion and migration of radon gas.
ABSTRACT: The importance of having an appropriate model to guide our imaginative thoughts and research is desirable in any discipline. This is particularly important in a slowly changing system under continuous development such as soils where the separation of cause and effect is most difficult. A model of soil development based on energy vectors can become as complex as the situation requires. The model discussed may enable one to design experiments which have a higher probability of definitive results than do previous models. Also the model seems to allow for easier extrapolation of results. Hopefully, the proposed model will help in predicting more accurately the effect of man's activity on soils of the world.

ANNOTATION: This article does not discuss trench covers.

ABSTRACT (from ENVIROLINE): To establish standards for decommissioning nuclear facilities, sites, and materials, the form of the standards, timing of decommissioning, occupational radiation protection, costs and financial provisions, and low-level radioactive waste should be considered. The waste disposal problem from decommissioning activities may be significant because of the volume of waste produced. Occupational exposures and costs, both sensitive to the timing of decommissioning actions, are some of the more critical problems associated with decommissioning waste. Other important considerations for decommissioning standards are briefly discussed.

ANNOTATION: The volume of low-level wastes and their impact on existing facilities are discussed. Trench covers are not mentioned.

ABSTRACT: This paper describes the efforts made toward the establishment of a pilot scale management system for the low and intermediate level radioactive wastes of the Atomic Research Center. The past and current practices in handling radioactive wastes are discussed and the assessment of their capabilities to meet the projections on the waste production is presented. The future waste managements of the Center was evaluated and comparative studies on the Lime-Soda and Phosphate Processes were conducted on simulated raw-liquid wastes with initial activity ranging from $10^{-2}$ $\mu$ ci/ml, to establish the ideal parameters for best attaining maximum removal of radioactivity in liquids. The effectiveness of treatment was evaluated in terms of the decontamination factor, DF, obtained.

ANNOTATION: The article deals with management of wastes before burial.

ABSTRACT: The purpose of this paper is not to offer a solution to the potential leachate problem facing each refuse disposal area, but to point out some of the factors involved and to call attention to the need for applying engineering principles to sanitary landfill design and operation.

ANNOTATION: The authors suggest clay, clay loam or artificial membrane as a cover for a sanitary landfill and indicate that these all require maintenance. The major problems with clay are that it gets muddy when wet, cracks when dry, and is difficult to dig, move and spread. These difficulties can generally be overcome by good engineering practices. Artificial membranes can only be used where most of the settlement has already occurred. Shallow-rooted ground cover should be used to minimize erosion and increase evapotranspiration.

SUMMARY: This report describes solid, low-level radioactive waste management programs at the Oak Ridge Y-12 Plant. The discussion includes methods of operation, monitoring activities in and around burial facilities, and an environmental assessment of the operation.

ANNOTATION: This paper says that excavated material is used for daily cover material. The remaining excavated soil is used for the final trench cover which varies in thickness from 5 to 15 feet. This cover is seeded with grass and pine seedlings for erosion control.
ABSTRACT: The problem of subsurface, radioactive-contaminant transfer is investigated theoretically through the development of a two-dimensional model which considers the simultaneous flow of water and mass. In addition to the well-known physical transport processes, convection and dispersion, the model treats radioactive decay and cation exchange which are two of the most important concentration attenuation processes. The influence of factors, which control the transport processes, on subsurface contaminant distributions is demonstrated through the simulation and analysis of a series of hypothetical cases. With respect to the physical transport processes, hydraulic conductivity, porous medium dispersivity and the location of the contaminant inflow zone are considered as controlling parameters. The attenuation processes are controlled by the following parameters, radioactive half-life, selectivity coefficients, cation-exchange capacity, ion charge and weathering rate.

The maximum extent of subsurface contamination in all cases is determined by the physical transport processes. Chemical and nuclear attenuation simply reduces the size of the contaminated region to some fraction of that which could be attributed to physical transport alone. The complexity of the transport process suggests that empirical evaluations of site behavior which are based on rigid guidelines are inadequate for siting and designing waste management sites, and for insuring the safety of potable water supplies.

ANNOTATION: The model used includes convection, dispersion, radioactive decay and cation exchange. Physical transport processes are governed by hydraulic conductivity, dispersivity and location of the inflow zone. Attenuation processes are governed by radioactive half-life, selectivity coefficients, cation exchange capacity, ionic charge and weathering rate. Cation exchange capacities are given for several clays. No mention is made of trench covers.

ABSTRACT: The proposed waste-management site at the Defense Research Establishment Shuffield appears suitable for storing solid low-level radioactive wastes with a half-life for radioactive decay less than 3000 years. This conclusion is based on model trials which generally indicate that the subsurface environment will be effective in limiting the dispersal of radioactive contaminants in the groundwater system. Contaminant attenuation is produced by the physical process of radioactive decay. A strong measure of contaminant confinement is provided by the relatively low seepage velocity within the porous medium. However, because of the uncertainties inherent in the definition of model parameters, and because there is no historical record with which to calibrate the model, the results of the simulations must be treated in a very general way.

Parameters in the model are derived from empirical relationships and a variety of field and laboratory studies conducted over the past two years. Piezometric data indicate that the site is predominantly a recharge area with the permeability of geologic units ranging from $1 \times 10^{-5}$ to $2 \times 10^{-8}$ cm/sec. Measured values of cation-exchange capacity for drift and bedrock units range from 25 to 105 mequiv./100 g. An unsaturated zone up to 36 m thick, a lack of water-level fluctuations, and a semi-arid climate are evidence of the limited quantities of natural recharge to the groundwater system. Soil-moisture data demonstrate the most favorable sites for recharge are depressions within the area.

ANNOTATION: The model is for a proposed site in a semiarid climate. No mention is made of possible cover designs.

ABSTRACT: None.

ANNOTATION: The authors state that a 5% slope is optimal for trench covers. The suggested design is a clay cover (bentonite, preferably), covered by at least two feet of soil to prevent cracking. A cover of half soil and half gravel is recommended. The suggested possible best sequence of material in a trench was, from the bottom, waste material, soil fill, compacted backfilled soil, clay trench cap, and cover soil and gravel final cover.

ABSTRACT: The confinement of nuclear wastes in geologic formations is being considered as a method of permanently disposing of the waste. Laboratory experiments (column infiltration, static absorption and batch partitioning experiments) were performed with nuclides of cesium, plutonium, neptunium, and americum to examine the migratory characteristics of long-lived radionuclides that could be mobilized by groundwaters infiltrating a nuclear waste repository and the surrounding geologic body. In column infiltration experiments, the positions of peak concentrations cesium in chalk or shale columns, plutonium in limestone, americum in limestone, sandstone or tuff, and neptunium in a limestone column did not move when the columns were infiltrated with water. However, fractions of each of the nuclides were seen downstream from the peaks, indicating that there was a large dispersion in the relative migration rates of each of the trace elements in the lithic materials studied.

The results of static absorption experiments indicate that plutonium and americum are strongly absorbed from solution by the common rocks studied and that their migration relative to groundwater flow is thereby retarded, a conclusion that is consistent with results of the column infiltration experiments. In addition, the reaction rates of dissolved nuclides with rocks were found to vary considerably in different rock element systems.

Batch partitioning experiments were performed to test whether absorption processes are reversible. After granulated basalt and americium-bearing water were contacted in an absorption step, part of the water was replaced with water free of americum and the americum repartitioned between rock and solution. The distribution of americum after desorption was comparable to the distribution after absorption. In contrast, when tablets of various rocks were allowed to dry between absorption and desorption tests, plutonium and americum were generally not desorbed from the tablets. This suggests that reversible reactions of nuclides between waters and rocks may be upset by treatments such as drying.

In batch partitioning experiments with plutonium- and americium-bearing water and granulated basalt of different particle sizes, the partitioning of americium and plutonium did not correlate with the calculated area of the fracture surfaces nor did the partitioning remain constant (as did the measured surface area). Partitioning is postulated to be a bulk phenomena with complete penetration of the ~500-μm size and smaller particles.
ANNOTATION: The experiments performed in this study were for deep geologic disposal of long-lived radionuclides. They are not meant as research on the low-level waste disposal problem.

ABSTRACT (from COMPENDEX): This brief review outlines several methods by which the U.S. uranium mining industry has sought to increase the sophistication of disposal and restoration techniques, while keeping pace with the continually changing federal and state regulations. Considerable progress has been made in the short span of 15 years and the industry has not only maintained environmental quality, but managed to increase production rates as well. Two key methods of waste disposal are highlighted: tailings ponds and deep well injection.

ANNOTATION: The article does not discuss trench disposal of low-level radioactive wastes.

ABSTRACT: This citation is from an abstract only.

ANNOTATION: The paper discusses the Barnwell site and was to include construction and operational aspects of the site. No further information is available.
ABSTRACT: Regulating a low-level waste disposal site reveals many interesting facets of how this nation's low-level waste is being managed. Incidents and occurrences at a burial site and after it is received at the burial site will be described. Regulating the site involves numerous disciplines of Engineering, Chemistry, Hydrology, Geology, Health Physics and others. Regulatory involvement of these elements will be reviewed. Classification of low-level waste as presently being implemented at the Chem-Nuclear, Barnwell, South Carolina, site will be discussed.

ANNOTATION: This paper is limited to the Barnwell site. No mention is made of trench covers.
INTRODUCTION: The use of synthetic flexible liners to control seepage in evaporation ponds, sewage lagoons, and industrial waste storage reservoirs spans twenty years.

The application of some of these synthetic flexible liners to contain and direct leachate flow in land disposal sites is already six years old.

The primary objections from towns, citizens, and even some engineers are normally a result of not understanding the "COMPLETE LINER SYSTEM."

Flexible liners offer new design criteria for landfills. They are often less expensive than rigid liners such as concrete and asphalt and remain flexible. Since leachate varies depending on what type of refuse is in the landfill, clays and other soil sealants do not always provide a positive barrier to control the leachate.

ANNOTATION: This paper does not deal with trench covers specifically. It is a concise overview on types of liners and was a reference in other papers that suggested using such liners in a trench cover.

ABSTRACT: This citation is for an abstract only.

ANNOTATION: The abstract is a basic discussion of favorable criteria for waste sites.

ABSTRACT: This summary describes the results of studies to identify and evaluate alternatives for long-term management of transuranic-contaminated waste at the Idaho National Engineering Laboratory.

ANNOTATION: No mention is made of trenches or their covers.

ABSTRACT: None.

ANNOTATION: This is a sales brochure for plastic covers and linings.

ABSTRACT: The objective of this study was to evaluate generically, the sensitivity of radionuclide migration to certain transport parameters, as related to shallow low-level radioactive waste burial sites. There are many site-specific studies of radionuclide migration through groundwater reported in the literature; however, no quantitative generic study of the effects of transport parameters could be found. This study could form a basis for establishing site boundaries.

A range of homogeneous soil types was considered in the analyses. A probable value of hydraulic conductivity, total porosity, effective porosity, and bulk density was selected for each soil type. Soils were assumed to be completely saturated. For each soil type, the time-varying concentrations of specific radionuclides were determined at given distances from the source.

Sensitivity analyses were performed for each soil type by varying the hydraulic gradient of the water table and the leach rate of the source. The sensitivity of distribution coefficients to pH was investigated for only the silt soil and three radionuclides, because of limited available data. Conservative analyses were conducted by considering only time decay of radionuclides resulting from groundwater travel and holdup due to ion-exchange with soil particles. More realistic analyses were performed using a three-dimensional dispersion model.

ANNOTATION: The model used assumed an impervious trench cover. It did not assume that the cover cap can withstand subsidence, weathering and other natural phenomena, so there is free access of leaching water. Options include radionuclide travel time with and without sorption; decay resulting from ground-water travel with sorption; and decay resulting from ground-water travel with sorption and dispersion. No specific information is given on how to design or improve trench covers.

ABSTRACT: Disposal of solid low-level wastes containing radionuclides by burial in shallow trenches was initiated during World War II at several sites as a method of protecting personnel from radiation and isolating the radionuclides from the hydrosphere and biosphere. Today there are 11 principal shallow-land burial sites in the United States that contain a total of more than 1.4 million cubic meters of solid wastes contaminated with a wide variety of radionuclides. Criteria for burial sites have been few and generalized and have contained only minimal hydrogeologic considerations. Waste-management practices have included the burial of small quantities of long-lived radionuclides with large volumes of wastes contaminated with shorter-lived nuclides at the same site, thereby requiring an assurance of extremely long-time containment for the entire disposal site.

Studies of 4 of the 11 sites have documented the migration of radionuclides. Other sites are being studied for evidence of containment failure. Conditions at the 4 sites are summarized. In each documented instance of containment failure, ground water has probably been in the medium of transport. Migrating radionuclides that have been identified include $^{90}$Sr, $^{137}$Cs, $^{106}$Ru, $^{239}$Pu, $^{125}$Sb, $^{60}$Co, and $^3$H.

Shallow land burial of solid wastes containing radionuclides can be a viable practice only if a specific site satisfies adequate hydrogeologic criteria. Suggested hydrogeologic criteria and the types of hydrogeologic data necessary for an adequate evaluation of proposed burial sites are given. It is mandatory that a concommitant inventory and classification be made of the longevity, and the physical and chemical form of the waste nuclides to be buried, in order that the anticipated waste types can be matched to the containment capability of the proposed sites.

Ongoing field investigations at existing sites will provide data needed to improve containment at these sites and help develop hydrogeologic criteria for new sites. These studies have necessitated the development of special drilling, sampling, well construction, and testing techniques. A recent development in borehole geophysical techniques is downhole spectral gamma-ray analysis which not only locates but identifies specific radionuclides in the subsurface.
Field investigations are being supplemented by laboratory studies of the hydrochemistry of the transuranic elements, the kinetics of solid-liquid phase interactions, and the potential complexing of radionuclides with organic compounds and solvents which mobilize normally highly sorbable nuclides. Theoretical studies of digital predictive solute transport models are being implemented to assure their availability for application to problems and processes identified in the field and laboratory.

ANNOTATION: The sites studied are Oak Ridge, Maxey Flats, Idaho National Engineering Laboratory, and West Valley. At most of the sites, trench covers are more permeable than the aquitards the trenches are in, causing water to overflow the trench. No other information on the covers are given.
ABSTRACT: This book is concerned with practices relating only to continuous operations and not to accidental releases of radioactive materials. It is written for use by those interested in low-level waste disposal problems and particularly for the health physicist concerned with these problems in the field. It should be helpful also to water and sewage works personnel concerned with the efficiency of water- and sewage-treatment processes for the removal of radioactive materials; to personnel engaged in the design, construction, licensing, and operation of treatment facilities; and to the student of nuclear technology.

ANNOTATION: Only a few pages of this book discuss land burial. Covers are discussed only as radiation barriers; wastes are covered with 3 or more feet of dirt, depending on the activity. Bulldozers are used for compaction. A now-abandoned practice for alpha-bearing waste covers of 1 foot of earth, 18 inches of concrete (to prevent digging up the waste) and 2 feet more of earth is mentioned.
ABSTRACT: AGNS will divide the majority of the contaminated solid waste generated during reprocessing of commercial spent nuclear reactor fuels into three categories: spent fuel cladding hulls, high-level general process trash (HLGPT) and low-level general process trash (LLGPT).

The LLGPT will be stored in cargo containers identical to those used for road, rail, and sea transport. As these cargo containers are filled, they will be covered with earth for protection from natural phenomenon. The cargo containers will be sufficiently monitored to allow detection and recovery of any radionuclides before they reach the environment.

The hulls and HLGPT will be stored in caissons within separate engineered soil berms. The caissons will be lined and capped to provide sufficient protection from natural phenomenon. The berms will include impervious clay layers at the bottom to prevent the downward movement of radionuclides and will be provided with sufficient monitoring to allow detection and recovery of radioactivity before it reaches the environment.

ANNOTATION: No mention is made of trenches or covers. The cover for the interim storage site is an asphalt grass seed mixture which is supposed to form a moisture barrier and prevent erosion.

ABSTRACT: This citation is for an abstract.

ANNOTATION: Abstract does not mention any aspect of trench construction.

ABSTRACT: This volume had no single abstract.

ANNOTATION: This is a program with abstracts; none of these articles deal with trench cover design.

ABSTRACT: This paper summarizes a master's thesis on the state-of-the-art for shallow land burial of solid low-level radioactive wastes. The coverage of the thesis, which is condensed for this paper, ranges from site selection to problem case histories. Inherent in such coverage is the assessment of risk, the discussion of operational and management problems and the real significance of offsite migration—this topic will be discussed in the light of the stands taken that the migration is a serious problem and that it is not. Emphasis is on the engineering parameters of importance in site selection, and what pretreatment, if any, is needed.

ANNOTATION: The problems discussed are radionuclide migration at four sites, removal of contaminated equipment at the Beatty site, poor records, and waste settling at the West Valley site. No mention is made of trench covers.

ABSTRACT: Compliance with the latest regulatory requirements addressing disposal of radioactive, hazardous, and sanitary solid waste requires the application of numerous qualitative and quantitative criteria in the selection, design and operation of solid waste management facilities. Due to the stage of flux of these regulatory requirements from EPA and NRC, several waste management options were identified as being applicable to the management of various types of solid waste.

This paper highlights the current regulatory constraints and the design and operational requirements for construction of both storage and disposal facilities for use in the management of DOE-ORO solid waste. Capital and operational costs are included for both disposal and storage options.

ANNOTATION: Included in this paper is the design of a burial trench which complies with the criteria EPA proposed in December 1978 for disposal of hazardous waste. This trench has a clay liner and a leachate collection system. The cover consists of a clay cap, earthen fill and a top soil cover.
ABSTRACT: This manual provides guidance in the selection of available engineering technology to reduce or eliminate leachate generation at existing dumps and landfills. The manual emphasizes remedial measures for use during or after closure of landfills and dumps which do not meet current environmental standards. Most of the techniques discussed in the report deal with the reduction or elimination of infiltration into landfills in one of five categories, active groundwater or plume management, chemical immobilization of wastes, and excavation and reburial. The technology presented is widely used in construction but has not necessarily as yet been applied to landfill closure.

ANNOTATION: The infiltration control discussed includes: changing the contour of the landfill cover to reroute precipitation, installing a low permeability cover to act as an infiltration barrier, and revegetating the site to stabilize the cover. The barriers discussed include fly ash, soil-cement seals, lime-stabilized soils, bituminous paving and membrane seals.


ABSTRACT (from Environline): Land burial practices for low-level radioactive wastes at federal and commercial sites are investigated. Though about 51 million cu ft of radioactive wastes have been buried through June 1974, the optimum mix of hydrogeological factors and engineering features is not yet known. Site selection criteria have not been established, and some disposal sites are now releasing radioactivity. NRC and ERDA should: comprehensively study existing sites; develop criteria for future sites; establish detection standards and improve radiation monitoring programs; improve management and regulatory activities; establish long-term care requirements for commercial sites; and develop a federal policy on correcting existing problems.

ANNOTATION: Compaction of waste is only effective until the cover is 3 feet thick. When the cover is thicker, you get a hard cover over permeable wastes.

ABSTRACT: None.

ANNOTATION: Testimonies by Cunningham, DeBuchanan, Kuhlman and Neal deal with past problems with trenches.
ABSTRACT (from Environline): Hearings were held to examine the problem of disposing of the radioactive wastes generated by two nuclear power plants located in Sheffield and Morris, Illinois. Associated issues were considered from both the environmental and industrial standpoints. Shipments of enriched uranium out of O'Hare Airport, Chicago were also discussed. Testimony was presented by Rep. Leo Ryan (D-Calif.), Rep. Floyd Fithian (D-Ind.), Rep. Arlan Stangeland (R-Minn.), and Representatives of USGS, ANL, General Electric Co., Associated Citizens for the Protection of the Environment, and Commonwealth Edison Company. Correspondence, memoranda, related documents, reports, and statements are transcribed.

ANNOTATION: These hearings cover the Sheffield site extensively, including its hydrology, geology, previous studies on it and the tritium migration. Only Keros Cartwright's testimony refers to possible problems with trench cover designs and suggests research is needed in this area. (Annotator's note: There is no nuclear power plant located in Sheffield. However, Sheffield is the site of a low-level radioactive waste disposal site.)

ABSTRACT: None.

ANNOTATION: The hearings were on the decommissioning and decontamination of nuclear facilities and nuclear waste disposal. They concentrated on the fuel reprocessing plant at West Valley.

ABSTRACT: None.

ANNOTATION: These hearings deal with general policies governing low-level sites, such as whether they should be on state or federal lands. They do not go into any specifics.
ABSTRACT: This is Volume 2 of four volumes of the record of "Hearings on Industrial Radioactive Waste Disposal." It covers the first half of the current waste disposal research and development program. It describes and discusses the treatment and controlled dispersal of low and intermediate level wastes to the atmosphere, surface waterways, the ground, and the ocean and environmental investigations associated with this phase of the development program. Volume 1 covers the portion of the hearings concerned with the origin and nature of various types of radioactive wastes evolved from nuclear energy activities and operations in use to manage these wastes at various AEC and other installations. Volume 3 covers the second half of the current waste disposal research and development program. It describes and discusses the handling, treatment, and proposed ultimate disposal systems for highly radioactive wastes that are primarily evolved from irradiated fuel reprocessing plants and discusses the future estimates and economics of disposal of radioactive wastes. It also includes a summary of environmental factors related to these estimates and a discussion of the industrial viewpoint of the radioactive waste problem. Volume 4 discusses the activities of Federal and State governmental agencies in radioactive effluent control and administrative relationships between these agencies. The international aspects of the problem are also dealt with in this volume.

ANNOTATION: Although testimony is included on ground disposal of low-level wastes, no mention is made of trench covers.

ANNOTATION: The hearings dealt mainly with high-level waste. The testimonies of Marcus Rowden and Roger Strelow specifically mention the shallow land burial of low-level waste. Neither of these mention trench covers.

ABSTRACT (from Environline): Hearings were held to consider the management of nuclear wastes from military programs and from civilian nuclear power facilities. How and where to store radioactive waste is the most serious problem needing resolution. Among the subjects discussed were: the role of DOE and NRC in waste management; current management practices and future alternatives; the proposed waste isolation pilot plant; proliferation; and the responsibilities of states and of the nuclear industry for waste management. Testimony was submitted by officials of DOE and GAO, the Governor of South Carolina (where a waste disposal site exists), and others. Correspondence and reports are transcribed.

ANNOTATION: Although several people testifying mention low-level wastes, trench covers are not given much attention. The hearings are mainly concerned with high-level and transuranic wastes.

ABSTRACT: None.

ANNOTATION: The environmental impact statement deals mostly with high-level waste, spent fuel and transuranic wastes. No details on trench cover design are included.
ABSTRACT: This document summarizes the report, "Waste Disposal Practices and Their Effects on Ground Water." All material presented in the Executive Summary is duplicated in the full report so that it will stand alone as a complete document.

ANNOTATION: Several methods of waste disposal are discussed, including landfilling. The problem of leachate from landfills is discussed, but landfill covers are not specifically dealt with.
Summary of Beneficial and Adverse Environmental Impacts:  
a. Foremost, application of the proposed Guidelines will contribute to significant overall improvements in environmental quality. Specifically, beneficial impacts can be expected for groundwater quality, surface-water quality, and air quality, as well as in the areas of increased protection of public health and safety.  
b. Existing facilities employing Guidelines recommended technologies to upgrade operations should eliminate or reduce to acceptable levels the adverse environmental effects resulting from present practices.  
c. Utilization of the Guidelines' recommendations should enable new and planned landfill disposal facilities to be sited, constructed, operated, and maintained in a manner that ensures a reasonable degree of protection for environmental resources and for the public welfare.  
d. Incorporation of the Guidelines recommended considerations and practices in landfilling solid wastes will increase energy usage for the design, installation, and operation of new technologies and consequently, increase the economic cost of landfill disposal of solid wastes.  

ANNOTATION: The guidelines for trench covers recommend a minimum of 6" of clay (K = 1 x 10^{-7} cm/sec) followed by 18" of top soil. Kaolinite and illite are noted as being better than montmorillonite for resisting shrink/swell dessication and cracking. Design modification and additives can be used to reduce runoff and permeability.
ABSTRACT: None.

ANNOTATION: The material underlying the trenches at Sheffield is "silt, loess, clay and sand overlying a shale." Movement of tritium in the ground water is noted. There is no discussion of the trench covers.

ABSTRACT: None.

ANNOTATION: This is a brief summary and does not mention trench covers.

ABSTRACT: None.

ANNOTATION: This article deals only with high level wastes.

ABSTRACT: The fissioning of uranium in a nuclear power reactor results in the production of two broad categories of solid radioactive materials: the high-level radioactivity of the irradiated fuel, and the low-to-intermediate radioactivity of miscellaneous reactor wastes. The latter includes the concentrates from various process systems that ensure that only minute amounts of radioactivity are emitted into the environment of the generating station site. For more than ten years, Ontario Hydro has been operating a centralized program for the management of miscellaneous reactor wastes at its Bruce Nuclear Power Development, between Kincardine and Port Elgin. The site facilities include both shallow in-ground and above-ground storage structures tailored to different types of waste and a radioactive waste volume reduction facility consisting of a radioactive waste incinerator and a mechanical compactor.

ANNOTATION: Low-level reactor wastes are stored in 10 ft. by 10 ft. by 32 ft. reinforced concrete vaults. The walls are 15 inches thick, with a 12-inch-thick lid. Only solid wastes are stored in the trenches. Water around the trenches is being monitored. No specific mention is made of trench covers.
Volclay Soil Laboratory. 1975. USE OF BENTONITE AS A SOIL SEALANT FOR LEACHATE CONTROL IN SANITARY LANDFILLS. 35 p.

ABSTRACT: None.

ANNOTATION: Bentonite can be sandwiched between soil layers to reduce infiltration. In sanitary landfills, the bentonite must be kept separated from the waste.
ABSTRACT: Since the mid-1940s, in excess of 250,000 m$^3$ of low- and intermediate-level radioactive solid waste, generated in operations at the Los Alamos Scientific Laboratory (LASL), has been disposed of by on-site shallow land burial and retrievable storage in dry volcanic tuff. Guidelines have been developed at LASL which regulate the construction of waste disposal facilities, burial and storage operations, disposal site maintenance and restoration, and documentation of all waste disposal activities. Monitoring programs at the past and current solid waste disposal sites have continued to show that, with the exception of low levels of tritium, no migration of contaminants away from their disposal location has been detected.

ANNOTATION: The major potential release pathways at LASL are infiltration in the wastes and erosion of the tops and sides of the mesa in which the wastes are buried. Pits are used for waste disposal. The pits are filled to 1 m from the top of the pit. The pits are backfilled with tuff and additional tuff is mounded over the pits to a depth of 1 m or more at the center of the pits. The covers extend at least a meter beyond the perimeter of the pits. The tuff cover is then covered by 10 to 15 cm of topsoil and seeded to control erosion.
ABSTRACT: This publication contains the proceedings of the Twelfth Midyear Topical Symposium of the Health Physics Society on Low-Level Radioactive Waste Management held in Williamsburg, Virginia, February 11-15, 1979. There are fifty-seven papers included covering such topics on radioactive waste management as: (1) the origin, (2) handling and transportation, (3) disposal operations and alternatives, (4) regulatory aspects, (5) environmental, and (6) public health aspects.

ANNOTATIONS: Nine of these papers have their own entry in this bibliography.

ABSTRACT: For 33 years Oak Ridge National Laboratory has routinely disposed of its radioactive solid waste by burial in shallow trenches. Burial of such waste can afford permanent isolation of the contaminants from man's environment, provided that the radionuclides, if leached from the waste, can be confined by geochemical processes to the geologic medium. However, mounting evidence indicates that some of the radionuclides from some of the burial areas at this facility have been transported in ground water and released to the surface and fluvial environments.

Several factors appear to have contributed to this problem. Among the hydrogeologic factors are the large amounts of annual precipitation, shallow depth to ground water, low permeability of the weathered shale underlying the sites, short distances between burial areas and drainages, and fracture and solution openings in the underlying rock that diminish the rock's sorptive efficiency. The potential for transport of radionuclides to land surface has been enhanced by a long period of operational practices conducive to the saturation of waste with water, and a dearth of site-specific monitoring that might have tested the ability of the geologic medium to retain radionuclides. In view of the burial grounds having become a source of radioactive contaminants in the drainage, some remedial and experimental measures have been implemented within the past few years. Insufficient time has yet passed to evaluate the long-term effectiveness of these measures.

The production of nuclear waste can be expected to increase over the next few decades as a result of expansion of the nuclear industry and increased use of nuclear power; this implies a need for new waste burial areas in this country. It would be prudent to recognize the causes of problems at existing sites and to be mindful of these factors in the design and operation of new sites.

ANNOTATION: At Oak Ridge, some trenches extend below the water table. Radiation has left the trenches through seeps, plant uptake and ground-water discharge. Experimental covers use a mixture of native soil and bentonite. Other remedial measures to reduce infiltration include clearing trees and other deep-rooted plants, filling cavities caused by trench cover collapse and paving runoff collectors. At the time the article was written, it was too early to assess the effectiveness of these measures.

ABSTRACT: This citation is for an abstract only.

ANNOTATION: There is no discussion of trench covers.
INTRODUCTION: A survey was conducted to measure the ranges of radioactivity in trench and groundwaters at commercial low-level radioactive waste disposal sites. At present, there are six licensed commercial sites for the burial of low-level radioactive wastes in the United States. These sites are located in Richland, Washington; Beatty, Nevada; Barnwell, South Carolina; Sheffield, Illinois; Maxey Flats (Morehead), Kentucky; and West Valley, New York. It is estimated that a total of 423,000 m$^3$ of waste has been buried at these sites between 1962 and 1976. Based on an estimated total burial capacity of 2,800,000 m$^3$ and on projections of future waste generation, it is anticipated that the six existing sites will be filled by 1990.

ANNOTATION: A wide range of water quality was seen from the various trenches. Trench covers are not discussed.

ABSTRACT: Currently the United States Geological Survey is conducting a study of the hydrogeological and geochemical behavior of commercially operated low-level radioactive waste disposal sites. The data collected from this study will be used to establish criteria for selection of new sites for disposal of radioactive wastes. As part of this study, water samples from trenches at the Maxey Flats, Kentucky, site were analyzed at Brookhaven National Laboratory to determine the source terms of the radionuclides and other components in solution in the trenches. Procedures for collection and filtration of the samples under anoxic conditions are described. The samples were analyzed for inorganic, radiochemical and organic constituents. The inorganic analysis includes the measurements of pH, specific conductance, alkalinity, and various cations and anions. The radionuclides were measured for gross alpha, gross beta, tritium, and gamma activities, followed by specific measurements of strontium-90 and plutonium isotopes. The organics were extracted, concentrated, and identified by gas chromatography/mass spectrometry. Considerable quantities of organics were found in most of the trenches; however, the organic composition of the trench waters vary. The presence of a variety of organic compounds in trench waters suggests that they may play an important role in the transport of radionuclides.

ANNOTATION: The trenches were covered with soil and planted with shallow rooted plants to prevent erosion.
ABSTRACT: Shallow land burial is intended to provide a waste emplacement with low probability for the release of radionuclides to the environment, and to provide a barrier against encroachment on the waste by man or his activities. Additionally, the emplacement conditions are designed to insure that a potential release cannot result in unacceptable radionuclide concentrations in man's environment. Site control requirements are intended to prevent unacceptable use or accidental excavation of the waste disposal site. Evaluation procedures generally provide definition of the containment capability of the site under present environment conditions. Long-term care requirements can continue site control measures, and provide a continuing check on the containment capability. However, significant changes in climate, hydrology, plant cover and land use which might alter the containment potential can occur in a time from of tens to hundreds of years, and true "perpetual" care cannot be guaranteed. This paper considers the possible long-term consequences of radionuclide uptake by plants and burrowing animals, or changes in site hydrology, and of inadvertant excavation of the buried waste by man at some distant future date.

ANNOTATION: The trench covers are described as having been constructed with trench material and planted to prevent erosion.

ABSTRACT: A state-of-the-art computer code has been developed that calculates the transport of pollutants through soils. The computer code calculates the one-dimensional transient response of a soil column to infiltrating water carrying a pollutant that interacts with the soil. The soil can initially contain a specified amount of water (0-100% of pore volume), and the surface boundary conditions can reflect either a variable rainfall or a variable pond height. The interaction includes both absorption and diffusion. These are the dominant interaction mechanisms for most heavy metals. However, the structure of the code is such that other mechanisms can be easily incorporated. Because of these capabilities the code is applicable to the evaluation of shallow land burial sites typically utilized for disposal of low-level radioactive wastes.

The process of modeling should not only produce manageable abstractions of reality but also focus on important characteristics of the system modeled. Among the major factors governing the movement of pollutants from residuals down through the soil profile are the characteristics of the residuals and the soils. Among the former are hydraulic conductivity (the ability of the material, sludge, etc., to transport fluid), leachability (the parting of soluble constituents under the effects of the percolating liquid), the extent of release of particulates (the washing out of suspended solids), the chemical behavior of interstitial fluids, and the presence of complexing agents. Important soil characteristics are hydraulic conductivity, the chemical environment, and the microbial environment.

The utilization of such a computer code requires that available data be examined and field investigations initiated as necessary to establish the physical properties that comprise the input to the code. Then the leachate characteristics of the soil would be experimentally determined in order to precisely establish the conductivity of the soil and to quantify the interaction mechanisms between the radionuclides and the soil. Finally a calculational parametric survey of the soil response would be performed.

The product of this assessment would be concentration-time and flux-time curves at depths corresponding to aquifers. These results would be used to determine the bottom-line impact, that is, the concentration of radionuclides in the aquifers surrounding an actual or proposed burial site.

ANNOTATION: No mention is made of trench covers.
ABSTRACT: To plan for the postoperational surveillance and control of the Savannah River Plant solid waste burial site, a model is being developed to simulate movement of radionuclides from buried solid wastes through the environment to man. Results from the study of the model will be used to validate current operating limits for burial and to establish criteria for future surveillance and control. A preliminary model has been formulated to estimate the rate and extent of $^{90}$Sr movement through a set of aquatic (ground water, creeks, and river) and terrestrial (vegetation, animals, and dust) pathways. Estimates based on pessimistic assumptions show that drinking water from the shallow ground water table in the burial region is the critical pathway for dose-to-man. Current and planned experimental programs to refine model parameters will be presented.

ANNOTATION: This article deals with the Savannah River Plant where no deep-rooted plants are allowed in the waste burial area.

ABSTRACT: None.

ANNOTATION: Although the report does not deal with cover design, it is a valuable source on modeling ground-water movement in the vadose zone.

ABSTRACT (from Envirolin): Environmental concern about radioactive wastes has focused on four areas: the difficulty of isolation and containment; the relative danger of different kinds of radiation; the forms of existing waste; and the location and type of disposal sites for radioactive waste. In March 1979, the Federal Interagency Review Group on Nuclear Waste Management reported that the feasibility of dry storage in geological repositories remained to be established. The safety of projected nuclear waste storage at the waste isolation pilot plant in Carlsbad, New Mexico, is under question. Research on the health effects of radiation exposure is summarized, and the effects on living cells of various types of radiation-alpha, beta, gamma, and neutron are discussed. Also discussed are characteristics of and problems posed by the following forms of radioactive waste: mill tailings, low-level wastes, intermediate waste liquids, transuranic wastes, airborne emissions, high-level wastes, and spent fuel. Nuclear decontamination and reactor decommissioning hazards are considered.

ANNOTATION: The author looks at the problem of nuclear wastes from an environmentalist's viewpoint.
ABSTRACT: This paper describes the hydrogeologic properties and origin of pore water in clayey glacial till and glaciolacustrine clay in six areas in south-central Canada, including four in southern Ontario, one in southern Manitoba, and one in south-central Saskatchewan. At each of the sites the water table is within the depth range of one to four meters. The results are appraised in light of a concept for long-term isolation of solid low-level radioactive wastes in large-diameter holes augered to depths of tens of meters below the water table. With the exception of one of the study sites, the sites are only research sites and are not under consideration for radioactive waste management. One of the sites is highly fractured, but at all other sites fractures were detected only in the surficial weathered zone. At all of the sites except one, a major component of Pleistocene-age groundwater was identified at depth. Mathematical analysis and the isotope data indicates that groundwater flow in these deposits is so slow that molecular diffusion rather than groundwater advection is the dominant process of solute migration below the weathering zone, even in zones where fractures are known to occur. Diffusion controlled subsurface regimes are the most favorable for waste disposal.

ANNOTATION: Burial beneath the water table in unweathered clay till is suggested because the low hydraulic conductivity of some tills causes diffusion to be the dominant transport process. Of four sites studied, three had calculated vertical linear groundwater velocities of 5 or less cm/year. At all sites the horizontal component of velocity was negligible.

Annotator's note: Entries 200-208 are not in alphabetical order because they were reviewed after the plates were made for publication. We decided to add them at the end rather than exclude them.

ABSTRACT: After the evaluation of more than 400 landfills, the Windham, Connecticut, landfill was selected for the implementation of a remedial action program. For the present study, SMC-MARTIN drilled additional wells to determine the thickness of the refuse, the depth of the water table under the landfill, the depth to bedrock and groundwater quality. An electrical resistivity survey was conducted in order to define the areal extent of the leachate plume.

Remedial action alternatives evaluated for this site included: regrading, revegetation, surface sealing, groundwater cutoff, and plume management. The first three methods proved to be the most cost effective. Suction lysimeters, pan lysimeters, staff gauges, and monitoring wells were installed to determine water movement into the landfill and the effectiveness of the remedial measures.

During the summer of 1979, a remedial program was implemented. The site was regraded, gas vents were installed, and 15 cm (6 in) of sand and gravel were emplaced with an additional layer of 10 cm (4 in) of fine-grained sand washings to protect the surface seal. A 20-mil PVC membrane seal was emplaced and covered with 46 cm (18 in) of sand and gravel into which composted sewage sludge and leaves were disced. Revegetation will be accomplished by hydroseeding with a mixture of grasses. Monitoring is being conducted to determine the effectiveness of the membrane seal.

ANNOTATION: No data was available on the effectiveness of the new landfill cover at the time of publication.
ABSTRACT: A comparative analysis of the most viable alternatives for disposal of solid low-level radioactive wastes is presented to aid in evaluating national waste management options. Four basic alternative methods are analyzed and compared to the present practice of shallow land burial. These include deeper burial, disposal in mined cavities, disposal in engineered structures, and disposal in the oceans. Some variations in the basic methods are also presented. Technical, socio-political, and economic factors are assigned relative importance (weights) and evaluated for the various alternatives. Based on disposal of a constant volume of waste with given nuclear characteristics, the most desirable alternatives to shallow land burial in descending order of desirability appear to be: improving present practices, deeper burial, use of acceptable abandoned mines, new mines, ocean dumping, and structural disposal concepts. It must be emphasized that the evaluations reported here are generic, and use of other weights or different values for specific sites could change the conclusions and ordering of alternatives determined in this study. Impacts and costs associated with transportation over long distances predominate over differences among alternatives, indicating the desirability of establishing regional waste disposal locations. The impacts presented are for generic comparisons among alternatives, and are not intended to be predictive of the performance of any actual waste disposal facility.

ANNOTATION: The shallow burial concept basically consists of burying the waste in trenches at a depth of 3 to 6 m and covering the waste with about a meter of soil. Specific characteristics of existing sites are given in an appendix. Migration if ions from the trenches has occurred due to water entering the trenches, but this release has not posed a threat to the public.

Improvements to the shallow land burial technique that were studied include improving the trench cover, better trench design, improved operational and water management techniques, improved waste forms and in-situ encapsulation of the buried wastes. Improved cover materials considered include clay or bentonite, soil additives, asphalt, plastic membranes and stainless steel. The clay cap would include one meter of clay which would overlap the caps of adjacent trenches, one meter of soil to prevent cracking and a final cover of crushed rock for erosion and animal control. In terms of cost, maintenance and self healing of cracks, this appears to be the most attractive alternative discussed.
ABSTRACT: To aid the U.S. Nuclear Regulatory Commission (NRC) in developing regulations for management of low-level radioactive waste, Ford, Bacon & Davis Utah, Inc. (FB&DU) is investigating possible waste disposal alternatives. A systematic method for categorizing these disposal alternatives which provides assurance that no viable alternatives are overlooked is reported. Alternatives are categorized by (1) the general media in which disposal occurs, (2) by whether the disposal method can be considered as dispersal, containment or elimination of the wastes, and (3) by the applicability of the disposal method to the possible physical waste forms. A literature survey was performed and pertinent references listed for the various alternatives discussed. A bibliography is given which provides coverage of published information on low-level radioactive waste management options. The extensive list of disposal alternatives identified was screened and the most viable choices were selected for further evaluation. A Technical Advisory Panel met and reviewed the results. Suggestions from that meeting and other comments are discussed. The most viable options selected for further evaluation are: (1) improving present shallow land burial practices; (2) deeper depth burial; (3) disposal in cavities; (4) disposal in exposed or buried structures; and (5) ocean disposal.

ANNOTATION: A brief history of shallow land burial and a general description of burial sites is given. In general, covers are up to 3 m thick, mounded, graded and often seeded with shallow rooted vegetation. Clay has been used to decrease cover hydraulic conductivity at some sites. Burial at depths of 10-15 m and engineered covers suggested alternatives over current practices.

COMMENTS REGARDING THIS REPORT: The aim of this report is to summarize and interpret pertinent information, primarily for those who may be involved in the evaluation and approval of proposed waste burial operations. This may be helpful for personnel of states and industries and their consultants. The information is not exhaustive and is presented briefly because complete details could not be obtained in this limited study.

Having in mind that summaries of acceptable practice are needed, conclusions and recommendations are included in the report. These are presented as informal suggestions rather than authoritative guidelines. If more systematic development of a guide is desired, these problems and the material in this report might be reviewed by some representative professional committee, which could then report a broad consensus of qualified opinion. Finally, the report has included in an appendix two selected examples of hydrogeological evaluations of proposed waste burial sites from the viewpoint of radiological safety.

ANNOTATION: The characteristics and operations procedures of the five commercial sites are discussed. Little mention is made of the trench covers. More detailed hydrogeologic descriptions are given of the Beatty, Nevada and Sheffield, Illinois sites.
SUMMARY: As a conclusion from the Nordic study on reactor waste it can be stated that the major tools are available to perform a careful safety analysis of specific management systems for reactor waste. Some further refinement would be useful mainly concerning the pathways for nuclide migration from repositories. Added knowledge will most certainly still further reduce the already low calculated radiation doses to man.

ANNOTATION: Storage, transportation and disposal of low and intermediate level waste arising from daily operation of nuclear power plants are discussed. The prime options for final disposal include shallow land burial, man-made structures, near-surface geological formations. Covers are not specifically discussed. Because of varying mechanical, physical and chemical properties, a combination of barriers is preferred to a single barrier to minimize the change that a single mechanism will destroy the barriers.

ABSTRACT: The U.S. Environmental Protection Agency contracted with the six states having commercial burial facilities for low-level radioactive wastes to obtain inventories of the types and quantities of wastes buried at these six sites. A compilation and interpretation of the inventory data is presented in tables and figures. Projections are made to the year 2000 of the quantity of low-level radioactive wastes that will result from the nuclear fuel and nonfuel cycle sources. In addition, assumptions are made relating these projections to the available capacity and operational life of the commercial sites. Based on estimates of waste generation rates, it is indicated, assuming present operational practices, that by the year 1998, the six existing sites will exhaust their current burial capacity.

ANNOTATION: Trenches are discussed, trench covers are not. In a typical trench, the solid waste has voids and the top meter of the trench is not used for waste. This results in a 30% void space for each trench.
ABSTRACT: Gas pressure in the unsaturated parts of radioactive waste-burial trenches respond to fluctuations in atmospheric pressure. Measurements of atmospheric pressure and the differential pressure between the trench gas and the atmosphere on several dates in 1977-78 were used to calculate hydraulic conductivity of the reworked silty-clay till that covers the trenches.

Generally, the hydraulic conductivity of covers over trenches that had a history of rapidly rising water levels is higher, at least seasonally, than that of covers over trenches in which the water level remained low. This supports the hypothesis that recharge occurs through the cover, presumably through fractures caused by desiccation and/or subsidence of the cover.

Hydraulic conductivities of the covers, as calculated from gas and air-pressure measurements at several trenches, were 100 to 1,000 times greater than those calculated from the increase in water levels in the trenches. This difference suggests that the values obtained from the air- and gas-pressure measurements need to be adjusted and are at present not directly usable in groundwater-flux calculations. The difference in magnitude of values may be caused by a rapid decrease in hydraulic conductivity during periods of recharge or by the clogging of fractures with sediment washed in by runoff.

Although the values calculated from air- and gas-pressure measurements are only relative, the method seems suitable for monitoring temporal changes in the hydraulic conductivity of a cover and for comparing hydraulic conductivity of trench covers of differing composition and structure.

ANNOTATION: Most of the infiltration at the West Valley site is caused by cracks in the till covers. Since the size of the cracks are dependent on the weather, the hydraulic conductivities of the covers vary seasonally. No method of improving the covers is proposed.

INTRODUCTION: At the present time, low and medium level wastes (placed in cannisters) are isolated from infiltration water by highly impermeable materials such as asphalt or clay which cap the burial facility. These caps may initially keep the cannisters dry, but their long term ability to do so is suspect. Asphalt tends to deteriorate with time; clay tends to crack when subjected to wetting and drying cycles.

An alternative to utilizing fine-textured materials as trench caps was first mentioned by Corey and Horton (1969). They suggested that medium and coarse textured materials, if properly layered, have the potential to serve as effective trench caps. Their experimental studies indicated that if a column of dry loam (or fine sand) overlying dry gravel was subjected to infiltration, then water entry into the gravel would not occur until moisture levels directly above the interface approached saturation. A waste facility designed so that moisture movement in the finer textured material took place only under partially saturated conditions would allow the gravel layer to remain dry and act as an "umbrella" over the waste. The inherent stability of the materials used would insure that the facility would not deteriorate over time.

The ability of unsaturated gravel to impede moisture flow, or more properly, the water retention capacity of a soil overlying a coarse material such as gravel, has been termed the wick effect. This phenomenon has been observed in many laboratory and numerical simulations involving moisture infiltration into partly saturated systems where the underlying material is substantially coarser than the material above. Previous work on the application of the wick effect to burial cap design has simply assumed that moisture movement into the coarse layer will not take place until pressure potential at the interface achieves a value of zero. A numerical simulation of one dimensional flow through a layered, unsaturated column will be utilized to test the error involved in this simplifying assumption.

ANNOTATION: Simulation showed that unsaturated gravel can act as an effective moisture barrier if overlain by unsaturated, medium-textured material, but that the effectiveness of this barrier has been overrated. For a simulation in which rainfall was followed by a period of redistribution, the gravel barrier was the least effective.