UNITED STATES GEOLOGICAL SURVEY'S HYDROGEOLOGICAL RESEARCH PROGRAMS AND PLANS RELATED TO DISPOSAL OF RADIOACTIVE WASTE INTO GEOLOGIC FORMATIONS

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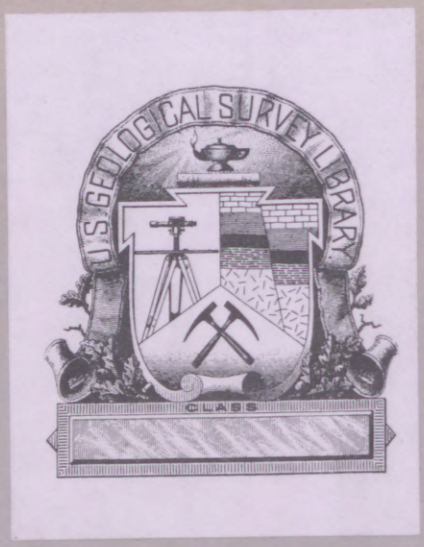
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By George D. DeBuchananne (Avrnale) 1919- and William S. Twenhofel (Stephens), 1918-

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UNITED STATES DEPARTMENT OF THE INTERIOR

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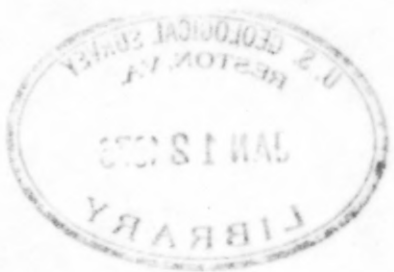

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November 1975

UNITED STATES GEOLOGICAL SURVEY'S HYDROGEOLOGICAL RESEARCH PROGRAMS AND PLANS RELATED TO DISPOSAL OF RADIOACTIVE WASTE INTO GEOLOGIC FORMATIONS

By George D. DeBuchananne[1/] and William S. Twenhofel[2/]

SUMMARY

The Geological Survey, United States Department of Interior, has cooperated with the United States Energy Research and Development Administration, formerly the Atomic Energy Commission, for more than 30 years on research related to the disposal of radioactive waste into geological formations. Results of most of this research effort have been published or otherwise released and references to them are in lists of publications of the Geological Survey. Hydrogeological field studies currently underway evaluate bedded salt deposits in New Mexico and Utah, a salt dome in the Gulf Coast region, and shales in the Rocky Mountain area for their potential as host geological formations for high-level waste repositories. Detailed field studies of the potential migration of waste nuclides from shallow land burial sites of low-level waste in Idaho and Tennessee are also underway.

As a part of its own research program, the Geological Survey has initiated geochemical and digital model studies of waste transport at four of its research centers. At the same time field

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studies on the hydrogeology of four state-owned low-level radioactive solid waste burial grounds are being made to provide the field observations of waste migration needed to test the theoretical and laboratory approaches. Hydrogeological criteria will be developed for use in the selection of future radioactive waste disposal sites.

INTRODUCTION

Since the beginning of the Atomic Age, man has known that disposal of radioactive waste would be a serious problem due to the longevity and toxicity of the waste products. It has also been apparent that, as most of the wastes are either in liquid or solid form, disposal is basically an earth-science problem that requires an understanding of the ultimate fate of the waste nuclides after disposal. Originally it was thought that it would be possible to release some of the nuclides directly to the hydrosphere, disposal of some in shallow burial grounds (landfills), and inject the liquid waste into deep saline aquifers that were of no economic value to man. Subsequent experience, however, has shown that the problem is more complex than originally considered and, even after more than 30 years of nuclear development, there appears to be no one simple fool-proof solution. The risk of various disposal alternatives in different geohydrologic environments is not yet known.

Nuclear chemists, engineers, and physicists should pursue the research necessary to determine the chemical and physical forms and characteristics (solubility, stability, and so forth) of different waste products prior to their storage, and the man-made facilities required to emplace and hold them, but it remains for the earth scientist to identify and describe the processes and principles of waste migration from the storage facility or point of discharge.

The Geological Survey has had a long history of working with the Atomic Energy Commission (AEC) now the U.S. Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC) on site selection for nuclear generating plants, laboratories, and processing plants; related water-supply problems; and evaluating the effects of underground weapons tests on rocks and water, but generally has worked only on part of the radioactive waste disposal problem. Although the Geological Survey participated in the preliminary evaluation of some disposal sites selected by ERDA or others, and has studied specific disposal sites after the site has been in use and problems had developed, most waste-disposal sites were selected and administered by contractors under the supervision of ERDA. Recently, however, the Geological Survey was requested by the United States Congress to develop hydrogeological criteria to be used in the selection and location of sites for future shallow burial of low-level radioactive waste. Natural hydrogeological processes and principles that control migration of low-level waste are, however, with the exception of those processes concerned with thermal effects and radiation damage, applicable also to the migration of high-level waste products so that criteria developed for one level of waste can be modified for or applied directly to the other. The Geological Survey has, in the past, evaluated geologic materials relative to high-level waste disposal for ERDA and, presently,

is participating in the evaluation of test drilling of salt deposits in New Mexico for ERDA, yet the responsibility for selection of a waste-disposal site remains with ERDA.

PAST GEOLOGICAL SURVEY HYDROGEOLOGICAL RESEARCH ACTIVITIES RELATED TO RADIOACTIVE WASTE

As you are aware, the United States of America has a wide variety of hydrogeologic environments that have potential for waste disposal. During the past 100 years, the Geological Survey and State Surveys have conducted reconnaissance and detailed resources investigation in most, if not all, of the country. Therefore, some basic hydrogeologic data is available on every hydrogeological environment in the country. The problem then becomes one of relating these reconnaissance-scale data with micro-scale data needed for detailed site-specific evaluations.

Before describing the research and development work contemplated by the Survey, it may be helpful to review some highlights of the Survey's past research work in hydrogeology as it relates to the radioactive waste disposal problems. Much of the work at this time was supported by the AEC. In addition to the reports published by the Geological Survey and listed at the end of this paper, many reports and articles authored by Survey scientists have been published in other Federal and State publications, technical journals, and symposium volumes.

Originally, most high-level radioactive wastes were liquids so an apparent solution to the waste problem was thought to be one of injecting the chemically complex liquids into deep permeable formations.

Working in cooperation with the AEC, Love and Hoover (1961) compiled general information on some 60 major sedimentary basins in the United States to aid in making the final selection of the 10 sedimentary basins that had the highest potential for waste injection. However, before this disposal concept was developed too far, work by Wahlberg, Baker, Vernon, and Dewar (1965) on ion exchange and adsorption characteristics of various rocks and minerals, and Roedder's (1959) work on geochemical and geophysical problems that could be expected in such an injection program, coupled with the poorly known hydrodynamic flow characteristics of deep basins made the subsurface injection of radioactive liquid waste appear to be relatively unattractive.

In the late fifties and early sixties it was believed that salt would be an acceptable geologic environment for the storage of all forms and all levels of radioactive waste. Pierce and Rich (1962) summarized data on all the known salt deposits in the United States. This summary showed that salt, either as bedded salt or as salt domes, occurs in 23 of the 50 United States. These original regional salt studies were used in the selection of the bedded salt deposits in Kansas and later in New Mexico as potential locations for high-level wastes repositories. The Kansas site was abandoned primarily for geohydrological reasons but the New Mexico site is still under active investigation. At the request of ERDA and

their contractors, the Geological Survey has been evaluating seismic, geological, and hydrological conditions at both sites.

During the late sixties and early seventies, the Geological Survey, at the request of ERDA, assisted in the hydrogeologic evaluation of deeply buried crystalline rock underlying the Savannah River Plant in South Carolina, and the deep (1,500 metres) basalts underlying the Hanford Reservation near Richland, Washington, for their suitability for storing high-level radioactive waste. Studies on both projects, however, were suspended and reportedly ERDA has temporarily shelved both programs.

A less publicized bit of research, yet one that may have good potential for the solution of some of the liquid waste problems for countries with limited choices of disposal environment, is the use of hydraulically induced fractures in shallow (300 to 400 metres deep) shales for injection of thin sheets of cement grout containing waste products. Originally adequate methods for either determining or predicting the orientation of such fractures were lacking. Work by R. J. Sun (1974), in cooperation with ERDA contractors, has defined factors controlling the fracture orientation. Subsequent field testing suggests that the results of his work will allow for a more positive and less costly test procedure for ascertaining the acceptability of a site for injection of radioactive grout.

PRESENT GEOLOGICAL SURVEY HYDROGEOLOGICAL RESEARCH PROGRAMS RELATED TO RADIOACTIVE WASTE

The current radioactive waste hydrogeological research programs of the Geological Survey are aimed at both high and low-level disposal problems. As stated before, hydrogeological principles and processes of waste migration are the same regardless of the classification of the waste. However, it must be clearly understood that only the techniques and the concepts of hydrogeological processes and principles can be transferred from one environment to another, not the results of a given investigation--each site problem is unique and must be analyzed as such.

The Geological Survey is continuing to assist ERDA in their overall program of high-level waste disposal and evaluation of shallow land burial of low-level solid waste. A hydrologist is assigned on a continuing basis to work with the ERDA Programming Staff. Joint programs underway and currently planned include the following types of investigations.

In cooperation with ERDA and its contractors, the Geological Survey presently has responsibility for describing and evaluating the hydrogeologic environment and natural seismicity of the Permian salt deposits in the Delaware Basin near Carlsbad, New Mexico. These salt deposits currently are being explored by means of boreholes and core analysis.

The Pierre Shale, a regionally extensive and very thick, flat-lying shale in the Great Plains adjacent to the Rocky Mountains, is being studied in terms of stratigraphy, internal lithology, and internal fracture systems. The first phase of this study would lead to the identification of specific sites for a potential waste repository. A detailed study of the hydrogeologic environment and the seismicity of the selected area will have to be made prior to the design and development of a physical disposal system.

The Salt Valley anticline in Utah is being studied and mapped on the surface and in the subsurface to evaluate the suitability of the salt core of the anticline for radioactive waste storage.

Salt deposits in particular, but other media as well, occur in geologic environments associated with potentially valuable mineral resources such as potash, oil, and gas. Thus, it has been necessary to carefully consider where these resources are located, what is their present and future potential for exploitation and utilization, and whether the geologic disposal of radioactive wastes is compatible with future exploration, development, and recovery of these resources.

At the Nevada Test Site, which is the area dedicated to underground testing of nuclear explosives, the Geological Survey, in cooperation with ERDA, has gathered a large amount of geologic, hydrologic, and geophysical data pertaining to the movement of

radioactive explosion products in volcanic tuffaceous rocks, alluvium, and granitic rocks. These data also are relevant to the evaluation of the potential of these rocks as media for storage of radioactive wastes. The Geological Survey is initiating a compilation and evaluation of the hydrogeologic studies at the Nevada Test Site as the first step in assessing the suitability of some part of the Site for radioactive waste storage. Emphasis will be directed to volcanic tuffaceous rocks, argillaceous rocks, and granitic rocks. In addition, the Survey has nearly completed a compilation of the tectonics, surface hydrology, and seismicity data of the Nevada Test Site as an aid to assessing its suitability, if needed, for surface storage or shallow burial of high-level radioactive wastes. I.J. Winograd's paper on "Radioactive waste storage in the arid zone", published in October 1974, EOS Transactions, The American Geophysical Union, v. 55, no. 10, presents an example of how this area could possibly be used.

Looking toward the direction of future research, the Geological Survey anticipates continued cooperation with ERDA in appraisal and exploration for waste storage sites in various salt deposits. For example, in addition to the New Mexico and Utah salt investigations, studies have just begun on the ground-water hydrology in sediments intruded by one of the salt domes in the Gulf Coastal Plain.

Much hydrogeologic research needs to be directed toward understanding the occurrence and movement of ground water in

argillaceous rocks, and in limestone, granitic, and metamorphic rock terranes in other hydrogeologic environments. At the present time no joint research effort is directed toward understanding ground-water movement in these media, but we are anticipating that an extensive program will be initiated in the near future.

In addition to the joint USGS-ERDA high-level waste program, two field investigations of other than high-level waste disposal are underway--one in the arid hydrogeologic environment of basaltic rock in Idaho and the other in the humid area of folded and fractured calcarous shales and limestones of East Tennessee. The problem in both environments is describing the micro-hydrogeology of the system so that hydrochemical data can be related to field observations to predict waste transport. The results to date of the study in Idaho have been very encouraging. Robertson (1974) has field tested a predictive waste transport model and found it to be accurate. This model will be a useful tool for designing a meaningful monitoring system for the Idaho Nuclear Engineering Laboratory area. The Tennessee program has just begun. Basic hydrologic field data will have to be collected before the hydrologic system can be described adequately. The hydrologic data will be used to develop a hydraulic model of the system. After it is verified, it will be used to design, construct, and verify a model to predict waste-solute transport. The predictive model will be used to select the most desirable locations for

observation wells to monitor the waste movement through the fractured calcarous shales.

That portion of the Geological Survey's radioactive waste program that is being funded entirely inhouse is directed at determining the processes and principles of waste migration. Since one of the Geological Survey's main activities is in water resources, it is also determining the availability of and uses of water by the nuclear industry. The waste program is twofold: theoretical laboratory research studies and actual field investigations at existing burial grounds. The field investigation program is similar to the joint USGS-ERDA low-level waste program except that the field studies are being made at six NRC licensed, commercially operated, radioactive solid waste burial grounds located on State-owned lands. Each of the sites is in a different hydrogeological environment.

Geochemical laboratory and model studies are being conducted at four of the Survey Research Centers--Reston, Virginia, Bay St. Louis, Mississippi, Denver, Colorado, and Menlo Park, California. The USGS-sponsored studies include:

1. Geochemical kinetics studies: adequate description of mass transport in hydrologic systems requires the knowledge of the kinetics of solid-liquid phase interactions. The rates and products of chemical reactions, changes in (relative) surface area with time, and the relationship of surface/volume ratio to bulk solution composition are needed.

2. Digital modeling of ground-water flow: accurate prediction of the movement of contaminants in a hydrogeologic environment requires knowledge of the velocity distribution of the transporting fluid. Many techniques have been established and implemented for solving ground-water flow problems and corresponding velocity distribution in two dimensions. However, solution to three-dimensional problems of potential interest have been infrequent because of problem size and computation work required. The determination of fluid velocity distribution in three dimensions will provide the necessary first step towards investigations of the movement of contamination in three dimensional ground-water problems.

3. Ground-water quality modeling: the accidental or planned injection of radioactive fluids into the ground-water environment will cause changes in the water quality. Prediction of such change is necessary to allow a decision-making capability prior to contamination and to provide a basis for remedial action in case of accidental contamination. Prediction of water quality is also necessary to solve "inverse problems" that is the determination of aquifer-parameters through various tracer tests.

4. Unsaturated zone solutes: ground-water quality often is significantly influenced by the recharge-water solutes, which in turn are affected by various chemical and dispersion processes within the unsaturated zone. The objective is to determine and interpret the effect of water content upon dispersion and selected chemical processes, occurring during seepage of solutions through unsaturated sediments and to utilize this data and numerical, computer-based approaches for developing methods of predicting the characteristics of unsaturated-zone processes, which determine the final solute composition of recharge waters.

5. Ground-water movement and hydrodynamic dispersion evaluated by single-well tracer injection for disposal of radioactive waste: to properly evaluate sites for disposal of radioactive wastes it is necessary to know the actual ground-water flow velocities, the natural hydraulic gradient and the characteristics of hydrodynamic dispersion, the distribution coefficient for each nuclide of concern, and the transmissivity of the system. These factors can

be determined by multiple well pumping and tracer tests. It is believed, but needs to be verified, that a single well could provide not only the needed geological knowledge during drilling, the transmissivity during pumping, but also local water velocities, hydraulic gradients, and distribution coefficients by tracer injections. If true, preliminary site evaluation by a single well could thus greatly reduce the cost of such evaluations.

6. Radiohydrology of selected nuclear waste landfill sites: since the beginning of the Nuclear Era, low-level radioactive waste has been buried in shallow trenches. The objectives are: (1) to determine distance and rate of radioisotope migration underground, if any, in different hydrogeological environments; to identify hydrogeological and geochemical factors controlling such migration and (2) to determine if waste transport can be predicted for a burial ground established in each hydrogeological environment. At each site, the Geological Survey is cooperating directly with the State agency that has the responsibility for administrating the burial-ground operation. Note that these investigations are similar to the low-level waste-burial investigations being jointly studied by USGS and ERDA but each is in a different hydrogeological environment.

   a. Humid climate--silt-rich glacial till locally overlain by thin outwash gravel and severely dissected--New York State

   b. Humid climate--coastal plain interbedded clay and sand deposits located well above local drainage features--South Carolina

   c. Humid climate--flat-lying interbedded fractured sandstones and shales on highly dissected highlands--Kentucky

   d. Humid climate--flat-lying fractured clay and shale in a glaciated area--Illinois

In addition to the radioactive waste disposal problem generated by the nuclear industry, there are other water-waste related problems which are being studied by the U.S. Geological Survey. Solution of some of the problems will directly or indirectly provide answers

to pollution problems that will become apparent if radioactive waste reaches surface streams. Other studies not involving radioactive waste concern waste heat discharges into surface waters at nuclear power plants. Two of these water-related problem areas are:

7. Heat transfer across the air water interface at a water body receiving waste heat discharges: the problem is to obtain a better understanding of the process to predict evaporation losses. The objective is to improve current methods for prediction of water temperature and evaporation under both natural and altered conditions. Models will be developed for cases where the vertical temperature stratification is an important factor; cases where the lateral temperature gradient dominates the process; and cases where the water is mixed.

8. Water availability: the problem concerned with the availability of cooling water for nuclear power plants.

Solutions of all the problems indicated above will still not result in the final answers to all of the waste disposal problems. As in the past, we expect new problems and even different facets of old problems to emerge and plague us. More important than these anticipated new problems are the problems that are now known to exist but have not been included in our current limited research program. These problems include:

1. Identifying the organic mobilizing mechanism and complexed solute compounds of radionuclides in waste streams originating at waste disposal sites.

2. Identifying chemical controls on radionuclide sorption and fixation in ground water and in river-estuary systems.

3. Determining effects, on local and national water resources, of a major nuclear accident and of radioactive waste contamination.

4. Determining potential for deep disposal of specific low-level liquid waste products such as tritium.

5. Determining risk probabilities of different hydrogeologic environments for management of all levels of radioactive waste.

The waste problems are dynamic, complex, and varied, but we are confident that seminars such as this and other cooperative efforts will provide useful ideas and concepts that will help us to design needed research to get the job done.

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