GEOGRAPHY, GEOLOGY, AND WATER RESOURCES OF THE NATIONAL REACTOR TESTING STATION, IDAHO
Part 1
PURPOSE, HISTORY, AND SCOPE OF INVESTIGATIONS
By R. L. Nace

Report not reviewed for conformance with Geological Survey editorial standards and usage of geologic names.

Prepared for the U. S. Atomic Energy Commission
Boise, Idaho 1956
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III
INTRODUCTION

Reason for Investigation and Report

The use of water, disposal of waste, and other operations on the National Reactor Testing Station (NRTS) depend on and affect a very large body of underground water in the Snake River Plain. The plain is a major geographic, geologic, and economic segment of southern Idaho, and the water is a principal natural resource of that part of the State. The ground water in the plain originates largely in peripheral uplands, moves through the central plain on which the station is situated, and is discharged through springs and seeps in the valley of the Snake River far to the southwest, chiefly between Milner and Bliss (Index map, fig. 1). Between the areas of intake and discharge ground water is pumped for irrigation, industrial, municipal, and rural domestic supplies. The United States Atomic Energy Commission needs information about the amount, availability, and chemical quality of water at the NRTS, and about the extent to which use of water on the station may affect or deny use of water in areas outside the station, and vice versa. The needs of the Commission for information, therefore, concern both local and broad regional problems of the water supply, geology, and geochemistry of the plain.
Figure 1.—Index map of southern Idaho showing location of National Reactor Testing Station on the Snake River Plain. (Circle, radius 50 miles, centers on CF area.)
The General Situation

The most efficient use of the reactor-testing station, and the creation thereby of the least possible hazard to the resources and human activities in the Snake River Plain, depend partly on having and using detailed information about the physical and geochemical environment of the station. That environment is a product of geologic processes operating through a long geologic time, but the features having the greatest importance in relation to the station are products of relatively recent geologic events. Reasonably full knowledge about the composition and structure of the earth materials underlying the plain, the history of the water resources and details of the hydrologic cycle, and relevant geochemical processes, is requisite to full exploitation of the station. Geologic and hydrologic studies, correlative with the engineering, climatological, and other investigations obtained by the Commission from other agencies and contractors, will help to assure sound and reasonably safe practices in construction and operations on the station.

The Specific Situation

The central subject of this report is the ground-water geology and hydrology of the National Reactor Testing Station, with special reference to problems of water supply, water use, and waste disposal, and to the relation of these to water supply and use on the Snake River Plain. Some of the findings may be significant to the atomic-energy industry generally. The United States Geological Survey has obtained, compiled, and analyzed a considerable amount of basic geologic and hydrologic
information. Specific problems concern the chemical suitability of
the perennial water supply and its adequacy for plant operations in
addition to other uses on the Snake River Plain; the location and
orientation of reactor plants so as to avoid contamination of their
own water supplies; the locations, spacing, and pumping rates of
wells; control and proper disposition of radioactive liquid wastes;
feasible remedial actions in the event of accidental hazard or damage
to water supplies; and public confidence in the intention and compet-
tence of the Commission to safeguard the water supplies of the Snake
River Plain from excessive depletion, contamination, or other damage.

All facilities on the NRTS have common requirements for a depend-
able water supply, adequate opportunity for the safe disposal of indus-
trial liquid waste and sewage, stable geologic materials on which to
found structures, and others. Much of the information in this report,
therefore, has applications at all station facilities. On the other
hand, special problems may arise with each facility because each differs
from all others in its type and functions. Such problems may require
specialized further work by geologists and hydrologists. Accordingly,
the report contains all available technical and scientific information
within the scope of the investigation that would be of value to special-
ists approaching such problems, even though some of the information is
not sufficient to lead to definite conclusions at this time.

Attempt has been made to present information in a readily under-
standable form and manner, but not all technical terminology could be
eliminated. A glossary of terminology is included as one part of the
report.
Investigations of ground water and ground-water geology by the Geological Survey are directed by A. N. Sayre, chief of the Ground-Water Branch, Washington, D. C. Technical supervision and coordination of hydrologic work, for the Atomic Energy Commission are by C. V. Theis, staff scientist, Albuquerque, New Mexico. Work in Idaho was supervised by R. L. Nace, district geologist, Boise, Idaho until June 30, 1956.

Other Investigations and Reports

A geological reconnaissance of the Snake River Plain in 1901 resulted in a general descriptive report (Russell, 1902) having great and lasting value. Kirkham (1927, 1931), reported on the geology of part of the eastern Snake River Plain and on the structure of the plain. Stearns and others (1936, 1938) published records of wells on the Snake River Plain and reported on the geology and ground-water resources of the plain east of King Hill. Stearns and others (1939) studied the geology and water resources of the Mud Lake basin, including part of what is now the NRTS. Reports by Nace (1948) and by Crosthwaite and Scott (1956) contain useful information about the geology and hydrology of part of the Snake River Plain. A station-evaluation report on the NRTS was prepared by the architectural and engineering firm of Smith, Hyneman and Grylls, Inc. (1949). During 1949-50 the Corps of Engineers, U. S. Army (1950), did shallow test boring on several potential construction sites, established altitude-control points for topographic mapping, and performed other engineering services for the Commission.

1/ See "Literature cited" at end of this report.
More than 30 interim and special reports have been prepared by the Geological Survey since 1949, chiefly on the ground-water geology and hydrology of potential and existing construction sites and areas of special interest in and near the NRTS. A list of those reports is given in table 2.
THE NATIONAL REACTOR TESTING STATION

Location and Extent

The National Reactor Testing Station includes nearly 700 square miles of "sagebrush desert" and basalt fields in the Snake River Plain of southeastern Idaho (fig. 1), lying within Tps. 2 to 7 N. and Rs. 28 to 33 E., Boise baseline and meridian (pl. 1). Most of the station is in Butte County, but small parts are in Jefferson and Bingham Counties. The station is nearly 35 miles long from north to south, and about 27 miles wide in its broad southern part. Atomic City (formerly Midway) is near the southern boundary; Howe is about 2.5 miles north of the central western boundary; Terreton is about 7 miles east of the northern part of the station. No other towns or villages are nearby. The Central Facilities area (CFA) is near U. S. Highway 20-26, which crosses the south-central part of the station, and is about 20 miles east of Arco, 50 miles west of Idaho Falls, and 55 miles northwest of Pocatello.

During World War II the U. S. Navy took over about 270 square miles of the Snake River Plain for a proving ground and gunnery range extending from the vicinity of Scoville northward to State Highway 28 (pl. 1). Two lines of permanent altitude markers and two ungraded roads extended the length of the gunnery range. An area southwest of the Naval Proving Ground was used by the U. S. Air Force as an aerial gunnery range during World War II. The NRTS includes all the former military proving grounds and a large adjacent area. The Navy administration, shop, warehouse, and housing areas became the Central Facilities Area.
Status of Construction and Development

The Geological Survey is not concerned with nuclear energy as such. The following information about nuclear-energy plants and their operation is about the minimum needed for general appreciation of the potential impact of the NRTS and its operations on the hydrologic and geologic environment. The control and disposal of radioactive wastes, for example, is an especially important problem, and the general nature of each facility is a necessary concern to those studying waste-disposal practices and plans.

Within the station, 2 to 15 miles of unoccupied area separates the reactor plants and other facilities (pl. 1). Most of the station still is unoccupied and numerous additional facilities could be accommodated without crowding. In the following descriptive notes the various plants are discussed about in the order in which construction was begun. Certain accessory plants, however, are discussed immediately after the plant to which they are adjunct. With one exception, all reactors that have been installed thus far are prototypes.

Experimental Breeder Reactor

Construction of Experimental Breeder Reactor no. 1 (EBR-1), the first reactor to be completed on the NRTS, was begun late in 1949 and the reactor went into operation late in 1951. The operator is Argonne National Laboratory. The reactor was designed to test whether atomic fuel can be generated more rapidly than it is consumed, and whether it is feasible to generate electrical power with heat transformed from nuclear energy.
The feasibility of breeding nuclear fuel was demonstrated by the EBR-1, and the first electric power converted from the heat of nuclear reactions was generated at the plant on December 20, 1951. The reactor supplied 1,400 kw of heat and 170 kw of electricity. Operating experience at EBR-1 provided data needed for designing an electrical-power-generating reactor.

Water for EBR-1 is provided by a deep well equipped with a submersible turbine pump. There is little or no radioactive liquid waste from the plant and no high-level waste, and all low-level waste and sewage are disposed to the ground in a seepage pit.

Materials Testing Reactor

The high-neutron intensity Materials Testing Reactor (MTR) was completed early in 1952 and was operating at its full original-design power of 30,000 kw by May of that year. Its operating power level has since been raised to 40,000 kw. The operating contractor is Phillips Petroleum Co. The initial prime purpose of the reactor was to test the effects of intense neutron fluxes on materials that may be used in other reactors. Additional tests are being made on a great variety of materials, and information applicable to reactor designs is being gathered. Data are obtained also on isotope production. Irradiation facilities have been made available to the public. Having a high flux, the reactor can produce isotopes with higher specific radioactivity than those from Argonne, Brookhaven, and Oak Ridge, which also offer service to the public.
Water is obtained from two deep wells with electrically powered shaft-turbine pumps. Low-level industrial-waste water is discharged to the environment through an open-surface infiltration pond in gravel.

Engineering Test Reactor

The Engineering Test Reactor (ETR) is being built adjacent to its companion reactor, the MTR, and is scheduled to be completed early in 1957. The architect-engineer and construction contractor is the Henry J. Kaiser Co. The operator will be Phillips Petroleum Co. The reactor will provide large experimental spaces in high neutron fields for testing the effects of intense radiation on materials. Tests will be made under temperatures, pressures, and other operating conditions similar to those in proposed reactors. The reactor will operate at a power level of 175 megawatts of heat. The fuel will be uranium enriched in U²³⁵, and the reactor will be moderated and cooled with ordinary water.

The ETR and MTR plants will be served by an integrated water system. One well in addition to the two now at the MTR site will furnish added production capacity. Waste liquid from the ETR will be disposed along with that from the MTR.

Submarine Thermal Reactor

The Submarine Thermal Reactor (STR),¹ a land-based prototype (Mark I) for submarine propulsion, is operated by Westinghouse Electric

¹/ The designation, SLW, is now preferred. All text and illustrations in this series of reports were prepared before the change was announced to the Geological Survey. A change at this time would entail expense and delay, so the old designations are retained.
Corpo Construction was started early in 1950 and test operation begun early in 1953. The reactor was assembled in a section of submarine hull and successfully operated by a trainee crew under simulated submarine conditions. The submarine USS Nautilus, launched in January 1954, began its sea trials on January 17, 1955 under nuclear power from a thermal reactor (STR Mark II), and cruised more than 25,000 miles by the end of the year. Currently, the reactor design is being modified, converting it to a test facility for investigating new developments in the design, technology, and operation of water-cooled nuclear power plants.

Water for the plant is supplied by two deep wells equipped with electrically driven shaft turbines. Low-level radioactive waste water is discharged to a covered leaching bed.

Large Ship Reactor

A Large Ship Reactor (LSR or ALW) is being built adjacent to the STR, to develop the prototype for a large-ship propulsion reactor. Preliminary work began late in 1955 and construction began in the spring of 1956. The unit will be a pressurized-water reactor, operated by Westinghouse Electric Corp. A unified water system serving the LSR and STR plants will require drilling of one well in addition to the two now used for the STR plant. Waste-disposal facilities in addition to those now available at the STR plant will be constructed.
Aircraft Nuclear Propulsion Area

Construction at the Aircraft Nuclear Propulsion Area (ANP) was begun late in the spring of 1953. The project includes administration buildings, assembly and maintenance shops, and an engine-testing facility, the Initial Engine Test Site (IET). Construction is at an advanced stage. The operating contractor is General Electric Co. The purpose of the project is to make development studies leading to nuclear propulsion for aircraft.

Water is obtained from two deep wells with electrically driven shaft turbines. Low-level waste liquid from the assembly and maintenance shops is discharged to a deep disposal well. A small-bore deep well at the IET site is used for disposal of liquid sewage effluent. Weather station "T" is in the ANP area.

Experimental Boiling-Water Reactors

In 1953 a temporary small, experimental water-cooled, water-moderated, remotely controlled boiling-water reactor (Borax I) was tested by Argonne National Laboratory near the EBR site to determine whether or not boiling within the core of a water-cooled reactor would cause unstable operation. The reactor was operated under conditions that might be expected ordinarily to cause a "runaway," but the early 1953 tests did not lead to a runaway. As a further test the power level was allowed to rise to more than a million kw within a tenth of a second. Destruction of the reactor core was nearly instantaneous. Melting of the core allowed fission products to escape, contaminating
an area of about 2 acres, which are isolated at present. Experiments with a second temporary boiling reactor (Borax II) were made during the winter 1954-55. The design was for a power level of 6,000 kw of heat at a pressure of 300 psi. In a third experiment (Borax III), the Borax II vessel was used with a new core having greater thermal power. A 3,500-kw turbine generator was installed. The reactor became critical on June 9, 1955, and on July 17, 1955 the town of Arco was lighted for about an hour with electrical energy exclusively from Borax III.

The experiments are especially important in relation to the safety of industrial-power reactors because of the promise of the self-regulating characteristics demonstrated by them. Moreover, a boiling reactor might be used as a direct source of steam, thus reducing capital costs for heat exchangers outside the reactor. The experiments are of special interest to the Geological Survey because the possible civilian use of such reactors has obvious implications in relation to water supplies.

Special Power Excursion Reactor Test

The Special Power Excursion Reactor Test (SPERT-I) and remote control center is a nonpressurized boiling-water reactor experiment somewhat more elaborate than the Borax experiments, and at a permanent site. The experiment is part of the Reactor Kinetics program to study boiling-water reactor-system behavior under adverse conditions, to determine top operating limits and points of weakness in design, and to study self-safety in mechanisms. Construction of SPERT-I was completed in 1955. Using a reactor core of aluminum-clad fuel elements, the reactor became critical on July 1, 1955.
Water for the installation is obtained from a well equipped with a shaft-turbine pump. A very small amount of sewage effluent and waste water is disposed of in a seepage pit.

Organic-Moderated Reactor Experiment

The Organic-Moderated Reactor Experiment (OMRE), using an organic-resin compound instead of water as a moderator, will be constructed near the SPERT site. The operating contractor will be North American Aviation Corp. The plant will be small, and water will be obtained from a deep well to be drilled at the site. The experiment is not a prototype power reactor, but will test the feasibility of using organic moderators in a system having flows, temperatures, and neutron fluxes comparable to those in full-scale reactors. The organic moderator-coolant will be the hydrocarbon diphenyl, which is used in industry as a heat exchanger, and the experiment is designed to generate 5 to 15 megawatts of heat.

Chemical Processing Plant

Construction of the Chemical Processing Plant (CPP) was begun in 1950 and operation began in February 1953. The plant recovers unused fuel from used reactor-fuel units and develops data on fuel processing. Processing is elaborate and costly but is an essential phase of the atomic-energy industry. Fuel elements are dissolved and unused fission-able material is extracted, eventually to be reduced elsewhere to metal and fabricated into new fuel units. The units go through this process frequently and the amount of highly radioactive waste-fission products
is large. Much of the waste-fission products from all NRTS reactors ultimately reaches the CPP, where they are held in large underground stainless-steel tanks. Fuel elements from other AEC installations also are processed and the waste-disposal problem is especially important at this plant. The plant was remodeled and enlarged in 1954, and was back in essentially full operation early in 1955.

Two deep wells equipped with electrically driven shaft turbines supply water to the plant. Low-level waste liquid is discharged to a deep disposal well.

Burial Ground

A burial ground for radioactive solid and semisolid waste is situated in the central southern part of the NRTS near the Big Lost River. Contaminated material and some semisolid chemical wastes are buried there in trenches in alluvial sediments.

Central Facilities Area

The Central Facilities Area (CFA) contains the field security headquarters and communications center, and suboffices of some AEC divisions and of contractors, a weather station (WBO), maintenance shops, laboratories, garages, warehouses, steel and lumber yards, fire department, medical dispensary, laundry, cafeteria, and other facilities. The CFA is used as a general supply, service, and on-site headquarters area for the entire NRTS. Water is supplied by two deep wells equipped with shaft-driven turbines. Some low-level radioactive waste liquid is discharged by the laundry to an activated-sludge sewage disposal plant. The liquid effluent from the plant is discharged to a leaching field.
HISTORY AND SCOPE OF THE INVESTIGATIONS

General geologic and hydrologic study of the NRTS and environs was made by standard methods. Special requirements and problems on the station, notably in certain phases of hydrology and geochemistry, required unusual studies and special techniques. The specialized problems, some of which are becoming critically important, necessarily were deferred from intensive study in the early period of investigation. In general, priority was given to the comprehensive study and analysis because the information was needed immediately and because the data obtained furnish the basic background for advanced study. The outstanding unsolved geohydrologic and geochemical problems on the NRTS are segregated and defined, and an intensive attack upon these problems is proposed.

The comprehensive study of the NRTS included the following principal phases:

Interim investigations and services
Collection and compilation of basic information
Analysis and interpretation of data
Special studies
Research (chiefly applied)
Planning and coordination with other programs

Operations in all phases were more or less concurrent because the work was contemporary with construction and operation on the NRTS. Some phases were dormant from time to time, while others were intensified in response to changing immediate needs of the Commission for information.
Early Period of Investigation

In 1948 the Geological Survey undertook to aid the Atomic Energy Commission in appraising the geologic and hydrologic features of potential sites for certain Commission facilities. For one facility, the National Reactor Testing Station, the choice from about 40 suggested sites was narrowed to two -- near Fort Peck, Montana, and near Arco, Idaho. In November 1948 the writer received in Boise, Idaho a telephone inquiry from the Washington, D. C. office of the Survey about the availability of 10 cfs of water from underground sources in the vicinity of old Pioneer Station. The reply, made in December, was tentatively favorable, but an opportunity for field reconnaissance was requested.

At that time, A. M. Piper, the Geological Survey's Staff Scientist at Portland, Oregon, was technical supervisor and coordinator of activities of the Water Resources Division on behalf of the Commission. He had made a brief study of the Fort Peck site. In December 1948 Mr. Piper and the writer made a rapid reconnaissance of an area (then called the Pocatello area) between Arco and Blackfoot. Commission plans at that time envisioned a facility which would require about 50 cfs of water within a few years, and about 100 cfs within 20 years. On January 2, 1949 Mr. Piper (1949) submitted a report indicating a favorable geologic and geographic environment in the Pocatello area, and an adequate supply of chemically suitable water.

On January 7, Roger S. Warner, Jr., then Director of Engineering for the Commission, notified Mr. Piper and the writer that the
Commission had retained as consultants the engineering firm of Smith, Hynchman and Grylls, Inc., of Detroit, Michigan, to make comparative engineering evaluations of the Fort Peck and Idaho sites. On January 11 the writer informally furnished to W. F. Fisher, of the consulting firm, information about coal, oil, and natural-gas possibilities in southeastern Idaho. The firm called a conference on January 17 in Pocatello, Idaho with representatives of the Commission, the Geological Survey, and the firm of Alvord, Burdick, and Howson, of Chicago, Ill., for the purpose of pooling and evaluating available information about the geology and water supply of the Pocatello area. Specific concern was with the regional geologic and geographic environment, the local factors that might influence the water supply for reactors, and the probable effects of reactor operations on the overall water supply of the Snake River Plain. Those present at the conference were:

Geological Survey: A. M. Piper, Lynn Crandall, R. L. Nace

On January 18 Mr. Stearns and the writer observed the performance of two wells in the Naval Proving Ground. The Navy wells are mediocre by common standards for the Snake River Plain, but on the basis of general knowledge it was believed possible to obtain the desired amount of water from properly constructed wells. The water requirement estimated at that time was 1.5 cfs in 1949, increasing gradually to 23 cfs
in 1955. About 75 percent of the maximum use was expected to be non-
consumptive. The total station area contemplated was 400,000 acres.
During January 15 to 18 the writer collected water samples from
scattered locations on the Snake River Plain, and the results of chemi-
cal analyses of these were submitted to the Commission by Mr. Piper on
January 25.

The final report of Smith, Hynchman and Grylls (1949), giving a
comparative evaluation of the Fort Peck and Pocatello sites, was sub-
mitted to the Commission on March 26, 1949. The specific conclusions
were preponderantly in favor of the Idaho site. Some basic require-
ments for a site were as follows:

1. Thoroughly dependable water supply.
2. Isolation from heavily populated areas.
3. Geologic conditions suitable for the founding of large, heavy
structures.
4. Nearby sources of manpower, materials, electric power, and
rail transportation.
5. Small earthquake risk.
6. Climatic conditions favorable to construction during most of
the year and favorable to year-round operation facilities.
7. Adequate surface and subsurface drainage.
8. Small regional and local security liabilities.
9. Suitable conditions for reasonably safe storage and disposal
of liquid waste.

Shortly after the consultants' report was submitted, the Commission
approved the Idaho site and made arrangements to take over the Naval
Proving Ground. The desired boundaries of the station soon were defined, and in April negotiations for a water right were begun with the Idaho State Reclamation Engineer.

On May 5 and 6, 1949, in company with Gardiner Luce, of the Washington Office of the Commission, the writer selected two alternate locations for a demonstration well on the station. A drilling contract was let by the U. S. Navy, agent for the Commission, and one of the sites was chosen by the Commission for drilling. The well was completed early in August and test pumping began on August 12. The average pumping rate was 1.4 cfs with a drawdown of about 15 feet. The well, though one of the poorer of those now on the NRTS, was considerably better than either of the old Navy wells, and confidence in the water supply was established. The well now serves the Experimental Breeder Reactor plant.

In May 1949, based on information then available and on the disiderata of conferences in Idaho with Commission representatives, a proposal was made (Nace, 1949) at the request of the Commission for a systematic, comprehensive study of the geohydrology of the NRTS. In the same month the writer conferred with Commission and Survey representatives in Washington, D. C. In June the proposal was adopted, in substance, by the Commission. A transfer of funds was effected on June 29 for work in FY 1950, and cleared the General Accounting Office late in July. The Survey staff in Idaho was enlarged promptly and by the end of the calendar year a substantial force was at work. A full force was available by mid-1950.
During the early period it was believed that development of the NRTS would proceed gradually from small-scale construction early in 1950 to construction on a larger scale within several years. The investigative proposal suggested a plan whereby, within two or three years, the Geological Survey would have completed a general geologic and hydrologic study, and would have released a general report. Thereafter, work would have been on specialized and advanced problems. The plan suggested certain "Urgent basic investigations" to be completed by June 30, 1950, supplemented or followed by "Further specialized investigation," "Continuing operations," and "Supplemental operations." By that plan much basic geologic and hydrologic data would have been accumulated and embodied in reports in advance of extensive construction.

The rate of construction soon was accelerated by the Commission, and the work of the Survey, therefore, necessarily was arranged to aid plans for specific construction sites. Much time was spent in field conferences and inspections, making pumping tests and site surveys, preparing site reports and advance summaries of data, selecting well sites, and functioning as on-the-spot consultants. Most such work was done between October 1949 and December 1953. The basic and other work lagged somewhat because all operations were essentially simultaneous. In the long run, however, the amount of information available for the present comprehensive report was greatly increased. The problem of digesting the data and preparing a comprehensive analysis has delayed completion.
After 1949 the activities of the Survey were rather diverse and a
chronologic account seems pointless in this context. A summary of each
principal activity during 1949-55 follows.

**Basic Investigations**

The ground-water supply of the Snake River Plain is thoroughly
dependable. In some localized areas on the plain the water is at
excessive depth, occurs in aquifers of low permeability, or is unde-
sirable in chemical quality and temperature. To determine whether a
sufficient quantity of suitable water would be perennially available
within the NRTS, and to analyse the regional implications of use and
development of that water, fairly intensive study was made. The data
collected cover about the full range of types needed for analysis of the
sources and quantity of ground-water replenishment; the quality and
quantity of ground water perennially available for pumpage in specified
areas; the local and regional effects of pumping; the course, rate of
underflow, and destination of specified segments of the body of ground
water; and various problems of liquid-waste disposal on or in the ground.

**Geologic Study and Mapping**

**Geologic mapping.**—A general areal examination of the NRTS was
made early in the investigation and a reconnaissance report was sub-
mitted (Table 2, rept. no. IDO-22012-USGS). The types of geologic
materials in the area were classified, and detailed mapping was begun
in October 1949 and completed in June 1953. Each geologic unit was
studied in detail, with special attention to characteristics that would
affect its hydraulic properties. Interim special geologic maps were made of construction sites and submitted with reports. The mapping was done by traversing each section on foot, recovering section corners, and sketching geologic boundaries and other data on aerial photographs furnished by the Commission. Samples of rocks, sediments, and fossils were collected for laboratory study. Each section was traversed along a sufficient number of lines to assure recognition of all outcrops that were mappable on the scale of the photos. Field notes were prepared and are on file for each section mapped, describing the topography, the type and distribution of geologic units, the estimated and measured thicknesses of overburden, the occurrence of volcanic vents, the locations from which soil, sediment, and rock samples were collected, and the rare locations where fossils were found. To obtain a finished map the geologic data were transferred from the photos to large-scale topographic maps furnished by the Commission. These were then redrafted at reduced scale for reproduction.

Test Drilling.—Exploratory drilling was an integral part of basic studies. The purposes were (1) to determine the character, subsurface distribution, physical interrelations, and water-bearing properties of the rocks and sediments from the surface downward into the zone of saturation; (2) to obtain samples of those materials for analysis and study; (3) to study the water-bearing properties of the several rock types; (4) to define the ground-water conditions in terms of the location, depth beneath the land surface, quantity, temperature, and chemical quality of the ground water, and the configuration of the water
(5) to aid study of the speed and direction of ground-water underflow into, through, and beyond the NRTS; (6) to establish in and near the NRTS a network of test holes which could be used as water-level observation wells and chemical and radiometric monitoring points. The test drilling, in conjunction with other work by the Geological Survey on the NRTS and elsewhere, will help ultimate compilation of a generalized hydrologic map of the Snake River Plain.

The work of test drilling was by private contractors, supervised and inspected by the Geological Survey, under eight drilling contracts. The first contract, awarded to the Cope Drilling and Pump Co., of Idaho Falls, was for 7 holes at widely separated localities. Work was started on October 1, 1949 and completed on May 12, 1950. The holes were distributed along a line from Atomic City toward Mud Lake (4 holes) and along the central axis of the NRTS (3 holes). Meanwhile, the Commission contracted independently for one test hole at the MTR site.

A second contract was awarded to the R. J. Strasser Co., of Portland, Oregon, for 6 test holes in the southern NRTS and on the plain south and southwest of the station. Work began on May 10, 1950 and was completed on December 31, 1951. Thus, 13 Survey test holes were completed by the end of 1951. Seven were within the station boundaries; an eighth was south of Terreton, between the Mud Lake Basin and the lava fields; a ninth was in the lava field northeast of East Twin Butte; two were in the plain south of the Big Lost River and west of the station; and two were south of the station near Big Southern Butte.
Meantime, the Commission had 6 additional production wells drilled, two each at the CPP, MTR, and STR sites, bringing the number of new production wells to 7 (including the one drilled earlier at EBR). Also, two temporary wells for highway-construction water were drilled for the Commission adjacent to the new highway from Rye-Grass flat to Idaho Falls. Drilling for the Commission was by the Cope and Strasser companies, by A. A. Durand and Son, Walla Walla, Wash., A. J. Schoonover and Sons, Burley, Idaho, and the Johns Investment Co., Idaho Falls, Idaho. In addition to its regular work on the NETS, the Geological Survey assisted the Commission with the inspection of production-well drilling, collecting samples of cuttings, logging holes, and making pumping tests.

In 1950 a Survey contract was let to the Cope company for drilling a single deep hole several miles north of the STR plant. Work began June 26, 1950 but was not completed until June 11, 1952, after reaching a depth of 1,497 feet. Two holes actually were drilled under this contract because on the first try the contractor could not reach the specified depth.

In 1951 a contract was awarded to the Cope Drilling and Pump Co. for drilling five test holes in Tps. 4 and 5 N., across the central part of the station, and a sixth hole adjacent to the old route of U. S. Highway 20, several miles west of the MTR site. Work was begun July 11, 1951 and completed June 30, 1952.

The drilling program was intensified in 1952 when two contracts were awarded to the R. J. Strasser Drilling Co. One contract was for reconditioning previously drilled holes to preserve them as observation
wells, for pumping the wells to get clear samples of water for chemical and radiometric analysis, and for drilling 5 shallow test holes in the flood plain of the Big Lost River. Work was begun December 10, 1951 and completed January 31, 1953. The other contract with the Strasser company was for drilling 10 test holes, 3 in and near the ANP site and 7 in a tract in southwestern Jefferson County adjacent to the northern part of the NRTS. Work began July 15, 1952 and ended August 11, 1953. The work in Jefferson County was part of an overall appraisal of water-development possibilities on and near the NRTS.

A seventh drilling contract was awarded early in 1954 to the Cope Drilling and Pump Co. for one test hole southwest of the Chemical Processing Plant. The hole was drilled as part of an effort to determine the direction and rate of flow of ground water southwest of the plant, by tracing the saline waste liquid discharged from the plant through its disposal well. The liquid was not found in the test hole. Accordingly, another contract was let in 1955, again to the Cope Co., for drilling 5 additional holes on a line transverse to the inferred direction of movement of the waste liquid. That effort, too, was unsuccessful. Further exploration and testing will be done.

The methods of drilling and finishing test holes and wells are described in part 2 and in Appendix 1. Graphic logs of all the test holes are included in the Appendix. The aggregate footage in the 39 deep test holes was 23,191 feet (including 3,018 feet in 5 holes drilled in 1955) and the total cost for contractual materials and services was $212,316.64 (table 1). The cost total is for contractual services only and does not include Geological Survey costs for supervising and
inspecting the work, studying cuttings, or evaluating the results. The average cost for contractual services was $9.11 per foot of finished hole. That cost is somewhat high, because it includes the expense of many pumping and bailing tests, and a considerable amount of work returning to and reconditioning some of the older test holes. The net cost for contractual services and materials for an average finished holes probably is about $8.00 per foot. The supervising, inspecting, and logging costs cannot be computed accurately because the work was done concurrently with other field work. An estimate, however, is about $1.50 per foot of hole. Thus, the overall cost of finished hole, to the stage of the completed geologists' log, is about $9.50 per foot.

Table 1.—Record of test drilling completed

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Working dates</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cope Drilling and Pump Co.</td>
<td>10-10-49 to 5-12-50</td>
<td>$24,037.50</td>
</tr>
<tr>
<td>R. J. Strasser Drilling Co.</td>
<td>5-10-50 to 12-31-51</td>
<td>32,884.38</td>
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<tr>
<td>Cope Drilling and Pump Co.</td>
<td>6-26-50 to 6-11-52</td>
<td>30,696.40</td>
</tr>
<tr>
<td></td>
<td>7-11-51 to 6-30-52</td>
<td>23,009.85</td>
</tr>
<tr>
<td>R. J. Strasser Drilling Co.</td>
<td>12-10-51 to 1-31-53</td>
<td>27,706.50</td>
</tr>
<tr>
<td></td>
<td>7-15-52 to 8-11-53</td>
<td>38,986.00</td>
</tr>
<tr>
<td>Cope Drilling and Pump Co.</td>
<td>1-20-54 to 6-2-54</td>
<td>13,641.00</td>
</tr>
<tr>
<td></td>
<td>6-25-55 to 3-1-56</td>
<td>21,355.01</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$212,316.64</strong></td>
<td></td>
</tr>
</tbody>
</table>
Geophysical exploration.—Geophysical exploration by seismic and electrical-resistivity surveying was done only in small sample areas, and little useful information was obtained. The results of gamma-ray logging of drill holes was quite satisfactory, and logs were made of 13 test holes, 1 production well, and 1 disposal well. Study of the movement of ground water, using experimental terrestrial electropotential methods, was attempted with equipment especially designed for that job. The experiment is elaborated on in later pages. The geophysical explorations are described in part 2.

Canvass of Wells and Observations of Water Levels

Records of wells and water levels are basic to practically all ground-water field studies. Before 1949 there were very few wells on or near the NRTS and little hydrologic information was available. Approximate logs and performance records were available of the two small production wells on the Naval Proving Ground. Wells at Atomic City, Cerro Grande, several stock wells on the Snake River Plain, and several abandoned holes on the NRTS yielded little hydrologic information other than the depth to water. A complete canvass was made of existing wells in the central Snake River Plain and the peripheral inhabited area east of Minidoka, west of Mud Lake, and north of the Snake River. The records of 398 wells in the central plain are tabulated in Appendix 2 of this report and their locations are shown on the map, plate 1 of part 3.

A general picture of the regional occurrence of ground water and of the configuration and position of the water table was developed, and
locations for test holes and observation wells were chosen. The well canvassing consisted of locating each well accurately within legal land subdivisions (by stadia traverse for most wells), measuring the depth of the well and the depth to water, and determining the altitude of the water table. A few wells were selected for observation by periodic measurement of water levels. The test holes, in addition to their other purposes, provided a network of observation wells in and near the station. Recording gages have been operated in two to 21 wells for periods up to 6 years, comprising about 800 well-months of continuous record of water-level fluctuations. Periodic measurements at weekly to annual intervals gave about 5,000 water-level measurements as of the end of 1955. About 300 additional measurements were made while canvassing wells and to obtain data for preparing water-table maps. As each test hole was drilled it was added to the network of observation wells, so that the net grew from several wells late in 1949 to 41 wells (5 with recording gages) in 1950, and to nearly 50 government and private wells at the peak of field study in 1953. Measurements were and are made of private wells in the vicinities of Cerro Grande, Arco, Howe, Mud Lake, and Terreton. For a time, twenty water-level recording gages were in operation. The number was reduced to 11 in 1955 and will be reduced to 5 gages in 1956. The records from these gages illustrate the value of systematic water-level study. Having operated a comparatively large number of gages for several years, and having made weekly and monthly measurements in many wells, the fluctuation patterns are sufficiently well delineated that the information essential for present purposes can
be obtained from 5 gages at key locations, supplemented by periodic measurements in about 40 other wells and test holes.

**Spirit Leveling**

Leveling was done to determine land-surface altitudes at well and test sites in order to compute the altitude of the water table, to establish local permanent altitude-reference marks near each test site, and to tie the altitude data in with the vertical-control grid of second-order benchmarks in the NRTS. Most of the level lines to sites outside the NRTS were started from United States Coast and Geodetic Survey bench marks. All altitudes are reported with reference to the mean sea-level datum of 1929, Pacific Northwest Adjustment of 1947. Most of the leveling was by spirit level and conforms to third-order leveling standards of the Geological Survey (Douglas, 1929). The altitudes of a few wells at remote locations on the plain were determined trigonometrically by transit-stadia traverse from bench marks. Some barometric leveling with surveying aneroids was done during reconnaissance work, but no permanent reference marks were established on the basis of barometric leveling.

The following leveling practices were followed at well and test-hole sites: Having leveled from a bench mark to a well or test hole, the altitude of the natural ground surface at the site, called the land-surface datum, was determined. A 4-inch concrete post 3 feet long, bearing a brass plate in its upper end, was set in the ground within about 50 feet from the test hole, and projecting several inches above the land surface. The brass plate bears the inscription, "U. S."
Geological Survey Gaging Station Reference Mark. The altitude of the upper surface of the plate was determined and the post then became a permanent reference mark. After completion of drilling at each test site, the altitude of a chiselled square in the upper surface of a concrete platform built around the upper end of the casing was determined. A measuring point for water-level measurements was then selected, usually a point on the top edge of the casing, and measurements to the water level subsequently were made from that point. The altitudes of the measuring points are used for all ordinary purposes. In case of damage or disturbance to these, the altitudes of new platforms and measuring points can be determined from the nearby reference mark without having to relevel from a bench mark. The concrete posts for reference marks are not buried to sufficient depth to be immune to frost heave, but the three-foot depth is sufficient for reasonable stability.

Surface-Water Investigations

The discharge of the Big Lost River below Arco and the disposition of the water that reaches the NRTS were studied. A gaging station has been operated by the Survey several miles downstream from Arco since August 1946 and has been sponsored by the Commission since October 1, 1952, when the station was rebuilt and modernised. Ten temporary measuring stations were established within the NRTS during the high-runoff period of 1952-53 to obtain information about percolation losses in the channel of the river. The discharge data are useful in connection with the following problems: the amount of discharge the river channel can accommodate without breaking out onto the flood plain in the NRTS; the
probable effects on the NRTS of an upstream cloudburst or dam failure; and the amount of water contributed by the river to ground-water recharge within the station.

Seepage losses from the river were given special attention because the rate of infiltration of natural water in the flood-plain gravel may be indicative of expectable infiltration rates in waste-disposal works in similar gravel. Also, study of correlative and later water-table fluctuations gave clues to the rate of percolation of vadose water downward through the zone of aeration, and to the time required for water to move from the surface to the water table. The records were used also to estimate the contribution of the river to ground-water recharge.

Chemical and Radiometric Analyses of Water

Chemical and radiometric analyses were made of water from wells and test holes on the station, from widely scattered private wells as far west as Gooding and Jerome Counties, and from a few springs in the valley of the Snake River. Information about the chemical quality and industrial utility of water was needed directly in connection with operating designs for facilities. Chemical data are useful also in the study of ground-water recharge and movement. Background (natural) radioactivity is of special interest because of its bearing on possible future changes in the radioactivity of the water. Water sampling was begun in 1949 and continued through 1955. Radiometric analyses were made for all test holes, all wells on the NRTS, and from many wells in the adjoining part of the Snake River Plain. For several years past practically all radiometric monitoring has been done by the Commission.
Hydrology of Basalt

Knowledge about the hydrology of basalt is poor compared to that about more ordinary types of aquifers such as gravel and sand. The subject requires extensive field research, but certain basic data are prerequisite to such research. Throughout the investigations systematic collection was made of data having possible bearings on basalt hydrology. The test drilling, for example, yielded qualitative information on water-bearing properties of the rock, such as rock porosity and formational porosity, the distribution of porosity and of various internal rock structures, and the distribution of permeable and non-permeable zones. Observations were made of the occurrence and distribution of old buried soil zones, caliche layers, and weathered zones in the basalt, all of which affect its water-bearing properties.

Indirect observations were made during pumping tests of production wells and test wells. The basic operations in such tests are observations of water-level fluctuations before, during, and after pumping, measurements of the rate and variations of pump discharge, instrumental observation of fluctuations in barometric pressure in the air, and observations of the physical appearance of the water that is being pumped. Once those data are obtained, they can be plotted, analysed, and interpreted by standard methods to derive hydraulic formulas and hydraulic constants for the formations. Whether the standard methods are applicable to the basalt aquifer and correctly portray its hydraulic properties is not known. Applied research is needed to find out.

Basic data related to the hydrology of basalt were obtained also by direct study of outcrops. Stratigraphic sections were measured and
described in detail from widely separated parts of the Snake River Plain, and freehand sketches were made of the physical characteristics of the basalt. A special field-research study of the hydrology of basalt was begun late in 1954 but has been in abeyance since mid-1955 for want of a qualified specialist.

The data from all types of field investigations are analysed and interpreted jointly by geologists and engineers in an effort to determine and describe the hydraulic properties of the aquifer. Those properties affect the yield, drawdown, and pumping lift of pumped wells, and they control the movement of waste liquid that is disposed at the surface, in the zone of aeration, or directly to the zone of saturation.

Amount of Water Available

The amount of water available in the Snake River Plain, and the amount that could be withdrawn economically from wells within the NRTS or within a reasonable distance therefrom, are important concerns. In the future it may be desired to establish facilities having a comparatively large water demand, or to provide a central water supply for several large facilities. The data on water-level fluctuations, on the hydrologic properties of the aquifer, on the sources and amounts of recharge, and the rates and directions of underflow, all are basic to ultimate determination of the quantity of water available to the reactor testing station. An estimate of that quantity is derived in part 3.
Construction of Wells and Effects of Pumping

The data obtained by test drilling on the physical characteristics of the subsurface materials, observations on the performance of wells, and observations of water-level fluctuations in relation to pumping, all have been useful aids to decisions about the appropriate constructional characteristics and spacing of wells on the reactor testing station, the pumping rates and pumping lifts to be expected, and other factors.

Laboratory Work

Laboratory work, chiefly of routine and standard nature, was done in connection with many phases of the field study. Chemical and radio-metric analyses of samples of water from the testing station and from outlying parts of the Snake River Plain were made in laboratories of the Geological Survey in Portland, Oregon, Salt Lake City, Utah, and Washington, D. C. Base-exchange tests of sediments were made in the Geochemistry and Petrology Laboratory of the Geological Survey in Washington D. C. The mineralogic composition of clay and silt samples was determined by X-ray diffraction analysis in the Geochemistry and Petrology Laboratory. Petrographic study of consolidated volcanic rocks was by standard methods in the same laboratory. Fossils were identified by the Paleontology and Stratigraphy Branch of the Geological Survey.

In field laboratories of the Geological Survey on the testing station and in Boise, Idaho, grade-size analyses of sediments from the station were determined by standard methods (see appendix 1-A). About 480 samples were analysed.
Specialized tests of disturbed and undisturbed samples of fine-grained sediments were made in the Hydrologic Laboratory of the Geological Survey at Denver, Colorado. Samples were collected from all areas where sediment is the principal geologic unit or where detailed study was necessary for special purposes. Tests included the mechanical composition, permeability when saturated, moisture content, Atterberg limits, and related physical properties. Much of the sedimentary material on the NRTS is unusual in character, and determinations of its permeability required the devising of special laboratory apparatus and special field apparatus for collecting samples.

Research

Research is needed on several basic problems in hydrology and geochemistry, with special reference to the pumping of ground water and the disposal of liquid waste. The problems in those fields in the NRTS are not unique, but their existence lends emphasis to the unsatisfactory status of information about such problems as the following:

1. Saturated permeability of very fine-grained and very coarse-grained sediments occurring at the land surface and in the zone of aeration.

2. Infiltration rate through the very fine-grained sediments and the effect on that rate of physical and chemical changes induced by waste materials in aqueous solutions.

3. Course and rate of percolation of water and waste liquids in the zone of aeration in sediments and in basalt.

5. Ion-exchange properties of sediments and basalt, especially in relation to reactor waste.


Owing to the more immediate demands for basic information of less specialized nature, little progress has been made in research in the above fields, most effort having been devoted to basic-data collection and conventional types of work. From the strictly scientific point of view (disregarding the operational handicap), that situation is satisfactory because most of the basic data is needed as a research tool. Important drawbacks to the research were that, in some instances, the problems were new (or were old ones with new angles) and the methods and equipment available for attack were not standard. Methods had to be devised.

Permeability of Geologic Materials

Methods for determining the saturated permeability of sediments have been used for many years in hydraulic laboratories. The results, though useful, probably do not represent accurately the true permeability of the material as it occurs in nature. For example, laboratory samples ordinarily contain entrapped air which is not present in a saturated zone in nature, because in the course of time circulating water dissolves and removes the air. Entrapped air reduces the permeability of a sample, but standard means had not been developed for exhausting all air from samples. In the process of collection, most samples are disturbed at least slightly, changing their structure and hence their permeability.
As part of its work for the Commission and elsewhere, the Geological Survey devised field equipment for collecting relatively undisturbed samples and laboratory equipment which effectively removes entrapped air. The "saturated permeability" indicated by the laboratory tests probably approaches the true saturated permeability. The results are useful when interpreted in the light of geologic knowledge about the field occurrence of the samples and the conditions under which they were collected. A pilot model of the permeability apparatus was assembled and put in operation on the reactor testing station in 1950. At about the same time, the apparatus was tested on a larger scale in Lincoln, Nebraska in connection with the work of the Survey in the Missouri River basin. Later, a hydrologic laboratory was set up in Denver, Colorado, and numerous tests have been made there.

The permeability of extremely fine-grained material on the NRTS is especially important because much of the northern part of the station is mantled by such sediments, which are an important factor in all problems concerning the surface disposal and surface storage of radioactive liquid waste in that region.

The permeability of coarse-grained sediments also is related to operational and disposal problems. Standard means are available for computing the permeability of coarse-grained materials that occur in the zone of saturation -- that is, from pumping tests and observations of wells which tap water in the zone of saturation, computations can be made of the field coefficient of permeability. On the NRTS the coarse-grained material is in the zone of aeration and pumping tests cannot be made. Intake methods, for determining permeability by injecting water
into the ground through intake wells, are not standardized. Moreover, at most places on the reactor testing station where tests might be made, a convenient source of water is not available. The tests would have to be continued for a considerable period of time in order to yield reliable results.

Infiltration and Percolation

The rate of infiltration of water from the surface into natural sediments is of concern in the design and operation of works for the surface disposal of liquid waste. Lacking empirical information, overdesign of the works may be necessary to assure a margin of safety. Work on the problem thus far has consisted chiefly of preliminary tests to develop satisfactory field methods. The infiltration rate in natural sediment treated with natural water, of course, would have no necessary relation to the infiltration rate after those sediments had been subjected to chemical action by industrial waste. Tests with industrial wastes may be necessary. The tests being made are with small ring infiltrometers and infiltration pits and it is not known what the relation of infiltration rates in such apparatus would be to the rates that may be expected in comparatively large infiltration basins.

Hydraulics of Aquifers

A beginning was made in the study of the hydraulics and hydraulic constants of the basalt aquifer on the NRTS, chiefly the making of observations during pumping tests. Similar observations were made in other parts of the plain where pumping tests could be arranged, chiefly on the North Side Pumping Division of the Minidoka Project.
earliest discharge-drawdown test of an NRTS well was that at the EBR well in August 1949. The test conditions were poor and equipment then available for measuring drawdown at the considerable depth (more than 600 feet) was unsatisfactory. Nevertheless, the results, and those of later tests at other wells, vindicated faith in the ground-water reservoir. About 17 tests have been made on the NRTS. The coefficient of transmissibility of the basalt aquifer has been computed for all production-well sites on the NRTS, and for several test-well locations. In deriving the coefficients it was presumed that water in the basalt behaves about the same as it does in a gravel aquifer -- that is, the flow through the aquifer toward the well is laminar (nonturbulent). Actually, it is not proved that the constants are applicable to the basalt aquifer, and research is needed in that phase of the problem. The problem is important both in relation to the performance of wells and in the disposal and ultimate destination of radioactive waste. The course and rate of movement of ground water and of waste liquids also are of prime concern to the Commission because, if the movement of water is slow, the decay factor in liquid waste may favor disposing of more highly active material than if the rate of movement is rapid.

A related problem is the relation of the direction of movement of ground water to the apparent direction of the maximum hydraulic gradient on the water table. In a homogeneous medium the two coincide. In a medium which has directional differences in permeability, however, the net movement of ground water is not parallel to the maximum hydraulic gradient. The amount of deviation in the Snake River basalt at a given location could be determined only by direct observation. To make such
observations it is necessary to have a point source of discharge for an identifiable liquid, and a pick-up point where that liquid can be detected as it arrives and passes.

**Ion Exchange**

Tests have been made of the ion-exchange properties of about 90 samples of the fine-grained components of natural sediments from the NRTS and of several samples of comminuted basalt. Inasmuch as the tests were made with standard solutions in the laboratory, they do not indicate precisely the exchange capacities for all the radioisotopes that occur in disposed liquids. Neither do they show the total exchange capacity of a gross natural sample containing both the coarse- and fine-grained aggregates. The standard laboratory methods currently in use are not adaptable to determinations for coarse-grained sediments exceeding the silt-size range. The results now available are helpful but fall far short of needs, especially in the case of the basalt, whose exchange or adsorption properties probably are quite different from those observed in pulverized basalt in the laboratory. The most significant results probably will be obtained by direct observation of the behavior of industrial wastes under natural conditions in the field.

**Equipotential Surveying**

An electrical equipotential apparatus for use at the NRTS was designed and constructed by the Geological Survey to aid study of ground-water movement. Owing to the low electrical conductivity of the basalt and the generally dry overburden, high voltage had to be applied to the ground and the pickup apparatus had to be extremely sensitive.
The experimental apparatus was operated intermittently during several months. Currently, the design is being altered. It is proposed to introduce a salt solution in the zone of saturation through a test hole, causing formation of a band of saline water moving down the water-table gradient away from the well. According to generally accepted theories of ground water movement, the saline water would move in a well-defined narrow band, following a streamlined path in the zone of saturation, and would not become diffused or diluted appreciably within finite distance. If that theory is correct, saline water, being more conductive than the natural water, would cause a downstream bulge in the equipotential lines around the home well, because there would be less drop in electrical potential along the path of the saline water. The position of the bulge would identify the course of the solution.

Equipotential surveying, if successful, will have wide uses in ground-water hydrology as well as serving special purposes in the study and detection of contaminants in ground water. Potential applications in waste-disposal problems are obvious.

Coordination with other Investigations

At all times since its inception, the work of the Geological Survey for the Commission has been coordinated on a national basis, so that the problems, techniques, and status of one project are known to those working on other projects. Technical supervision and coordination have prevented duplication of effort and have helped to maintain cosmopolitan points of view. Somewhat more detailed coordination has occurred at the local level.
Some fundamental features of the regional occurrence and use of ground water in the Snake River Plain are under investigation by the Geological Survey as part of a Survey Federal program and programs in cooperation with the State of Idaho and with other Federal agencies. The work is expected to continue for some years and is coordinated under the direction of the Boise, Idaho office of the Geological Survey. All the active and proposed investigations on the Snake River Plain are mutually helpful and complementary to the investigation for the Atomic Energy Commission. Coordination of the timing and places of exploratory and other studies assure that the specific needs and objectives of each program and project are met, at the same time that there is a material contribution by each to overall knowledge of the geology and water resources of the Snake River Plain.

The Geological Survey, in cooperation with the State of Idaho, is making a survey of ground-water resources in the Mud Lake area, which is scheduled for completion in three or four years. A general report on the project will be issued about in 1959.

The Geological Survey issued a preliminary report (Nace, 1948) on the North Side Pumping Division of the Minidoka Reclamation Project, about 70 miles southwest of the NRTS. A follow-up study (Crosthwaite and Scott, 1956) also has been made. The reclamation project may entail pumping as much as 1,000 cfs of ground-water for irrigation during the growing season each year. Several hundred additional cfs is being developed by private enterprise adjacent to the project. The developments tap the same body of ground-water as that beneath the NRTS.
A study by the Survey has been in progress for several years in the Snake River Plain west of a line between Minidoka and Craters of the Moon. Work includes the maintenance of observation wells and spring-discharge gaging stations, quality of water study, and analysis of regional geologic and hydrologic relations.

All these studies are related to investigations for the Atomic Energy Commission, especially with reference to the amount, the course, and the rate of movement of the ground water. Other studies, directly or indirectly related to the general problem have been made on the Fort Hall Indian Reservation, in the Aberdeen-Springfield irrigation area, and in the Big Wood River basin.

Technical Conferences

The Survey participated in many technical conferences at Washington, D. C., Idaho Falls, and the NRTS. Only the more significant ones are noted here.

On November 30 - December 1, 1949 the writer participated in a conference at Idaho Falls with Commission staff members and representatives of the Blaw-Knox Construction Co., contracting architects for the MTR plant. The topics discussed included water requirements, number of wells needed, water system, well construction, well specifications, and disposal of industrial waste and sewage. Present at the discussion were Messrs. F. E. Smith, G. M. Hostetter, B. P. Shephard, L. M. Hale, Nat H. Godbold, and Howard Noble, representing the Commission, and Messrs. F. Gronemeyer and L. C. McGrath representing the Blaw-Knox Construction Co.
An early conference on waste disposal was attended by the writer at Idaho Falls on December 6, 1949. The Atomic Energy Commission was represented by B. P. Shephard and L. M. Hale, the State Health Department by A. L. Biladeau, and the Blaw-Knox Corp. by F. Gronemeyer. The discussion covered various possible methods for the disposal of industrial wastes and sewage effluent, as by injection in intake wells, disposal to leaching beds, and discharge to infiltration ponds.

Another conference in Idaho Falls was on March 9-10, 1953 and concerned technical and policy problems of the Commission in the light of the relation of geology and hydrology to plans and operations at the NRTS. Discussion in the conference included a general resume of plant operations, pertinent hydrologic factors and hydraulic principles, adsorption and ion exchange, ground-water contamination, and AEC policy and procedure. Informally, in connection with inspection and familiarization trips to the NRTS, problems of radioactive solid-waste disposal were discussed. Specific subjects were the types and amounts of radioactive and nonradioactive liquid wastes that are or may be disposed of at the NRTS; solid-waste disposal at Burial Ground D; ground-water development and utilization; operational and health hazards within the NRTS resulting from waste disposal in or on the ground; health hazards beyond the boundaries of the station, where contaminated ground water might enter domestic, municipal, irrigation, and hydropower water systems; "permanent" storage of radioactively "hot" liquid waste on the NRTS. Geology and ground-water hydrology are factors in all those problems. The Commission was represented in the conference by L. E. Johnston, Bion Phillipson, G. V. Beard, Joseph Roarty, F. E. Smith, Lewis Narrow,

On Mar. 10, 1953, the writer was appointed by the Manager of the Idaho Operations Office as a member of the Idaho Environmental Advisory Committee of the Commission, a group which meets semiannually with Commission representatives, reviews operations and the safety program, and advises the Commission of its recommendations.

In 1951 the Geological Survey initiated a series of several technical conferences concerning the nationwide work by the Survey for the Atomic Energy Commission. The meetings were attended by representatives of the Survey in charge of or doing work at the Hanford plant, Richland, Washington; National Reactor Testing Station, Idaho Falls, Idaho; Nevada Test Site, Las Vegas, Nevada; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; Argonne National Laboratory, Lemont, Illinois; Brookhaven National Laboratory, Upton, Long Island, N. Y.; Knolls Atomic Power Plant, Schenectady, New York; Oak Ridge National Laboratory, Oak Ridge, Tennessee; and others. Representatives of the Commission, usually Messrs. A. E. Gorman and Joseph Lieberman, also attend the conferences. The Director of the Survey or his representative commonly attends the opening of the meeting, and Division and Branch chiefs attend some parts. The first meeting was February 13-15, 1951 and was attended by 14 Survey representatives and 2 Commission representatives. The program consisted of a description of the geologic, hydrologic, and geochemical problems at each installation, an
outline of investigations being made, a summary of progress, and a forecast of further study. Discussions usually are made also of special problems having nationwide interest in relation to atomic energy, such as the types and uses of ground-water tracers, ion exchange of radioactive materials in natural earth materials, ground-water hydraulics, ultimate and interim disposal of radioactive wastes, and many others.

Analysis and Interpretation of Data

Analysis and interpretation of data obtained are a major part of the work, especially during the two years just past. The intention is to describe and interpret observed facts, including analysis of the interrelations between natural phenomena and operations of the Atomic Energy Commission and its contractors. The amount of basic information now available is sufficiently voluminous that considerable further analytical work, beyond that reported herein, can be done with a minimum of additional field work.

Special reports

During early phases of construction various types of information were needed by the Commission for planning and layout purposes. Special reports were made by the Survey on each of the construction sites which now contains a facility (excepting the SPERT site), on several still-unoccupied sites, on potential construction sites that were disclosed by geologic mapping, and on the general geology and hydrology of the station. Thus, there is a backlog of general information on potential sites for additional facilities. Many "spot" studies were made and
reported on in letters and memoranda covering subjects as diverse as
drilling specifications and repair of defective wells; filing on
water rights with the State Reclamation Engineer; feasibility of dis-
charging nontoxic liquid waste in intake wells and in surface infiltra-
tion basins; the underground behaviour, course of movement, and destina-
tion of liquid wastes; the probable yield and chemical quality of water
from proposed wells; the feasibility of a central well field for supply-
ing a large amount of water to grouped facilities or to a hypothetical
single large facility; the maximum amount of water that could be pumped
practically on the NRTS, and the effect that such pumpage would have on
water levels and water supplies elsewhere; the rate of underflow of
ground water through the NRTS and westward; the possibilities of a
severe earthquake or lava eruption on the NRTS and when it might occur;
and the geologic nature of foundation materials. Needless to say, the
replies to some of those questions were tentative.

Thirty-one special reports were made formally to the Commission
during 1949 to 1955. Many informal oral and written-memorandum reports
were made, covering the full range of subjects that have been studied.
A list of the special reports (IDO series) and of the more important
miscellaneous reports is included in table 2. The area covered by each
"area" report is shown on plate 1. Summary monthly reports of progress
were submitted to the Commission and to the Washington office of the
Geological Survey, with informal weekly reports to the Commission.
| Table 2.--Reports by the Geological Survey to the Atomic Energy Commission, Idaho |
| Technical Reports, Series IDO-22000-USGS |
| 22001 | Jones, J. R., and Voegeli, P. T., 1951, Geology and ground water at site 2A, Reactor Testing Station, Idaho: (typewritten), 40 p., 3 pls., 5 figs., May. |
| 22002 | Jones, J. R., Deutsch, Morris, and Voegeli, P. T., 1951, Geology and ground water at site 3, Reactor Testing Station, Idaho: (typewritten), 32 p., 2 pls., 7 figs., May. |
| 22003 | Nace, R. L., and Voegeli, P. T., 1951, Geology and ground water at site 1 and an adjacent area to the east, Reactor Testing Station, Idaho: (typewritten), 17 p., 1 pl., 4 figs., June. |
| 22004 | Nace, R. L., Jones, J. R., Voegeli, P. T., and Deutsch, Morris, 1951, Geology and ground water in the central construction area, Reactor Testing Station, Idaho: (typewritten), 61 p., 4 pls., 9 figs., May. |
| 22005 | Nace, R. L., 1949, Memorandum report on pumping test of Arco Reactor Testing Station production-well no. 1 \( \text{[EBR-1]} \): (typewritten), 6 p., 1 fig., August. |
| 22006 | Stewart, J. W., 1950, Results of pumping test on MTR production well 1, Arco Reactor Testing Station, Idaho: (typewritten), 9 p., 3 figs., April (revised June 28, 1950). |
| 22007 | 1950, Results of pumping test no. 2 on MTR production well 1 \( \text{[MTR-1]} \), Arco Reactor Testing Station, Idaho: (typewritten), 7 p., 2 figs., June. |
| 22008 | 1950, Results of pumping test on STR production well 1, Atomic Energy Commission Reactor Testing Station, Idaho: (typewritten), 5 p., 1 fig., August. |
| 22009 | 1951, Results of discharge-drawdown test on Navy well no. 2, Atomic Energy Commission Reactor Testing Station, Idaho: (typewritten), 5 p., 2 figs., March. |
Table 2.--Reports by the Geological Survey to the Atomic Energy Commission, Idaho--Continued

| 22011 | Stewart, J. W., 1951, Results of tests on wells at sites 3 and 7, Reactor Testing Station, Idaho: (typewritten), 29 p., 15 figs., December. |
| 22012 | Nace, R. L., and Jones, J. R., 1950, Reconnaissance of the geology in the Atomic Reactor Testing Station, Idaho: (mimeographed), 19 p., 1 fig., April 10 (revised). |
| 22013 | Jones, J. R., and Jones, S. L., 1951, Results of tests on wells at sites 3 and 7, Reactor Testing Station, Idaho: (typewritten), 38 p., 1 fig. |
| 22014 | Nace, R. L., 1951, Memorandum: Compiled logs of ABC wells STR-2 and CPP-2: (typewritten), 8 p., September. |
| 22016 | Nace, R. L., and Barraclough, J. T., 1952, Ground-water recharge from the Big Lost River below Arco, Idaho: (typewritten), 31 p., 3 pls., 3 figs., January. |
| 22019 | Deutsch, Morris, and West, S. W., 1952, Geology of site 14 and vicinity, National Reactor Testing Station, Idaho: (typewritten), 37 p., 2 pls., 3 figs., April. |
Table 2.—Reports by the Geological Survey to the Atomic Energy Commission, Idaho—Continued

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Title</th>
<th>Type</th>
<th>Pages</th>
<th>Figures</th>
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</thead>
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<tr>
<td>1952</td>
<td>Nace, R. L., and Jones, J. R.</td>
<td>Geologic and topographic features of the northeastern part of the National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
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<td>Nace, R. L.</td>
<td>Construction possibilities at the National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
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<td>Map</td>
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<td>1952</td>
<td>Nace, R. L.</td>
<td>Water supply and waste disposal at proposed ANPR site, National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
<td>15</td>
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<td>1952</td>
<td>Deutsch, Morris, Voegeli, P. T., Nace, R. L., and Jones, J. R.</td>
<td>Geology and ground water in the northeastern part of the National Reactor Testing Station, Idaho</td>
<td>Mimeographed</td>
<td>61</td>
<td>5</td>
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<tr>
<td>1952</td>
<td>Deutsch, Morris, Nace, R. L., and Voegeli, P. T.</td>
<td>Geology, ground water, and waste disposal at the Aircraft Nuclear Propulsion Project site, National Reactor Testing Station, Idaho</td>
<td>Mimeographed</td>
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<td>1953</td>
<td>Nace, R. L.</td>
<td>Altitude and configuration of the water table beneath the National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
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<td>1953</td>
<td>Voegeli, P. T., and West, S. W.</td>
<td>Potential construction sites in the central western part of the National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
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<td>1953</td>
<td>Deutsch, Morris</td>
<td>Geology and hydrology of site 6, National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
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<tr>
<td>1953</td>
<td>Voegeli, P. T., and Deutsch, Morris</td>
<td>Geology, water supply, and waste disposal at sites 11 and 11A, Burial Ground D, and vicinity, National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
<td>42</td>
<td>3</td>
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<td>1954</td>
<td>Deutsch, Morris, Nace, R. L., and Shuter, Eugene</td>
<td>Geology and ground-water resources of a part of western Jefferson County adjacent to the National Reactor Testing Station, Idaho</td>
<td>Typewritten</td>
<td>24</td>
<td>3</td>
</tr>
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</table>
Table 2.--Reports by the Geological Survey to the Atomic Energy Commission, Idaho--Continued

22029 Travis, W. I., 1954, Progress report on operations of stream-gaging station, Big Lost River near Arco, Idaho, water year 1953: (typewritten), 4 p., 3 figs., April.

22030 __________, 1955, Progress report on operations of stream-gaging station, Big Lost River near Arco, Idaho, water year 1954: (multigraphed), 4 p., 2 figs., October.


Miscellaneous Technical Reports and Memoranda


__________, 1949, Memorandum: Deep exploratory drilling in the Snake River Plain: (typewritten), 6 p., December.

__________, 1950, Production wells at MTR and STR sites: Memorandum to Messrs. Frank Smith and Warren Evans (typewritten), 2 p., Nov. 27.

__________, 1951, Condition of MTR production well 2: Memorandum to Director, Engineering and Construction Division (typewritten), 2 p., Feb. 2.

__________, 1951, Finishing and testing MTR production well 2: Memorandum to Director, Engineering and Construction Division (typewritten), 3 p., Feb. 2.


Table 2.—Reports by the Geological Survey to the Atomic Energy Commission, Idaho—Continued

Miscellaneous Technical Reports and Memoranda—Continued

_, 1952, Ground-water recharge from the Big Lost River below Arco, Idaho, April 30–May 2, 1952: Memorandum to Director, Engineering and Construction Division, AEC, Idaho Operations Office (typewritten), 3 p., May 27.


_, 1953, Memorandum: Earth fractures in the ANP area, NRTS, Idaho: (typewritten), 8 p., August.

_, 1953, Earth cracks in ANP area and vicinity, National Reactor Testing Station, Idaho: (typewritten), 5 p.


Administrative and Planning Reports

(all by the writer)


Comprehensive Report

A comprehensive, detailed report on all phases of work by the Geological Survey is a scheduled result of the basic investigations. Compilation and analyses of data leading to the report were continuous processes throughout the period of study, but chiefly in the winter months each year through the winter 1955-56. Owing to the accelerated program of construction, the preparation of nearly 1,000 pages of special reports and about 125 illustrations, unavoidable personnel turnover, and other factors, completion of the report has been delayed repeatedly. The amount of data available in the late stage of report writing necessitated complete reorganization and rewriting of the report, a task undertaken by the writer late in 1955. The result is the following report sections and appendixes:

Part 1. Purpose, history, and scope of investigations. IDO-22032-USGS.

2. Geography and geology. IDO-22033-USGS.

3. Hydrology and water resources. IDO-22034-USGS.

4. Geologic, hydrologic, and geochemical factors in the waste-disposal problem. IDO-22035-USGS.

5. Construction sites and problems. IDO-22036-USGS.

6. Summary, with glossary and abbreviations. IDO-22037-USGS.

Appendix 1. Basic geologic data. IDO-22033-USGS.

2. Basic hydrologic data. IDO-22034-USGS.

Special report. Hydrologic properties of the Snake River basalt.

IDO-22038-USGS.
Summary of Accomplishment

This report covers all phases of work by the Geological Survey for the Commission on the NRTS, but by no means is a final word on all problems that involve the geology and hydrology of the National Reactor Testing Station and of the Snake River Plain. Parts of the report raise more questions than they answer, as in the cases of the hydraulic properties of the Snake River basalt, the movement of ground water, and the ultimate fate of dissolved radioactive solids in liquid waste discharged to the environment. On the other hand, the first step toward solution of a problem is its accurate definition, even though final conclusions do not follow immediately. The descriptions of the physical geology of the station and its regional geologic setting, the nature of the bedrock and overburden, the position and general configuration of the water table, the sources and amount of ground water available and the feasibility of its recovery, and of similar topics are sufficiently definitive for most general purposes and for the solution of common and routine problems.

For special and local purposes, detailed and intensified special studies no doubt will be required from time to time as new construction proceeds, and as new problems arise or old ones become critical. This report is believed to provide a useful basis from which to approach such further problems. On the whole, the principal objectives of the basic investigations have been accomplished, and substantial progress has been made on specialized studies.

The site, though less than perfect, is acceptable for the National Reactor Testing Station in all principal aspects. Most of the physical,
hydrologic, and geochemical factors in the station environment favor reasonably economical construction and operation, adequate abatement of safety hazards, and efficient development. So far as is known to the writer, no major engineering problems have arisen from poor geologic or hydrologic conditions or from lack of information about such conditions. Space is adequate for dispersal of reactor plants and for additional construction. A supply of water of good quality is available in quantity far exceeding foreseeable needs; the supply is as near to complete dependability as could be found in an underground source. The geology of the area is suitable for the construction of all reactor plants now planned or built, and for many more. Conditions are suitable also for the disposal by prudent means of large amounts of low-level radioactive liquid waste. Widespread damage to the water supply of the Snake River Plain can be prevented and could result only from imprudence, accident, or sabotage. Additional facilities could be established on the station without crowding and without creating undue local or regional hazards. The waste-disposal problem is under control for the time being. Though ultimate disposal of high-level radioactive wastes remains a major problem, the same problem would exist regardless of where the station was located.

All the above factors and problems are discussed in the several sections of the report, and relevant features of the physical environment are described and interpreted.
ACKNOWLEDGMENTS AND PERSONNEL

Valuable assistance and information were provided to the Geological Survey by the Commission throughout the study. Special debts for administrative assistance are acknowledged to L. E. Johnston and A. C. Johnson, successive managers of the Idaho Operations Office, to A. R. Lee, information officer, and to A. E. Gorman, of the Reactor Development Division, Washington, D. C. The Engineering and Construction Division of the Idaho Operations office, represented by F. M. Leppich, F. E. Smith, A. L. Biladeau, and L. M. Hale, has been very helpful at all times in technical problems. R. E. Georgi, Director of Security, and his staff have been most helpful in security problems. Dr. G. V. Beard and Percy Griffiths, of the Health Physics Division, were most helpful in chemical and radiometric studies of water. Important climatological data were furnished by P. A. Humphrey and E. M. Wilkins of the U. S. Weather Bureau, who also reviewed and criticized the section on climate in part 2. W. G. Strasser and R. L. Strasser, of the R. J. Strasser Drilling Co., and C. P. Cope, of the Cope Drilling and Pump Co., provided useful information about drilling techniques, test-hole construction, and drilling characteristics of earth materials. The Geological Survey is indebted to the many residents on the Snake River Plain, who supplied logs and other information about their domestic and stock wells.

The variety and scope of geologic, hydrologic, and geochemical problems on the NRTS exceed the ordinary scope of individual competence. Therefore, personnel from several branches of the Geological Survey contributed special services. C. S. Ross, R. A. Bailey, and
Charles Milton, of the Geochemistry and Petrology Branch, studied and reported on the petrology of consolidated rocks; Dorothy Carroll and Hildreth Schultz determined ion-exchange capacities of fine-grained sediments; J. C. Hathaway and Carol J. Parker made x-ray diffraction determinations of the mineralogic composition of fine sediments. Helen Duncan, of the Paleontology and Stratigraphy Branch, identified the invertebrate fossils. J. C. Wright, of the Mineral Deposits Branch, made a field reconnaissance on the Snake River Plain, and suggested means for the correlation of basalt flows. H. Cecil Spicer, of the Geophysics Branch, directed electrical-resistivity and seismic surveys of small areas in the NRTS. H. E. Skibitske, assisted by A. E. Robinson, both from the Phoenix, Arizona office of the Ground Water Branch, designed and installed equipment for electropotential surveying.

A list of all Geological Survey field personnel who have worked on the project is contained in table 3. Much of the data and many of the illustrations used in various parts of this report, were compiled by the junior authors, assisted by J. R. Jones, S. L. Jones, N. B. Crow, A. E. Peckham, and R. O. Smith. Preliminary notes for parts of the report were prepared by Morris Deutsch and P. T. Voegeli. Final compilation and writing of the entire report was by the author of part I, who accepts the responsibility for all facts, interpretations, and conclusions.
Table 3.--Geological Survey field personnel who have worked on the NRTS project

<table>
<thead>
<tr>
<th>Name</th>
<th>Net time spent on project</th>
<th>Nature of work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piper, A. M.</td>
<td>2 years (not full time)</td>
<td>Staff Scientist. Technical supervision and review.</td>
</tr>
<tr>
<td>Theis, C. V.</td>
<td>5 years (not full time)</td>
<td>Staff Scientist. Technical supervision, coordination, and review.</td>
</tr>
<tr>
<td>Nace, R. L.</td>
<td>7 years (not full time)</td>
<td>District Geologist. Planning, direction, and review of all work in Idaho. Part-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>icipated in all phases of field work and report writing.</td>
</tr>
<tr>
<td>Newell, T. R.</td>
<td>3 years (not full time)</td>
<td>District Engineer. Supervised stream gaging.</td>
</tr>
</tbody>
</table>

**GEOLOGISTS**

<table>
<thead>
<tr>
<th>Name</th>
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<th>Nature of work</th>
</tr>
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<tbody>
<tr>
<td>Crosthwaite, E. G.</td>
<td>3 months</td>
<td>Logged drill cuttings; co-author of report on logs of test holes and wells drilled in and near the NRTS.</td>
</tr>
<tr>
<td>Crow, N. B.</td>
<td>1½ years</td>
<td>Geologic mapping (59 sections); inspected deep test-drilling; special studies of the size-grade characteristics of sediments. Logged drill cuttings; co-author of report on logs of test holes and wells.</td>
</tr>
<tr>
<td>Name</td>
<td>Net time spent on project</td>
<td>Nature of work</td>
</tr>
<tr>
<td>-----------------</td>
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<td>------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Deutsch, Morris</td>
<td>3½ years</td>
<td>Chief of field party for 1 year; geologic mapping (61 sections); pumping and recharge tests of wells; special site studies; compiled geologic and hydrologic data; co-author of numerous special reports.</td>
</tr>
<tr>
<td>Fennerty, F. E.</td>
<td>3 months</td>
<td>Compiled field data on hydrology of basalt.</td>
</tr>
<tr>
<td>Jones, J. R.</td>
<td>3 years</td>
<td>Chief of field party for 3 years; geologic mapping (29 sections); special site studies; pumping and recharge tests of wells; co-author of numerous special reports.</td>
</tr>
<tr>
<td>Jones, S. L.</td>
<td>3 years</td>
<td>Studied size-grade characteristics of sediments; geologic mapping (8.5 sections); logged drill cuttings; co-author of several reports on test holes and wells.</td>
</tr>
<tr>
<td>Littleton, R. T.</td>
<td>1 month</td>
<td>Logged drill cuttings.</td>
</tr>
<tr>
<td>Peckham, A. E.</td>
<td>10 months</td>
<td>Inspected and supervised special test drilling; reviewed and compiled drill logs; compiled various data for comprehensive report; mechanical analyses of sediments; geologic mapping (9 sections); assisted stream gaging and gamma-ray logging.</td>
</tr>
</tbody>
</table>
### Table 3.--Geological Survey field personnel who have worked on the NRTS project--Continued

<table>
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<th>Name</th>
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<td><strong>GEOLOGISTS--Continued</strong></td>
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<tr>
<td>Rex, R. W.</td>
<td>3 months</td>
<td>Geologic mapping (42.5 sections); assisted seismic and resistivity exploration; assisted pumping tests.</td>
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<tr>
<td>Smith, R. O.</td>
<td>9 months</td>
<td>Geologic mapping (108 sections); inspected test-drilling; special study of earthcracks at ANP site; pumping tests; logged drill cuttings.</td>
</tr>
<tr>
<td>Voegeli, P. T.</td>
<td>4 years</td>
<td>Chief of field party for 9 months; geologic mapping (127 sections); pumping and recharge tests of wells; special site studies; co-author of numerous site reports and reports on test holes and wells; logged drill cuttings; special study of earthcracks at ANP site; assisted gamma-ray logging.</td>
</tr>
<tr>
<td>West, S. W.</td>
<td>1 year</td>
<td>Geologic mapping (48 sections); co-author of 2 special site reports; test-hole logging; assisted in seismic and resistivity exploration.</td>
</tr>
<tr>
<td><strong>ENGINEERS</strong></td>
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<td></td>
</tr>
<tr>
<td>Barraclough, J. T.</td>
<td>6 months</td>
<td>Stream-gaging on Big Lost River; assisted gamma-ray logging; co-author of one hydrologic report.</td>
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Table 3.--Geological Survey field personnel who have worked on the NRTS project--Continued

<table>
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<th>Name</th>
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<td><strong>ENGINEERS--Continued</strong></td>
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<tr>
<td>Fader, S. W.</td>
<td>6 months</td>
<td>Well inventory; spirit leveling; pumping tests.</td>
</tr>
<tr>
<td>Kellogg, R. W.</td>
<td>6 months</td>
<td>Supervised early deep test-drilling.</td>
</tr>
<tr>
<td>McQueen, I. L.</td>
<td>1 year</td>
<td>Made permeability studies; pumping tests; compiled data on chemical quality of water.</td>
</tr>
<tr>
<td>Mower, R. W.</td>
<td>1 month</td>
<td>Compiled, interpreted, and evaluated pumping-test data.</td>
</tr>
<tr>
<td>Stewart, J. W.</td>
<td>5 years (not full time)</td>
<td>Assisted the district geologist in planning, direction, and review; pumping and recharge tests and analysis of data; co-author of numerous special reports; planned and supervised the observation-well program; compiled, interpreted, and evaluated hydrologic data; reviewed all phases of engineering work.</td>
</tr>
<tr>
<td>Tuller, W. H.</td>
<td>Intermittent</td>
<td>Miscellaneous stream gaging.</td>
</tr>
<tr>
<td>Travis, W. I.</td>
<td>Intermittent</td>
<td>Analysed streamflow data and prepared progress report on stream gaging.</td>
</tr>
<tr>
<td>Skibitzke, H. E.</td>
<td>2 months</td>
<td>Mathematician. Designed and built equipotential-survey equipment and instructed personnel in operation of gamma-ray logger.</td>
</tr>
</tbody>
</table>
Table 3.--Geological Survey field personnel who have worked on the NRTS project--Continued

<table>
<thead>
<tr>
<th>Name</th>
<th>Net time spent on project</th>
<th>Nature of work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitehead, R. L.</td>
<td>2 years</td>
<td>Scientific Illustrator. Drafted most illustrations for all reports; compiled hydrologic data and drafted hydrographs.</td>
</tr>
<tr>
<td>Brandvold, G. E.</td>
<td>1 year</td>
<td>Compiled hydrologic data; assisted in pumping tests, seismic and resistivity exploration, and laboratory work; measured observation wells; installed and serviced water-level recording gages.</td>
</tr>
<tr>
<td>Carson, R. H.</td>
<td>5 years (not full time)</td>
<td>Instrument man for level and transit surveys; measured observation wells; installed and serviced water-level recording gages; assisted in seismic and resistivity exploration and in pumping and recharge tests; well inventory; inspected deep test-drilling.</td>
</tr>
<tr>
<td>DeCoria, K. E.</td>
<td>4 months</td>
<td>Measured observation wells; collected sediment samples; rodman (spirit leveling).</td>
</tr>
<tr>
<td>Gill, B. L.</td>
<td>2 months</td>
<td>Well inventory; rodman (spirit leveling).</td>
</tr>
</tbody>
</table>
Table 3.--Geological Survey field personnel who have worked on the NRTS project--Continued

<table>
<thead>
<tr>
<th>Name</th>
<th>Net time spent on project</th>
<th>Nature of work</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENGINEERING AIDS--Continued</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irminger, C. B.</td>
<td>1 year</td>
<td>Measured observation wells; collected sediment samples; installed and serviced water-level recording gages; made mechanical analyses of sediments.</td>
</tr>
<tr>
<td>Ragsdale, R. F.</td>
<td>3½ years (not full time)</td>
<td>Measured observation wells; installed and serviced water-level recording gages; assisted in pumping and recharge tests; rodman for level and transit surveys.</td>
</tr>
<tr>
<td>Robinson, A. E.</td>
<td>2 months</td>
<td>Directed equipotential surveying.</td>
</tr>
<tr>
<td>Shutter, Eugene</td>
<td>1 year</td>
<td>Geologic mapping (21 sections); measured observation wells; assisted in pumping and recharge tests; co-author one special report; installed and serviced water-level recording gages; well inventory; assisted seismic and resistivity exploration; assisted stream-gaging; collected sediment samples.</td>
</tr>
<tr>
<td>Sisco, J. E.</td>
<td>2 months</td>
<td>Measured observation wells; well inventory; made mechanical analyses of sediments; rodman for spirit leveling; assisted in pumping test; installed and serviced recording gages.</td>
</tr>
</tbody>
</table>
### Table 3.—Geological Survey field personnel who have worked on the NRTS project—Continued

<table>
<thead>
<tr>
<th>Name</th>
<th>Net time spent on project</th>
<th>Nature of work</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENGINEERING AIDS—Continued</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sisco, H. G.</td>
<td>5 years (not full time)</td>
<td>Measured observation wells; well inventory; assisted pumping, and recharge tests; instrument man and rodman (spirit leveling); inspected deep test-drilling; installed and serviced water-level recording gages; assisted in stream gaging and in seismic and resistivity exploration.</td>
</tr>
<tr>
<td><strong>HYDROLOGIC FIELD ASSISTANTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day, T. P.</td>
<td>1 month</td>
<td>Rodman (spirit leveling).</td>
</tr>
<tr>
<td>Johnson, D. L.</td>
<td>2 weeks</td>
<td>Geologic mapping (parts of 19 sections).</td>
</tr>
<tr>
<td>Mack, L. E.</td>
<td>3 months</td>
<td>Inspected deep test-drilling program. Assisted in geologic mapping.</td>
</tr>
<tr>
<td>Ringe, D. L.</td>
<td>3 months</td>
<td>Geologic mapping (65.5 sections).</td>
</tr>
<tr>
<td>Schwarze, D. M.</td>
<td>1 month</td>
<td>Assisted equipotential surveying.</td>
</tr>
<tr>
<td>Tate, J. H.</td>
<td>5 months</td>
<td>Compiled climatological and chemical data for comprehensive report; designed various illustrations for comprehensive report.</td>
</tr>
<tr>
<td>Urffer, D. S.</td>
<td>2 months</td>
<td>Assisted equipotential surveying and gamma-ray logging.</td>
</tr>
</tbody>
</table>
Table 3.--Geological Survey field personnel who have worked on the NRTS project--Continued

<table>
<thead>
<tr>
<th>Name</th>
<th>Net time spent on project</th>
<th>Nature of work</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHYSICAL SCIENCE AID</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiatt, W. H.</td>
<td>1½ years (not full time)</td>
<td>Measured observation wells; rodman (spirit leveling); assisted in geologic mapping; installed and serviced water-level recording gages.</td>
</tr>
<tr>
<td>Kinnison, P. T.</td>
<td>6 months</td>
<td>Geologic mapping (99.5 sections).</td>
</tr>
</tbody>
</table>
LITERATURE CITED


GENERALIZED GRAPHIC LOGS OF TEST HOLES
GENERALIZED GRAPHIC LOGS OF TEST HOLES

CONSTRUCTION DIAGRAM

DIAGRAM

DEPTH (FEET)

GEOLOGICAL SURVEY

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PLATE 5

GEOLOGICAL SURVEY

PLATE 5

GEOLOGICAL SURVEY

PLATE 5
GENERALIZED GRAPHIC LOGS OF TEST HOLES
<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Resistivity (ft-lb)</th>
<th>Increases</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>50</td>
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</tr>
<tr>
<td>675</td>
<td></td>
<td>700</td>
</tr>
</tbody>
</table>

**Construction Diagram**

- **Components:**
  - Clay
  - Basalt
  - Sand and Gravel
  - Basalt
  - Sand and Gravel
  - Basalt
  - Clay
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Basalt
  - No Sample
  - Saltil
  - Clay

**Altitude (feet):**

- 5,000
- 4,900
- 4,800
- 4,700
- 4,600
- 4,500
- 4,400
- 4,300
- 4,200
- 4,100
- 4,000
- 3,900
- 3,800
- 3,700
- 3,600
- 3,500
- 3,400
- 3,300
- 3,200
- 3,100
- 3,000
- 2,900
- 2,800
- 2,700
- 2,600
- 2,500
- 2,400
- 2,300
- 2,200
- 2,100
- 2,000
- 1,900
- 1,800
- 1,700
- 1,600
- 1,500
- 1,400
- 1,300
- 1,200
- 1,100
- 1,000
- 900
- 800
- 700
- 600
- 500
- 400
- 300
- 200
- 100
- 0

**Generalized Graphic Logs of Test Holes**

- **Locations:**
  - 2N-31E-35adl (field no. 1)
  - 2N-29E-30adl (field no. 11)
  - 2N-28E-35adl (field no. 11)

**Notes:**

- Water-level (500 ft.)
- Perforations & Bonding - Spiral Pattern
- casing shoe
- Lead packer
- Welded joint (600 ft.)
- O.D. casing

**Department of the Interior**

** Geological Survey**

**Gamma-Ray Log**

**Depth Radioactivity (feet) Increases**
GENERALIZED GRAPHIC LOGS OF WELLS

2N-29E-1ad (field no. CF-2)

2N-29E-1ai (field no. CF-1)
GENERALIZED GRAPHIC LOG OF A TEST HOLE AND A WELL

PLATE 17

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY