of the salt during Quaternary time has averaged only a few miles per million years. Also, in central Kansas present rates of denudation have been found to average less than 1 ft per 1,000 years while stream incisions in the same area during Quaternary time have not exceeded several hundred feet. Finally, investigations have revealed that the buried wastes would not be affected adversely by the advance of a new continental ice sheet.

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GEOHYDROLOGY OF BURIED TRIASSIC BASIN AT SAVANNAH RIVER PLANT

At the Savannah River plant near Aiken, South Carolina, as at other locations where there are chemical-separation plants for the processing of nuclear fuels, the high-level radioactive wastes are stored in concrete-and-steel tanks buried just beneath the surface of the ground. This waste is of such activity and longevity that it cannot be dispersed into the environment, but it must be contained for periods of time extending at least into hundreds and perhaps thousands of years. One concept for the terminal containment of this waste is to store it in excavated chambers within the bedrock, which is covered by about 1,000 ft of coastal plain sediments at the plant site. As part of the safety evaluation of this concept, the geology and hydrology of both the coastal plain sediments and the bedrock have been studied. Intensive investigation of bedrock waste storage now has been postponed indefinitely while other concepts of waste storage and management are being investigated.

A buried Triassic basin that might have potential for waste storage was discovered beneath the southern third of the plant site. Investigation into the characteristics of this basin was started in 1971. This was not an engineering on design study but was aimed at understanding the geohydrology of the Triassic basin to determine its compatibility with the safe storage of waste.

Seismic surveys, gravity and magnetic surveys, and the drilling of several exploratory wells indicate that the Triassic basin is about 30 mi long, 6 or more mi wide, and perhaps 5,300 ft thick. One well penetrated the Triassic border, a second was in the center of the basin, and a third investigated an intrabasin fault. The rock is predominantly mudstone of very low permeability, with a few lenses of poorly sorted gritty sand. The water yield of all the exploratory wells is extremely low, and water-transmitting fractures are virtually nonexistent.

In 2 wells within the basin, heads above land surface have been measured that cannot be explained by connection with a recharge area. Ten possible explanations have been evaluated: aquifer head, fossil head, tectonic compression, rapid loading and compaction of sediments, water derived from igneous intrusions, infiltration of gas, precipitation of minerals, phase changes, temperature increase, and osmotic membrane phenomena. Systematic evaluation, particularly of the time for dissipation of the elevated head to the head of its surroundings, eliminates most of these explanations. Those that remain as possible explanations are: tectonic compression, temperature increase, and osmotic membrane phenomena. It is not known at present whether the high head is general over the entire basin or only in segments of it.

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DESIGN, DRILLING, COMPLETION, OPERATION, AND COST OF UNDERGROUND WASTE-DISPOSAL WELLS IN GULF COAST REGION OF TEXAS AND LOUISIANA

The first factor in considering the feasibility of underground waste disposal is the quality of the waste stream. A practicable method or methods of removing suspended solids must be planned. Equally important is that the effluent be chemically stable, after filtration, under elevated temperature conditions of the injection zone. Compatibility of the waste with the indigenous brine is necessary to avoid plugging. The disposal well is the final filter in the waste-disposal system; it is the nature of filters to become plugged, and a filter several thousand feet underground is difficult to clean and the cleaning process is usually expensive.

Once the suitability of the waste stream for underground waste disposal has been determined, the reservoir must be selected. Existing knowledge of the subsurface gained from oil and gas exploration will provide enough data to plan the well depth at which several probable reservoirs will have been penetrated. Sand parameters measured in the disposal well will permit selection of the most suitable reservoir. The geologic subsurface study will provide information as to the areal extent and thickness of probable reservoirs.

Well design must meet state requirements for protecting surface freshwater sands and confining the waste to the selected reservoir. Drilling and well-completion techniques, including casing and cement selection to meet corrosion protection needs, should all be planned so as to offer maximum protection against failure of any part of the waste system.

The quantity and quality of the waste stream, the type and size of drilling equipment, and the type of contract used are the principal factors affecting the cost of a disposal well. Area experience with drilling conditions and potential problems, together with a good equipment and material-inspection program, will produce surprising cost reducing results.

Operating an underground disposal well properly is just as important to success as good well design and good reservoir selection. Operating personnel should receive careful training in how to handle new waste sources and maintain good instrumentation and records. A dependable underground disposal system should include a standby or alternate well.

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POTENTIAL IMPACT OF COMMERCIAL LOW-LEVEL RADIOACTIVE-WASTE DISPOSAL PRACTICES ON HYDROGEOLOGIC ENVIRONMENT

The present practices, trends, and conditions in the shallow land burial of "low-level" radioactive wastes have a potential impact on the hydrogeologic environment and on environmental safety. New data are available from recently conducted inventories and surveys of operating conditions at the 6 commercial radioactive waste burial facilities in the United States.

"Low-level" radioactive wastes (as defined by the AEC) are being buried under widely differing conditions caused by local variations in geology, hydrology, weather, and operating procedures. The wastes themselves vary greatly in character from relatively harmless (due to decay or dilute concentration) to extremely hazardous (due to chemical or radioactive toxicity). Other new data include: (1) the potential environmental impact which present trends in "low-level" waste character and quantities pose to the hydrogeologic environment and environmental safety; (2) specific areas where better knowledge of waste—hydrogeologic interrelations may be needed; and (3) recommendations concerning present practices, or as necessary, for acquiring the information required to evaluate present practices.

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DECISION MAPPING—TOOL FOR UNDERGROUND WASTE MANAGEMENT

Deep-well disposal is one possible method for disposing of waste liquids. Serious concern must be given to the degrading effects on the subsurface environment that such a practice may involve. Yet probably there are geohydrologic basins suitable for injection of waste. At the same time, need for the detailed, and probably very costly, investigations of such basins that must precede injection should not be minimized.

The attractiveness of deep-well disposal usually is related to the favorable costs for injection compared with other disposal methods, such as high-temperature incineration, encapsulization, or others. Presuming that a given sedimentary unit has been evaluated thoroughly and found quantitatively and qualitatively suitable for waste injection, one still must evaluate whether it is more economically desirable to have each operator drill his own disposal-well facility, or whether it is more advantageous to collect the waste of several operators for disposal in a common well or wells. The economic scale advantages of centralized processing must be balanced against the costs of transporting the waste to the centralized facility. The optimal configuration of a centralized disposal system depends on the relative level of these costs. An additional advantage of centralized waste disposal is the greater effectiveness with which local, state, and federal development and operating regulations may be enforced.

We have developed a general mathematical model which allows rough optimization of a multisource, variably distributed system based on limited data. The model is expressed in terms of a decision map which indicates the optimal configuration to serve distributed sources of waste and illustrates the sensitivity of the configuration to important parameters, such as mean-source separation and waste load, which characterize the source population. Application of this economic model provides additional input to the waste-management authority who must integrate these data with environmental factors to produce a final recommendation.

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FEASIBILITY STUDY OF LIQUID-WASTE INJECTION INTO AQUIFERS CONTAINING SALT WATER, WILMINGTON, NORTH CAROLINA

An experimental system to inject liquid industrial waste into deeper sedimentary aquifers containing salt water was installed by Hercules, Inc., at Wilmington, North Carolina, in the spring of 1968, under a permit issued by the State Board of Water and Air Resources. The initial experimental system consisted of 1 injection well and 3 observation wells completed between depths of 850 and 1,050 ft, and 1 observation well completed in the next higher aquifer at a depth of about 700 ft.

The injection zone is an aquifer consisting of sand layers and some thin beds of limestone interbedded with silty sand and sandy silt. The aquifer has low permeability and productivity. The water in the aquifer is salty, with a natural artesian head of about 65 ft above land surface.

The system was placed in operation in May 1968, injecting the by-product from the manufacture of dimethyl terephthalate (DMT).The liquid, deaerated and filtered through 200-μ mesh screen, consisted of water containing acetic and formic acids with some methanol and having a pH of about 4. The maximum injection rate was about 200 gal/minute.

The pressure in the injection and observation wells rose sharply during the first few months of operation. By September 1968, the waste had passed the observation wells which were only 150 ft from the injection well, making the system obsolete for observing the rate and direction of waste movement through the aquifer. By June 1969, the injection well had become plugged with sand, and a new system was designed.

A new injection well and a part of the new observation-well system were completed and placed in operation in January 1971. One of the initial observation wells also was used for injection of part of the waste. Additional observation wells were added, and in 1972 the monitor system consisted of 6 wells completed in the injection zone at distances of 1,500–2,000 ft from the points of injection, 3 wells completed in the 700-ft zone, and 1 well completed in the 300-ft zone. The monitor system and data-collection program have provided much useful information on injection of this type of waste in relatively shallow sedimentary rocks.

The long-term feasibility of such a system appears doubtful, as the aquifer does not appear to be sufficiently permeable to accept the waste at a continuing rate of 200 gpm. Considerable difficulty also has been encountered in maintaining the injection and observation wells.

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HYDROGEOLOGY OF LIQUID-WASTE STORAGE IN FLORIDA

Restrictions on surface-waste disposal practices have caused many to look to subsurface storage of liquid waste in deep saline aquifers as a most practicable and economical alternative. Also, temporary subsurface storage of excess storm runoff and treated sewage as potential sources of fresh water to augment supplies in water-short areas is being investigated. Liquid wastes are being injected into deep, saline, carbonate aquifers at sites in the western panhandle and the southern peninsula of Florida. Additional sites are being considered in the central peninsula. The wastes, including acidic, high-oxygen-demand industrial plant effluents and variable temperature and density, secondary sewage plant effluents, and oil-field brines, are injected into permeable saline zones separated from shallower freshwater aquifers by one or more confining layers which have very little or practically no permeability. There are distinctive differences in stratigraphy between the panhandle and the peninsula of Florida. Hence, the geologic and hydrologic environments for subsurface waste storage also are different.

At a site near Pensacola, in western Florida, acidic liquid waste has, for nearly 10 years, been injected into a 1,400–1,700-ft deep, moderately permeable, carbonate zone of late Eocene age, separated from shallower freshwater aquifers by a widespread, 200-ft thick, nonpermeable, confining, plastic clay layer of middle Oligocene age. The calculated pressure effects of this injection now extend outward more than 30 mi. The