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THE UNDERGROUND DISPOSAL OF LIQUID WASTES AT THE HANFORD WORKS, WASHINGTON

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THE UNDERGROUND DISPOSAL OF LIQUID WASTES AT THE HANFORD WORKS, WASHINGTON

An Interim Report
Covering the Period up to January 1, 1950

by

R. E. Brown and H. G. Ruppert

February 1, 1950

Development Division
HEALTH INSTRUMENT DIVISIONS

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Hanford Works
Richland, Washington

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ABSTRACT

The Hanford Works area, originally believed to be suitable for the temporary or interim underground disposal of certain radioactive wastes, pending the devising of more adequate and safer methods of disposal, has served as a test area for the Atomic Energy Commission for such disposal practices since beginning of operations of the plant. The history and development of the methods of underground disposal at the Hanford Works are described, as is an extensive program of investigation and exploration to determine what specifically resulted from those waste disposal practices and what might be expected to happen in the future. The first phase of this work, limited to the areas immediately adjacent to the waste disposal units, is discussed in a previous interim report. This work indicated that the methods of disposal had created no unforeseen or unanticipated hazards in the areas investigated, that the Works area was probably as ideal an area for such experiments as could be found, but that certain factors and conditions limited the waste disposal practices and strongly indicated the need for considerable additional information.

An exploration program to obtain necessary basic hydrologic and geologic information in the vicinity of the 200 areas resulted in the assemblage of a great deal of information and numerous tentative conclusions pertinent to and significant to the immediate waste disposal problems. This program is described in detail in a separate preliminary interim report, the facts and conclusions of which are summarized as is a generalized geologic picture of the Hanford Works area determined by that program.

The present report brings the waste disposal information up to date, re-evaluates the earlier-obtained information in the light of more recently gathered information, and generally confirms the conclusions resulting from the early phases of the investigation and exploration program.

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The exploration and observation program within the 200 areas indicates that the plutonium and most of the fission products in the radioactive wastes are removed within a relatively short distance of the waste disposal units. Uranium and certain fission products, including ruthenium and zirconium, are demonstrate to be the most likely elements to remain in solution and to travel the farthest from the point of injection. Plutonium, of greatest concern in waste disposal operations, is demonstrably removed from the solutions within a shorter distance than any other of the investigated radioactive elements in every case The ground water in two locations, one in each 200 area, is contaminated by radioactive waste, at each location injected close to or directly into the ground water through reverse wells, neither of which has been in use for at least two years. An analysis of the results of the two-year sampling program of the ground water beneath the 200-East area is presented. Evidence from both locations indicates that the ground water beneath the 200 areas is currently immobile, owing to the creation of artificial ground water mounds, formed by the discharge of about 6,200,000,000 gallons (19,030 acre feet) of non-radioactive water to the ground in five principal discharge areas. Such activity as is present in the ground water and such as may penetrate to the ground water will thus remain in place until radioactive decay and diffusion reduce the activity level below the significantly contaminated or reporting level. Moreover, a means also exists by which such activity can be held in place by artificially-formed ground water dams until radioactive decay, diffusion and possible artificial dilution have reduced the activity to acceptable levels.

Radioactive wastes discharged to the ground total 55,500,000 gallons, containing an estimated 800 grams of plutonium and 7400 curies of fission products. Other than the radioactive wastes discharged into the deep reverse wells, no

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radioactive materials are known or believed to have penetrated to the ground water table. Plutonium, presumably introduced into the ground at or near the ground water table through the deep reverse wells, is not known to be in solution or traveling in the ground water.

Preliminary laboratory experiments generally confirm the empirical findings, and together with the observations made in the field indicate that no serious hazards have been or are being created, but that the need exists for an extensive series of laboratory experiments, in addition to further and continuous field investigations.

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INTRODUCTION

History of Problem

Disposal of liquid radioactive wastes from the separations plants (200 Areas) at the Hanford Works has been a problem of paramount importance since beginning of operations. The highly active wastes were originally scheduled for storage in underground steel and reinforced concrete tanks designed to reduce the possibility of tank failure to a minimum; mildly active wastes were scheduled to be mixed with uncontaminated effluent water and disposed of by seepage into and evaporation on the ground surface. Some such disposal of the low activity wastes was necessary, for the volumes of low level wastes precluded the practicability of storing them in tanks such as those designed for the highly active wastes. These low level wastes also contained insufficient amounts of radioactive elements for economical recovery, in contrast to the higher level wastes, so that such a disposal method was indicated, if feasible.

Dr. R.S. Stone, Dr. S.T. Cantril and H.M. Parker called attention to the high evaporativity rate in south central Washington, which would cause radioactive materials to deposit on the ground surface in such spreading areas, from where the wind would remove much of the activity and spread it over the surrounding region. The active wastes were then scheduled for discharge into reverse wells, originally provided for the low level wastes. These wells ranged in depth from 150 to 300 feet and were perforated near the bottom. Three disadvantages in the use of the reverse wells for the management of large volumes of waste were quickly recognized:

1. The wells were easily plugged by solids introduced into them, and by sand washed into them through the perforations.
2. Radioactive wastes were discharged close to the ground water table.

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3. The behavior of the activity in the ground was more difficult to follow than at shallower depths.

Reverse wells are regarded as a mistake for all except small quantities of waste, and disposal into buried cribs and tile fields was therefore substituted. The disposal of active wastes into the ground was, however, always recognized as a temporary but necessary expedient, which permitted the operation of the separations plants pending the development of intrinsically safer and more effective means of ultimate disposal (1).

Discharge into the ground offered a ready, cheap means of disposal by which the radioactive materials might be removed from the solutions and concentrated on the sediments, thus leaving large volumes of presumably innocuous waste water to move downward to the water table and from there eventually to the Columbia and Yakima Rivers. Preliminary reports by Gillson (9), and Piper (20) indicated that such disposal could be practiced on a limited scale under controlled conditions, and pointed out some of the problems that would be encountered and exploration that could be undertaken. Preliminary laboratory tests by Overstreet and Jacobson (15), Healy (10), and Kay (12), demonstrated that the fixation of radioactive elements on the sediments was probably effective enough to make such a method of disposal possible, although none of these investigations purported to be definitive. Moreover, experiments with stored 2nd cycle wastes demonstrated that the accumulation of an active sludge at the bottom of the tank created a supernatant liquid that could be discharged to buried cribs. The discharge of these wastes to the ground afforded an incidental means of determining what might result from the sudden release of large quantities of wastes of infinitely greater activity through tank failure and similar disaster. Cal-

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culations indicated that if such low activity wastes as were scheduled for disposal into the ground were introduced directly into the ground water, the dilution by that ground water would materially reduce the activity level, which would be further reduced by the radioactive decay resulting from the time necessary for that contaminated water to move to points of use or to the Columbia or Yakima Rivers. Those conclusions have been largely demonstrated and are discussed in some detail in this report. Further dilution by the Columbia and Yakima Rivers was believed to be more than ample additional safeguard. This is adequately demonstrated by the results of sampling of the Columbia River following both advertent and inadvertent release of wastes to the river.

Previous Work

A report prepared by Overbeck (14) in 1946, estimated the feasibility and cost of a well drilling program to check the laboratory results, to determine what had happened to the wastes already discharged to the ground and what hazards, if any, had resulted. The outcome of the resultant drilling program in the 200-West area is summarized in a published interim report (2,3). That report discusses the drilling program in the 200-West area, the equipment and methods employed, personnel, safety precautions, sampling and sample analysis and tentative conclusions based on the limited work done and the short time that the disposal methods were observed. The present report discusses the outcome of that same drilling program in the 200-East area, and the results of a series of observations on the waste disposal units made over a period of nearly three years since drilling began in both areas. Publication of the results of the drilling in the 200-East area was purposely withheld pending completion of an adequate number of observations over a sufficiently long time to permit the formation of tentative conclusions and to further validate the earlier expressed opinions resulting from the drilling in the 200-West area.

A drilling program, begun in April 1948, and completed in February 1949, outlined the geologic and hydrologic features of the region in the vicinity of the 200 areas. This project, a cooperative project with the U.S. Geological Survey, Ground Water Branch, is described in a preliminary interim report (16). The area covered by that project is essentially that area covered by Plate 1. Additional drilling is planned to expand this first exploratory program and to develop geologic and hydrologic information where additional information is indicated as needed.

Acknowledgments

The present report is based on information and samples gathered by members of the Geology group: geology by R.E. Brown and M.W. McConiga, water and radioactive sediment samples by H.G. Ruppert and L.P. Rolph, and ground water information by M.W. McConiga. Particular assistance and information were also supplied from time to time by J.M. Smith, Jr., H.J. Paas of the Site Survey group, J.W. Healy of Methods and Control, W. Singlevich of the Control group, and R.C. Thorburn of the Methods group. Members of the U.S. Geological Survey field party, headed by G.G. Parker, were also of considerable assistance during their stay on the project in analyzing the general problems encountered.

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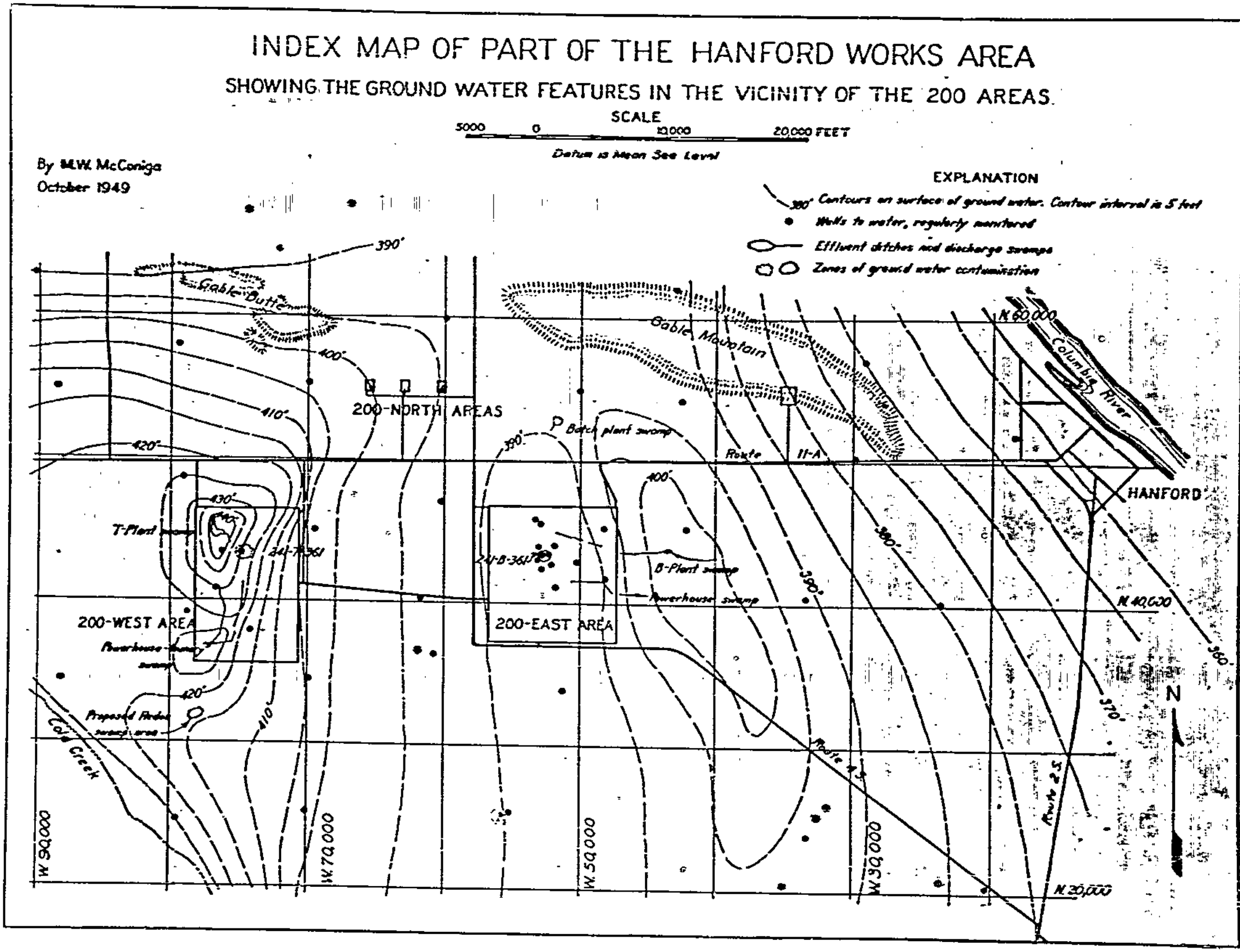

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PLATE 1

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GENERAL GEOLOGIC FEATURES

The general geologic picture of the south-central part of Washington is summarized by a number of workers. These reports are predominantly highly generalized, inadequately detailed, and based on insufficient field work, or if adequately detailed are so limited in areal extent as to be nearly valueless in the general study of the region.

The following description is a brief summary of the geologic history and conditions with emphasis on those features related to underground waste disposal practices.

The Hanford Works area lies entirely within the Pasco basin, a downwarped section of the Columbia River plateau area in south-central Washington. The basin is bounded on the north by the Saddle Mountains, on the east by the gently rising lavas of the plateau about to Walla Walla, on the south by the Horse Heaven Hills, and on the west by the basalt ridges of the Yakima Range. The basin is essentially the lowest part of the Columbia River plateau of central Washington, toward which the lavas of eastern Washington dip at an average slope of 25 feet per mile.

The basalts which underlie nearly the whole of eastern Washington are a part of the vast Columbia River volcanic series, predominantly of Miocene age. These lavas, accumulated to a known thickness of 2200 feet, and a probable thickness in excess of 6,000 feet, consist of flows of basalt, referred to locally as the Yakima basalt, interbedded with tuffs, sandstones, shales, and siltstones, in part and tentatively identified with the Ellensburg formation of the late Miocene age. The lavas and interbedded sediments are folded and locally faulted into a series of essentially east-west trending folds which attain their greatest magnitude west of the basin and gradually die out east-

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ward. The Horse Heaven Hills, the Rattlesnake Hills, the Yakima Range, the Saddle Mountains and Frenchman Hills are such anticlinal or up-folded masses of the basalt bedrock, separated by synclinal or down-folded areas now present as alluvial-filled valleys. Gable Mountain and Gable Butte represent the locally-faulted eastward extension of one of these anticlinal folds. The detailed structure of the bedrock beneath the Hanford Works area is not known, owing to lack of available exposures and insufficient wells into the basalt bedrock, although the general structure is known from the logs of a few deep wells that penetrate the basalt throughout the basin.

The Pasco basin contains the dissected remnants of an early Pleistocene lacustrine fill (river flood-plain or shallow lake deposit) which overlies the basalt. This formation is exposed at the type locality (where the beds were first noted, and from which they were originally described) in the White Bluffs of the Columbia River from a point opposite the 300 area to a point approximately opposite the 100-F area. The Ringold formation also underlies much of the area lying north and east of the Rattlesnake Hills, where it is generally concealed beneath later river sediments, lake and flood-plain deposits, and wind-laid sediments.

The Ringold formation was laid down in a shallow lake in late Pliocene or early Pleistocene time, prior to at least the last period of glaciation of the Ice Age. The Columbia River, dammed by the rising Horse Heaven Hills, was diverted from its course over Satus Pass, and forced into other channels during its attempt to find a path through the mountains. Channels which the Columbia River scoured across the basalt beneath the Hanford Works area at this time were then filled with sediments of the Ringold formation, which accumulated to a level approximately 1000 feet above present sea level.

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Following deposition of the Ringold formation, the Columbia River broke through the Horse Heaven Hills at Wallula and established a new channel which it maintained throughout the continuing rise of the Horse Heaven Hills. Much of the Ringold formation beneath the project area was stripped away and reworked by the eroding and degrading river. A thick series of coarse terrace gravels, containing some reworked Ringold sediments, was deposited upon the eroded surface of the Ringold formation and upon those areas of basalt from which the Ringold formation was removed.

The period of the Ice Age was followed by the deposition of additional terrace gravels and glacial outwash deposits laid down as the ice in northern Washington melted and as floods of meltwater poured across central Washington. A rise of base level of the Columbia River, possibly initiated by a rise in sea level, a sinking of the land mass, or local damming of the Columbia River by ice jams, freezing of the river, landslides or lava flows, singly or in combination, again resulted in the formation of a shallow lake within the Pasco basin. A deposit of fine-grained sediments known as the Touchet beds (named from the type locality at Touchet, Washington) were laid down over the surface of the terrace gravels, the Ringold formation where exposed, and the basalt, where Ringold sediments and terrace gravels were stripped from the bedrock. These sediments, characteristically unconsolidated silts and find-grained sands, are reported up to 1150 feet above sea level. Typical exposures of them occur in the Yakima Range and Rattlesnake Hills up to that altitude so that Gable Mountain and Gable Butte were presumably covered by these sediments. Removal of the cause for the higher base level permitted the Columbia River to rapidly and thoroughly remove most of the unconsolidated Touchet sediments from the project area, so that today these sediments are found only along the lower flanks of the

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Rattlesnake Hills and Yakima Range and in Cold Creek Valley.

The geologic history of the region was completed with the deposition of loess (wind-reworked and wind-deposited silt and fine sand), and the formation of sand dunes.

The geologic picture of the post-basalt sediments beneath the Hanford Works area is thus quite complex. Ringold sediments, reworked Ringold sediments, fluvial gravels, terrace gravels, probable alluvial fan deposits, and Touchet sediments are intimately intermingled within an area measuring 15 miles long and 8 miles wide, over a vertical range drilled of about 800 feet. A detailed and accurate picture of the subsurface geology therefore, can be obtained only by prohibitively expensive exploration. A fairly accurate picture of the conditions existing beneath the 200 areas was obtained as a result of the large number of wells drilled in and about those areas for waste disposal studies and observations.

The 200 areas lie above a broad basalt ridge or elongate dome which attains a maximum elevation of about 400 feet and an average of probably 330 feet. This ridge terminates to the north and presumably to the south and west where channels or valleys were cut in the basalt by the early Columbia River. One valley, outlined by 14 wells drilled to the basalt, trends southeastward between Gable Mountain and Gable Butte, just east of the 200-North areas, thence east-southeastward parallel to Gable Mountain. A smaller, less well-defined channel apparently passes south of Gable Butte, beneath the 200-North areas and joins the previously described channel. West of the 200-West area a probable channel trends south from a point between Gable Butte and Yakima Range to a point west of the southwest corner of 200-West area, at which point it turns south-south eastward and heads toward the Yakima River at the Horn. This channel in the basalt, inadequately defined and explored to date, apparently is the channel referred to by Warren (24) as the main channel of the

Columbia River during the period the river attempted to maintain its channel across Satus Pass prior to deposition of the Ringold formation. Additional exploration is needed to define adequately these channels in the basalt. Sufficient work was done, however, to demonstrate that channelling and canalizing of the radioactive waste liquids, as suggested by Gillson (9) and Piper (20) is apparently not greatly significant to the waste disposal problem.

The channels in the basalt were filled with fluvial gravels and sands, which gradually gave way upward to the silts, clays and fine-grained sands of the Ringold formation as the Columbia River ponded. Much of the Ringold formation was stripped from the area as the lake drained through Wallula Gap, and a series of terrace gravels were deposited, some of which consist of reworked sediments of the Ringold formation. Differences in opinion as to what constitutes the Ringold formation within the Hanford Works area can thus easily result. The U.S Geological Survey, as the result of their studies in the project area, call essentially all the sediments Ringold in the southern part of the 200-East area from the basalt bedrock to the surface, although such materials are coarse sandy gravels, not correlatable with definite beds of Ringold sediments in the White Bluffs at the same elevations. Some of these gravels are obviously fluvial gravels, deposited on the eroded surface of the basalt prior to ponding of the Columbia River, and are certainly within the lower part of the Ringold formation, as described by Parker and Piper. However, the Ringold formation in the White Bluffs indicates that a lake existed in the Pasco basin at stratigraphic horizons that now range from elevations of less than 400 feet to more than 900 feet, for the sediments exposed between those elevations are clearly lacustrine, and not fluvial. Therefore, the assumption that coarse Ringold sediments of fluvial origin occur at an elevation of nearly 750 feet in the vicinity of the 200 areas does not explain how fluvial sediments accumulated in one locality, whereas lacustrine sediments accumulated only a few miles away within the same basin. If some of these coarse gravels are alluvial deposits derived from the Yakima Range or Rattlesnake Hills, then the criterion of dominance of quartz particles over basalt used for differentiation of Ringold formation from the terrace deposits fails, for such alluvial materials should consist almost exclusively of basalt and its decomposition and disintegration products, and not of quartz, which occurs in quantitatively unimportant amounts within the local region in the Yakima basalt and intercalated sediments.

Examination of numerous excavations throughout the region of the 200 areas discloses that, at least to a depth of 50 feet, the sediments are generally clearly fluvial in origin. Some of these excavations were not available at the time the U.S. Geological Survey completed their field work, and several wells were also drilled following their departure. The almost complete lack of difference between the samples to a depth of nearly 200 feet from the thirteen wells to water in the area suggests that the Ringold formation as currently defined may not exist in the vicinity of the 200 areas at the elevations ascribed to it by Parker and Piper, and that much of the gravels mapped by them as Ringold formation may be later terrace gravels. Additional extensive areal and regional studies can resolve many of these and similar problems.

The Touchet beds, known to occur only in the southern and western parts of the Hanford Works area, are well exposed in the banks of Cold Creek, and in several wells drilled adjacent to and in Cold Creek Valley. Exposures here are identical to those at the type locality near Touchet, described by Flint (8). The sediments are buff to cream-colored silts and fine sands, generally well stratified with cut and fill (fluvial) bedding common. Sedimentary dikes are characteristic of the beds. The sediments, unlike those of the Ringold forma-

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tion, are free from caliche and contain no significant amount of calcareous material, whereas the calcareous nature of the Ringold sediments is one of its indentifying features. Glacial erratics of granite, gneiss, schist, quartzite, and related rocks are prominent on the upper surface of the bed, where they wer dropped from ice floes derived from the disintegrating glaciers in the north. The beds were recognized as a distinct soil type by Kocher and Strahorn (13) and by Strahorn, Carpenter, Weir, Ewing, Krusekopf, Heck, and Lunt (22), although lack of regional work prevented a complete study of the sediments. Th U.S. Geological Survey classified these sediments predominantly as Ringold, although preliminary work suggests that at least some of these sediments are actually Touchet, and that the differences in the chemical and physical properties of the sediments of the two formations are great enough to cause important differences in the way they will react to wastes planned for disposal south of the 200-West area.

OBJECTIVES OF PROGRAM

Little published information is known to be available on the underground disposal of wastes, or the manner or means by which pollution or contamination is removed from liquids percolating or seeping through soil or sediments. Nothing is known of the action of radioactive contamination within the soil or sediments, with the exception of the investigations previously discussed and currently being carried on at the Hanford Works. The purposes and aims of the investigations are nearly identical with the purposes of the investigation in the 200-West area of the Hanford Works, but the different underground conditions in the 200-East area resulted in an emphasis on a new set of problems and in a reanalysis of the information obtained in the 200-West area.

The purposes, essentially as outlined in the previous report, are as follows:

1. To determine what has happened to radioactive wastes already placed in the ground through reverse (dry) wells, and subsurface cribs.
2. To determine the way that the activity spreads and increases in concentration with the addition of more radioactive wastes.
3. To predict, on the basis of information obtained from Objective 1, where the plutonium and fission products wastes will go that have been and may be discharged into the ground in the various waste disposal areas.
4. To determine if wastes containing greater quantities of plutonium and fission products than have been discharged underground can be safely discharged in a similar manner.
5. To determine if underground waste disposal is feasible over a long period of time, particularly in the areas under discussion, and to determine, if possible, what period of time will be safe for such underground waste disposal.
6. To compare the relative efficiency of absorption of reverse (dry) wells, subsurface cribs, trenches, and tile fields.
7. To obtain all the geologic information possible, coincident with the drilling, on subsurface geologic and ground water conditions, so that as much might be known about this incompletely and inadequately studied area as possible.

FIELD PROGRAM

Equipment and Methods Employed -

The drilling machines, equipment and methods used in drilling in the 200-East area and the 200-West area since publication of the earlier report were

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essentially the same as discussed in the previous report. The more efficient rod and plunger "suction" type or "sand-pump" bailer was used for the first time in the 200-East area in the 5-6 crib and tile field area on the recommendation of the U.S. Geological Survey, in place of the standard dart-type bailer. The new bailer permits bailing the wells nearly dry and thus results in less carry down of the sludge to lower levels and permits the obtaining of more accurately representative samples of the sediments. It also recovers the coarse drill cuttings which the dart-type bailer is less able to do. The results obtained from drilling in the 361-T, the 231 and 201-T tank crib areas demonstrated that carry-down of contamination was probably small to non-existent when considerable care was exercised in the use of the dart-type bailer; however the sand-pump bailer is obviously better for drilling contaminated ground where such carry down of contamination in the drill cuttings is even only remotely possible.

The change from dart bailers to the sand pump bailer necessitated changing the method of handling the bailer, because the sand pump must be inverted to empty it. An invertor was fabricated by a Maintenance Division welder which solved the problem, and made handling the sand pump bailer easier and safer than handling the dart-type bailer. A short section of 8-inch casing partly closed at the lower end was mounted on a pivot on a firm base. The bailer is raised from the well, the lower end inserted in the invertor and the bailer tilted by means of paying out the sand line until the bailer is emptied.

Other drilling equipment, personnel, and safety precautions were the same as described in the previous report.

The drilling plan for each site followed the pattern reported in the earlier report. The almost complete lack of contamination encountered underground greatly simplified the problem of radiation safety precautions and the problem of location of well sites. Information obtained from the early drill-

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ing in both the 200 areas considerably simplified the drilling plans for areas explored at a later date, and resulted in locating the later wells more advantageously than would have otherwise been the case. This was particularly true in the 200-West area where exploration of the impermeable silt-clay bed indicated preferred sites for later waste disposal units and for monitoring wells in the tank farm areas and adjacent to the waste disposal units.

All wells drilled were carefully surveyed by the Project Engineering Divisions, and the locations and elevations accurately determined.

Sample Analysis

The analysis of sediment samples believed to be contaminated was the same as described in the earlier report by Brown and Ruppert (2,3). The significant level of activity in the sediments was chosen at 0.05 microcurie/kilogram for fission products and 0.04 microgram/kilogram for plutonium. An analysis of the beta-gamma activity in a sample of coarse sand and fine gravel from the concrete mix plant showed 0.002 microcurie/kilogram of sediment. The figures for significant activity are therefore considerably above the figures for the natural radioactivity of some of the sediments that occur within the Hanford Works area. The following figures (7,11,19) are average for the radioactive constituents of basalt, which constitutes the dominant rock type in the sediments and in the bedrock at the Hanford Works, and are probably representative for the basalt encountered there:

Basalt:
1.1×10^{-12} gm radium/gram rock
0.9×10^{-6} to 3.5×10^{-6} gm uranium/gram rock
2.8×10^{-6} to 9.0×10^{-6} gm thorium/gram rock
1.8×10^{-2} gm potassium/gram rock (radioactive K)

The water samples were evaporated in a radiochemical laboratory and the residue counted for fission products with a mica-window tube with a geometry of approximately 24 percent. The alpha analysis was made by chemically extracting

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the plutonium and counting the concentrate in a standard alpha counter. The usual sample size was 500 milliliters; however sludge samples from the H.I. Shaft contained such high activity that the sample size was reduced to 0.02 grar to prevent undue radiation exposure to laboratory personnel and also to stay within the upper limit of the counters.

The lower limit of fission product contamination in the water was chosen at 20 micro-microcuries/liter and the lower limit of alpha contamination was chosen at 10 dis./min./liter. The correctness of the choice of the "significant" level of contamination was confirmed by averaging the results obtained from the two-year sampling program, up to January 1, 1950. Analyses of 612 water samples from wells free of alpha contamination from radioactive wastes in the 200-East area, show that the alpha activity level is 7.6 dis./min./liter. A fluorophotometer analysis on a 3-gallon sample from 361-B-11 indicated that all the alpha activity was due to uranium probably that occurring naturally in the water. The beta-gamma activity, on the basis of 366 samples from wells uncontaminated by wastes containing fission products, averages 9.4 micro-microcuries/liter of water. These figures are similar to the activity levels in uncontaminated wells outside the operating areas sampled by the Geology group and by the Site Survey group.

The average of 139 samples from 24 wells drilled under the direction of the Geology group outside the operating areas for ground water monitoring purposes indicated an alpha content of 4.5 dis./min./liter and the average of 145 samples from the same wells indicated a beta-gamma content of 11.1 micro-microcuries/liter. An insufficient number of samples have been taken from many of these wells, however, to be statistically significant. Therefore, these last figures may not be truly representative.

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Samples of water obtained from a well in Benton City by the Site Survey group consistently show an alpha count of about 40 dis./min./liter, due to uranium probably the natural uranium content of the water. This figure is four times the activity level chosen by the Geology group as the significant level of activity of water contaminated by radioactive waste.

Activity levels of water presently accepted as permissible for drinking purposes are 5.6 dis./min./liter for uncontrolled release of plutonium, and 100 micro-microcuries/liter for fission products. Much of the water, particularly in the 241-B-361 area, reported as contaminated is therefore essentially and practically uncontaminated. Actually it is contaminated because the activity is above the natural radioactive content of the water.

Examination of Samples

Duplicate, one-pint samples were regularly taken at depth intervals of 5 foot during drilling operations except where significant changes in the earth materials made additional samples advisable, or in such cases where contamination was either suspected or known to exist. Samples were then taken at one-foot intervals.

All samples were taken to a central storage building, where the jars were cleaned, relabeled, the samples examined and described, and the samples stored on easily accessible shelves. A portion of each was carefully washed to remove silt and clay, in order that the coarser materials could be examined. Standard, routine examination of the samples, the same as for the previously-reported drilling in the 200-West area, included a megascopic and hand lens examination of the constituent grains, with additional examination by microscope if such was warranted. Routine chemical tests also were made to determine the calcareous character of the sediments. One complete chemical analysis of the sediments

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from the ground surface of the 200-East area was made by the Technical Divisions as a part of the complete study. Various physical tests such as specific gravity, size classification, specific mineral content, porosity and moisture content also were made on representative and typical samples. The results of these observations were combined with the drillers' logs of the wells and the reported drilling behavior of the sediments, so that a detailed and complete record of the materials was maintained.

Progress

A total of 82 wells (not previously reported) was drilled in connection with the waste disposal program between May 12, 1947 when drilling began near the 201-B tank crib in the 200-East area and October 7, 1949 when reopening of the 241-T-361 reverse well was completed. This total does not include 26 observation wells drilled outside the operating areas and which were largely covered in a preliminary interim report by the U.S. Geological Survey (16) as a cooperative program of investigation, neither does it include a number of test holes and water supply wells drilled at numerous locations throughout the region. Of the 82 wells, 23 were drilled in tank storage areas, 16 were drilled near waste disposal units that were in use, 34 were drilled near waste disposal units that were not in use, and the remaining 9 wells were drilled near outlying installations. The program was completed with no significant radiation exposure to personnel, and with no detectable spread of contamination. Table 1 is a summary of the wells drilled to date. Table 2 is a summary of the samples, both liquid and solid, taken by the Geology group for analysis for radioactive contamination in a radiochemical laboratory during the period up to January 1, 1950. Table 3 "Summary Figures, 200-East Area Waste Disposal Units", and Table 4, "Summary Figures, 200-West Area Waste Disposal Units", summarize the amounts of activity

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recorded as discharged to the individual systems and the amounts of activity, where determined, found within the contaminated zones. The figures for amounts of activity recorded as discharged to the appropriate settling tank, storage tank, crib or reverse well are based on "S" Division monthly summary reports and Technical Divisions (Metallurgy and Control Division) radiochemical laboratory analyses, supplemented in some instances by special analyses and reports. The figures for calculated activity in the ground are based on samples obtained by the Health Instrument Divisions Geology group and analyzed by the Health Instrument Divisions Control radiochemical laboratory. In all cases, the point at which the recorded activity was discharged is given, whether that was to a storage tank or settling tank prior to discharge to the ground, or directly to the ground.

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TABLE 1

SUMMARY OF WELLS DRILLED

TYPE OR LOCATION	NO. WELLS	TOTAL DEPTH IN FEET	NO. SEDIMENTS SAMPLES
Wells Not Previously Reported			
200-East Area:			
361-B reverse well	11	3520	713
5-6 crib and tile field	9	1350	274
224-B (201 tank cribs)	4	720	220
241-B, 2nd cycle crib	14	2100	434
241-BX Area	7	1050	214
241-BY Area	7	1175	237
292-B-1 reverse well	1	110	22
200-West Area:			
241-TX Area	9	1350	272
234-5 Area	11	1650	331
241-T-361 (reopened)	1	38	9
300 Area Waste Ponds	3	226	43
100-F Area Waste Trench	1	67	13
100-B Area			
108-B Crib	3	270	54
321 Crib Area			
321-1 water well	1	117	23
	82	13743	2859
Wells Previously Reported			
200-West Area:			
231 Area			
No. 1 and No. 2 cribs	8	1291	270
231-W-150 reverse well	3	525	210
361-T Area	13	1495	656
241-T Area			
224-T (201-T tank cribs)	8	1055	386
2nd cycle crib	15	2095	482
241-TX (231)	3	450	166
TOTAL OF WELLS PREVIOUSLY REPORTED	50	6911	2170
TOTAL OF WELLS NOT PREVIOUSLY REPORTED	82	13743	2859
GRAND TOTAL	132	20654	5029

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TABLE 2

SUMMARY OF SAMPLES ANALYZED IN A RADIOCHEMICAL LABORATORY
JANUARY 1, 1950

SEDIMENT SAMPLES

300 Area:	
Wells 303-1 and 2	29
Wells 300-3 and 4	49
200-East Area:	
H.I. Shaft	7
5-6- Tile Field Test Holes	60
5-6 Tile Field Test Wells	8
Well 361-B-13	1
Wells near 361-B reverse well	147
224-B Area Wells	147
Well 292-B-1	22
200-West Area:	
241-T Area (Obtained with casing sampler)	4
Well 241-T-1, 46' level	39
241-T Area (2nd cycle)	87
224-T Wells	277
241-TX Wells	93
361-T Wells	554
231 Wells	358
234-5 Area (46' beneath the #1 and #2 cribs)	10
241-T-361 reverse well	9
TOTAL	1901

Alpha activity ranged from less than 1000 dis./min./kg. to 14,800,000 dis./min./kg.

Beta activity ranged from less than 0.05 microcurie/kg. to 1830 microcuries/kg.

LIQUID SAMPLES

H.I. Shaft	105
5-6 Tile Field #1 and #2 Test Holes	11
241-T 2nd cycle crib wells	25
TOTAL	141

Sample size ranged from 1 milliliter to 500 milliliters.

Alpha activity ranged from less than 1000 dis./min./liter to 72,300 dis./min./liter.

Beta activity ranged from less than 20 micro-microcuries/liter to 51 micro-curies/liter.

WATER SAMPLES

361-B Area (11 wells)	904
300 Area (3 wells)	285
108-B Area (3 wells)	244
Wells 231-2, 224, T-4, 224-B-4, and 241-BY-2	113
Observation wells	167
241-T-361	87
TOTAL	1700

Sample size ranged from 100 milliliters to 12 liters.

Alpha activity ranged from less than 10 dis./min./liter to 1,100 dis./min./liter

Beta activity ranged from less than 20 micro-microcuries/liter to 4,300 micro-microcuries/liter.

Sampling frequency ranged from once a day to once every 6 months.

SLUDGE SAMPLES

H.I. Shaft	4 (Total)

Beta activity ranged from 4,900 to 9,000 microcuries/liter.

Alpha activity ranged from 50,000,000 to 90,000,000 dis./min./liter.

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TABLE 2 (Cont.)

TOTAL SAMPLES ANALYZED

Sediments	1901
Water	1700
Liquid	141
Sludge	4
TOTAL	3746

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TABLE 3

Summary Figures, 200-East Area Waste Disposal Units, January 1, 1950

Unit	Total Volume Waste in Liters	Recorded Radioactivity (Amounts Approximate)	Radioactivity Discharged	Calculated Radioactivity	In Use
241-B-361 (reverse well) 8", 302' deep	30.6×10^6	4275 g Pu 3800 c F.P.	To tank	None found 1.2 c F.P.	No, unit discharged into ground water
"5-6" crib & Tile Field 14' x 14' x 7'	18.4×10^6	95 g Pu 2050 c F.P. *1200 c F.P.	To ground		Yes
241-B #1 & #2 cribs (201-B tank cribs) 12' x 12' x 4'	3.3×10^6 May, 1947 22.3×10^6 January 1, 1950	600 g Pu 800 c F.P. 2180 g Pu 4000 c F.P.	To tank	None found at 18' radius, May, 1947	Yes
241-B #3 crib & Tile Field (2nd cycle) 12' x 12' x 7'	7.5×10^6	7 g Pu 12 c F.P.	To ground		Yes
	78.8×10^6 liters				

* Rough estimate of activity present based on the approximate half-life of the wastes

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200-EAST AREA

241-B-361 REVERSE WELL AREA

History of the Unit and Exploration

The 241-B-361 reverse well was drilled as 8-inch well to a depth of 302 feet and was completed October 9, 1944. The bottom 50 feet of the casing was perforated and the well put into service about April 1, 1945 at the beginning of operations of the concentration plant, receiving radioactive wastes from the 224-B Building and the cell washings from the 5-6W cells in the 221-B plant. On September 21, 1947, the 5-6W wastes were routed to the 201-B tank crib, and on September 24, the 224-B wastes were similarly diverted to the 201-B tank crib. A total of about 8, 100,000 gallons of radioactive waste was discharged from the 224-B and 221-B Buildings to the 241-B361 settling tank and the overflow discharged to the reverse well during this period of operation. This contained an estimated 4275 grams of plutonium and about 3800 curies of beta-gamma activity.

An analysis to determine the amount of uranium present in the normal 5-6 wastes indicated that less than 8 percent of the alpha activity could be ascribed to uranium (17).

An undetermined but considerable amount of the activity was deposited on and with the sludge in the 241-B-361 settling tank, and the supernatant discharged into the well.

On September 19, 1947, a water sample from well 224-B-4 (see Plate 2) indicated the presence of alpha activity in the ground water 2150 feet north of well 241-B-361. Resampling of the well water indicated that the earlier results were probably erroneous and that the ground water in that locality was not contaminated with radioactive materials. Routine sampling to date has shown no evidence of ground water contamination at that location. The altitude of the water table in well 224-B-4 demonstrated, however, that well 241-B-361 penetrated about 10

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feet into the ground water and that the radioactive wastes had probably been discharged directly into the ground water. The 224-B and 5-6W wastes were accordingly routed to the 201-B tank cribs as noted above and a well drilling program as originally outlined by the U.S. Geological Survey was immediately begun to determine the extent of ground water contamination by the radioactive materials.

Well 361-B-1, 500 feet east of the reverse well, was completed on November 11, 1947, and indisputably proved that the ground water was contaminated with both alpha and beta-gamma activity. Water from wells 361-B-2 and 361-B-3 was also contaminated to a lower degree. Additional wells were drilled to the east and southeast in both the direction of greatest contamination and the indicated direction of movement of the ground water, respectively, at progressively greater distances to delimit the zone of contamination and to determine the effectiveness of radioactive decay, dilution, and retention by the sediments in reducing the activity of the contaminated water. Each well was drilled at least 30 feet into the ground water, and the casing was perforated, as if the well were to be used for water supply. The ground water was thus free to circulate through the casing, and changes in the activity levels could be accurately detected.

No contamination was detected on the sediments in any of the wells, including 361-B-9, 50 feet from the reverse well, although water containing at least a few of the radioactive elements passed through those sediments. Some of the activity, including all the plutonium, was presumably deposited on the sediments within, at most, the 50-foot distance from the reverse well to well 361-B-9.

The thickness of the zone of ground water contamination is not definitely known, but on the basis of the above information it is at least 30 feet in depth, and probably extends at least to the basalt bedrock underlying the area, to a

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depth of water of probably 60 feet (see Plate 7, cross section A-A'). The basalt is probably the lower limit of the zone of contamination, for except where highly jointed or scoriaceous, its permeability and porosity are quite low. Wells 361-B-5 and 361-B-11, which penetrated about 10 feet of basalt, produced almost no water from the basalt, although a considerable quantity was available from the coarse sands and gravels directly overlying the basalt and mapped as the Ringold formation by the U.S. Geological Survey. Other wells in the 200-East area which were drilled to water either did not penetrate to basalt or the casings were stopped on what were believed to be basalt boulders above the actual bedrock (Well 224-B-4). A large quantity of water entered the well both above and below the 5-foot boulder or lava flow, if such it was, yet little came from the basalt. The basalt beneath the contaminated zone is therefore probably considerably less permeable than either the Ringold formation or the terrace gravels at that location and serves as an effective floor for the contamination.

The body of contaminated water had, at its maximum extent, the form of a gigantic, elliptical lens, up to about 60 feet thick, 2500 feet long, and 1000 feet wide. The shape and extent of the lens and the distance from the reverse well at which contamination was detected suggests that the ground water moved southeastward at an average rate of 500 feet a year. Continuing observations suggests that the velocity was greatest during early operation of the plants, and that the rate of movement of the water decreased until it became immobile beneath the 200-East area, owing to the increasing height of the 200-East area ground water mound, about a mile and a half east of the area (see Plate 1). The effect of this mound and the one beneath the 200-West area are discussed elsewhere in this report.

The Water Sampling Program

The water in each well was sampled on completion of the well and at weekly

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intervals thereafter, and the samples counted for alpha and beta-gamma contamination. A total of 930 water samples, including 192 duplicate samples, was obtained from the date of initial sampling to January 1, 1950. The results of those weekly analyses are shown on Plate 3 illustrating the contamination trends from the date of initial sampling. Duplicate 500-milliliter water samples were taken each week and the analyses of the two samples averaged. Contamination trends for the water in each well were clearly defined after approximately six months and single 500-milliliter samples were taken from each well. Individual variations from the well-defined trend were then clearly indicated. The trends for some wells were so clear-cut that predictions made up to six months in advance for the activity level were later verified. Samples were also taken several times from the surface of the ground water (at the water table) and from the bottom of wells 1,2,3,4,5,6,7, and 9. Analyses of these samples showed no significant difference in the intensity of contamination between the water at the water table level and the bottom of the wells, indicating that thorough mixing of the contamination was accomplished within, at most, the interval of 500 feet between the reverse well and wells 361-B-1,2, and 3. Water from the bottom of well 361-B-9 was more active than from the water surface, but this was due at least in part to the higher rust content of the bottom samples, as discussed in following paragraphs.

Mixing of the radioactive wastes in the 241-B-361 area was apparently accomplished within a short distance of the discharge point, and was uniform throughout that part of the ground water body that could be sampled. Observations in coastal areas indicate that sea water invades the fresh ground water as a distinct, solid front when serious overpumping is praticed, but observations here suggest that mixing resulted from the method of waste disposal. The

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200-EAST AREA CONTAMINATION DIAGRAMS

221-B AND 224-B BLDG. WASTE DISPOSAL

241-B-361 REVERSE WELL AREA

Radioactive-Contamination Trends in Water Wells

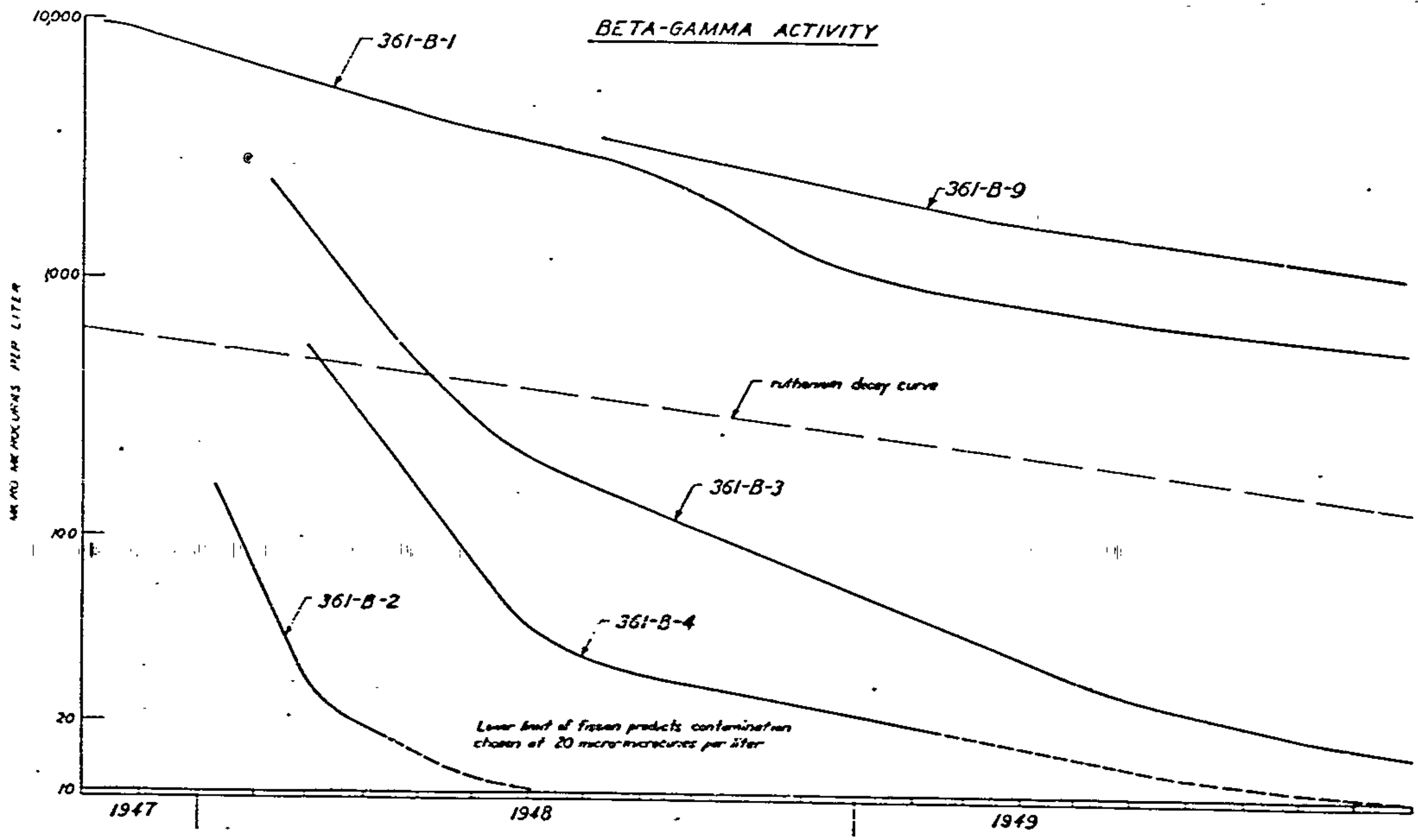

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PLATE

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difference in specific gravity between sea water and fresh water (1.025 to 1.000) accounts for the solid front and lack of mixing, but the differences between radioactive waste liquids and pure water are probably generally smaller. The specific gravity of the wastes from the 224 buildings ranges from 1.04 to 1.08 prior to discharge to the settling tanks, whereas the 5-6 wastes are reportedly nearly 1.00. Solid material in the liquid wastes is largely deposited in the tanks, and the clearer supernatant, with decreased specific gravity and activity, flows into the disposal unit. The 241-B-361 settling tank, of about 35,000 gallons capacity, was bypassed when the 5-6 crib and tile field was installed, because the tank was nearly filled with sludge, indicating a significant sludge content of the wastes that had passed through the tank. Thus, the introduction of waste liquids into the ground water over a period of time, during part of which the ground water moved a significant distance, combined with diffusion and dilution processes to thoroughly mix the waste liquids with the ground water. Differences of specific gravity between the waste liquids and the ground water were presumably small enough to eliminate either floating of the wastes on the surface of the water or settling of the wastes to the presumed floor of contamination, the basalt bedrock. When radioactive wastes are discharged above a shallow water table, as in the 241-T area, those wastes spread or float along that water table and may be deposited on the sediments either in the capillary moisture zone or at the ground water surface (see Plate 10, also Plates 6 and 7, HW Report 9671). Floating of activity on the surface of the ground water is also suggested in the 241-T-361A reverse well area, as discussed in a later part of this report.

A number of samples from well 361-B-9 were analyzed for uranium and plutonium by the fluorophotometer, ether extraction and TTA methods. Results proved that at the distance of 50 feet from the reverse well to well 361-B-9 no plutonium was present, and therefore the plutonium present in the original wastes discharged to the reverse well was removed from the solutions within that 50-foot distance, although some was discharged directly into the ground water. Accurate estimates of the amounts of plutonium and fission products discharged from the settling tank to the reverse well are impossible to make, for the percent retained in the settling tank is not known, other than that it is considerable. All the alpha activity in the ground water is therefore presumably due to uranium. This uranium is undoubtedly present as uranyl ion, which is not likely to show appreciable retention on earth materials. Conceivably it may have been fixed at one time on the sediments, but could well be removed as the aqueous solution weakened.

A 3-gallon sample of water was obtained from the bottom of well 361-B-9 on January 12, 1948, the rust allowed to settle and the clear water decanted. Nearly one gram of rust was collected. An analysis indicated 8.8 microcuries of fission products/kilogram of rust and considerable alpha activity interpreted due to 0.63 gram uranium/kilogram of rust. The average water analysis for beta-gamma activity for December, 1948, was 2000 micro-microcuries/liter or kilogram. Therefore, weight for weight the rust was 4400 times as active as the water. This has been confirmed by British experimenters who demonstrated that removal of the normal coating of iron hydroxides on sand greatly reduced the retention of fission products. The rust sample was also analyzed for fission products. The results are compared to an analysis reported by Overstreet and Jacobson (15) for a random sample of W-6 liquors as follows:

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Element	Half Life of Probable Isotopes	Radioactivity of Rust uc/kg.	Radioactivity of Rust % of total	Radioactivity in W-6 Sample % of total (total activity not reported)
Ru	1 yr.	5.550	63	1.69
Sr	25 yrs.	0.615	7	not reported
Zr	65 days	0.352	4	58.4
Cs	33 yrs.	0.088	1	1.39
Ba & Sr				27.
UX1				3.27
Cb				25.6
Ce				4.75
Y & Pr				.22
Te				4.29
Rare earths (including Ce, Y, Pr, La, etc.)		0.088	1	
			76%	126.61%

Columbium, present as a daughter element of radioactive zirconium, was not tested for in the rust sample but may be expected in amounts greater than zirconium, for wastes of age greater than several months. The resulting total yield of more than 80% is considered an essentially complete analysis, as is indicated by the comparison between the two analyses.

A 3-gallon water sample was taken from well 361-B-1 on May 3, 1948, and analyzed for fission products. The results are as follows:

Element	Half Life of Probable Isotopes in Water	Radioactivity uuc/liter	Radioactivity % of total
Ce	275 days	8.7	0.3
Y	60 hours & 55 days	58.0	2.0
Rare earths (other than reported)		29.0	1.0
Sr	25 years	8.7	0.3
Cs	33 years	not detected	
Ru	1 year	1840.	63.4
Zr	65 days	174	6.0
Cb	35 days	not checked for	
		Total yield	73.0%

Columbium is present as a radioactive daughter of the zirconium as previously noted, but was not checked for. The indicated total yield, including columbium, is thus more than 80%, which figure is considered to include

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200-EAST AREA CONTAMINATION DIAGRAMS

221-B AND 224-B BLDG. WASTE DISPOSAL

241-B-361 REVERSE WELL AREA

Radioactive-Contamination Trends in Water Wells

ALPHA ACTIVITY

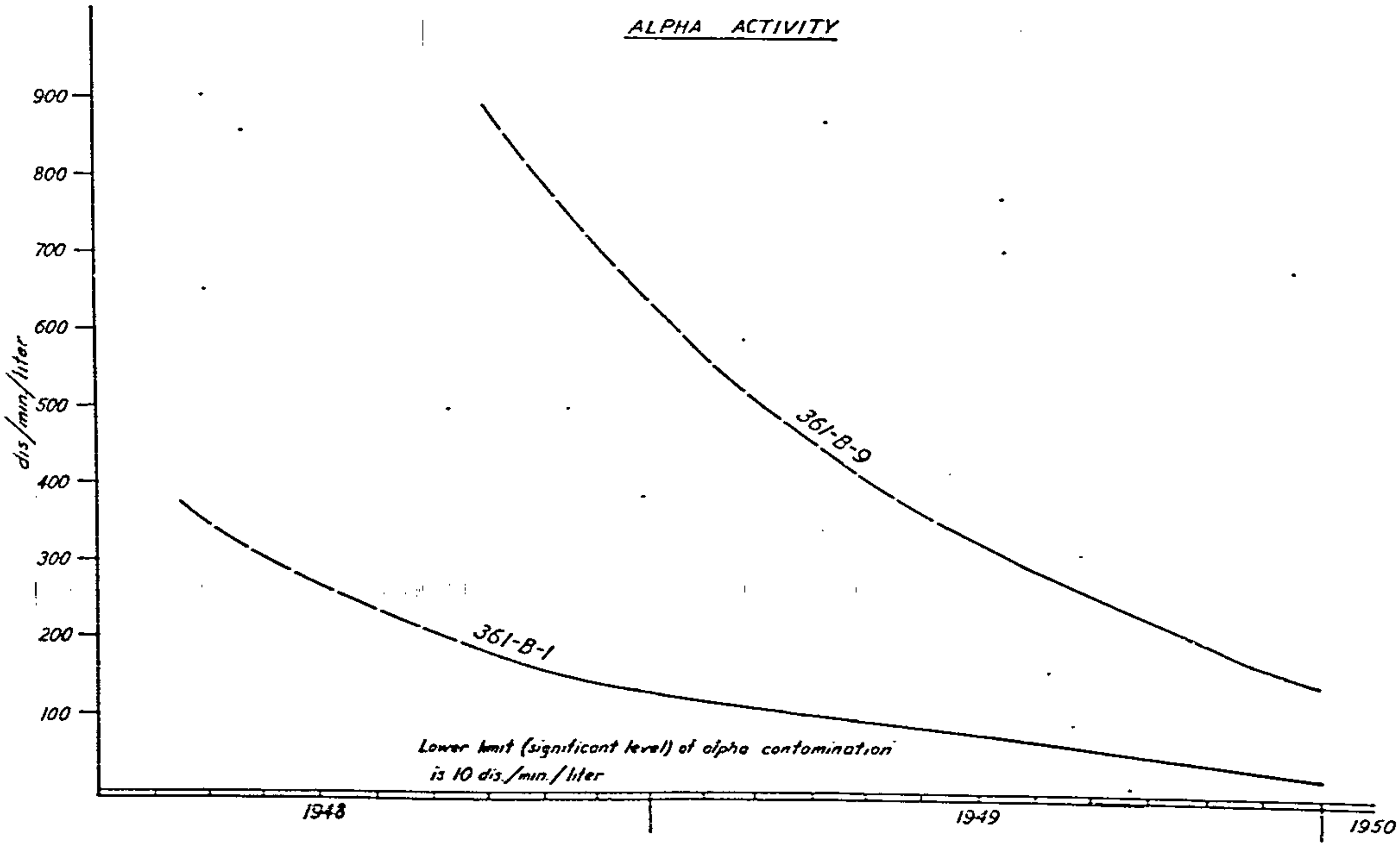

PLATE 4

essentially all the radioactive elements. The results are nearly identical to the fission products analysis of the rust previously discussed. Total activity of the water was 2900 micro-microcuries/liter. The percentage of elements present in the water with half-lives measured in years is clearly small.

Analysis of Results of Sampling Program

Plates 2,3,4,5, and 6 demonstrate the facts determined by the 24-month water sampling program of the 241-B-361 area. Plate 3 shows the beta-gamma contamination trends in the water in the individual wells, and for comparison, a curve for the activity trend of radioactive ruthenium. The activity on this plate is plotted on a logarithmic scale, so that the decay curve for the ruthenium is represented as a straight line. Water samples were taken from all the wells every week to determine the trend of the activity levels and to enable water from the uncontaminated wells to serve as a continuous check on the chosen significant activity levels, of 20 micro-microcuries of fission products and 10 uranium alpha dis./min./liter.

The curve for the beta-gamma activity trend of the water in well 361-B-9 is nearly parallel to the decay curve for ruthenium, the predominant beta emitter in the ground water at the present time (see Plate 3). Activity in the water from well 361-B-1 diverges from the ruthenium decay curve more markedly, whereas the activity curves for wells 361-B-3 and 361-B-4 diverge from it greatly. In the one-year period from November 10, 1947 to November 10, 1948, the decay of ruthenium should have reduced the activity in well 361-B-1 from 9200 to 4600 micro-microcuries/liter, but the actual decrease was to 1600 micro-microcuries/liter, and a drop to 580 micro-microcuries for the year ending November 10, 1949. Similarly for well 361-B-3, for the one year period from February 4, 1948 to February 4, 1949, the theoretical reduction due to decay should be from 2500 to

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1250 micro-microcuries/liter, but the actual reduction was from 2500 to 48. The activity in 361-B-4 dropped from 500 to less than the significant level of 20 micro-microcuries/liter between March 4, 1948 and September 1, 1948, most of this decrease taking place in the first 100 days. Water samples from well 361-B-9, however, on September 1, 1948, had an approximate activity of 2500 micro-microcuries/liter, and on September 1, 1949, an activity of about 1150, for a reduction in activity far nearer to that accountable by the decay of ruthenium. The results are summarized as follows for the periods stated:

	Radioactive decay of Ru should reduce activity to:	Actual activity in % of original detected activity
361-B-1	50% of original detected activity	17% of original detected activity
361-B-3	50% of original detected activity	2% of original detected activity
361-B-4	70% of original detected activity	4% of original detected activity
361-B-9	50% of original detected activity	46% of original detected activity

This demonstrates that one or several of three things may be happening: the ruthenium may be concentrated in the water near wells 361-B-9 and 361-B-1, with less ruthenium but greater amounts of shorter-lived elements in the water in wells 3 and 4, the contaminated water in wells 361-B-3 and 361-B-4 may be subject to greater dilution by and diffusion into the natural ground water, or the activity may be slowly depositing on the sediments.

No evidence supports the first suggestion, rather all evidence indicates that ruthenium will remain in solution the longest and will be one of the least likely to be concentrated in any one well area to the exclusion of the other elements. This is demonstrated by the fission product analyses of the 22-foot and the 37-foot sediment samples from well 361-T-6, which show a marked increase in ruthenium downward, away from the crib (see discussion of 361-T area). The samples show an increase in activity present due to ruthenium in the lower sample and in the percent of total activity, whereas the percent of total activity

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and the actual activity for nearly all the other elements decreased. Ruthenium should thus be present in greater percentages in wells farther from the point of injection, because: (1) Radioactive decay will decrease the amounts of the shorter-lived elements present owing to the time necessary for the wastes to move from the reverse well to the well being observed. (2) Elements other than ruthenium tend to deposit on sediments more readily. The fission product elements with which we are here most concerned (Sr,Ru,Zr) will probably remain largely in solution if they have not been deposited on and within the sediments close to the well shortly following their discharge into the ground water.

The decrease in level of activity in the ground water is thus apparently due to radioactive decay, dilution, diffusion, and some removal of activity by the sediments. The effect of slow deposition or concentration on the sediments is believed to be minor, for changes in the physical or chemical nature of the solutions would first be necessary. Calculations were made to determine the probable dilution effect of the ground water, on the basis of the decay period earlier mentioned. The results are summarized as follows:

WATER CONTAMINATED BY FISSION PRODUCTS (Gallons)

a.	Estimated contaminated water, November 1, 1947	400,000,000
b.	Estimated contaminated water July 1, 1949, considering radioactive decay alone	250,000,000
c.	Volume of water decontaminated (to below the significant level) (a-b)	150,000,000
d.	Water actually contaminated July 1, 1949	44,000,000
e.	Volume of water decontaminated to or below the significant level probably owing to dilution and diffusion (b-d)	206,000,000

In the same manner, the dilution and diffusion effect on the uranium-contaminated zone was calculated. Radioactive decay is not significant in these

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determinations; therefore dilution, diffusion, and removal of activity by sediments are the only apparent factors that may be important in the reduction of the activity levels and the volume of contaminated water. The slopes for the uranium-contamination curves for the water from 361-B-1 and 361-B-9 are greater than that part of the slopes of the beta-gamma activity of the water from the same wells attributed to dilution and diffusion processes (total slope less that attributed to radioactive decay of ruthenium). A definite trend for the activity in the water in well 361-B1 was not established prior to October 1948, nor that for 361-B-9 prior to June 1949, owing to the wide variation in uranium-alpha activity at the low levels encountered prior to those dates. Thus the early parts of these two curves may be somewhat in error and the following figures subject to a significant plus or minus factor.

Contaminated water November 1, 1947	75,000,000 gallons
Contaminated water July 1, 1949	42,000,000 gallons
Decrease in activity probably owing to dilution, diffusion, etc.	33,000,000 gallons

The existence of significant diffusion and dilution processes thus certainly seems assured.

Dilution was also prominent in the reduction of the activity level when the original wastes were discharged into the ground. About 8,000,000 gallons of radioactive wastes were discharged to the ground, but the estimated amount of contaminated water present in the ground November, 1947, was about 400,000,000 gallons. The original wastes were therefore apparently diluted at least 50 times. If the activity penetrates any significant distance into the basalt or if the activity is removed from the sediments following earlier deposition, then this dilution factor will be still greater, Similarly the average content of fission products in the waste solutions was 0.9 microcuries per liter, but

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the highest analysis obtained in the water was about 0.01 microcurie/liter. The indicated dilution factor is thus about 100. If we consider decay and assume that some of the activity was removed in the 241-B-361 settling tank, then the dilution factor apparently checks with the factor obtained by relative volumes of water and waste. Similar dilution determinations were not made based on the uranium content of the original wastes, the alpha activity of the contaminated water, and the relative volumes of waste and contaminated water owing to the lack of adequate control and lack of adequate uranium analyses of the original wastes for quantitative comparisons.

Contamination contour (isoactivity) maps were constructed at three-month intervals on the basis of the trend curves, and the amount of water estimated lying within the boundaries set by the reporting limits and contaminated by fission products and uranium. The precise location of the contour lines could obviously not be drawn on the basis of the limited number of control points, so considerable license was used to present the most logical and reasonable picture The consistent use of the same interpretation and presentation of the sample analyses gives a true picture of the changes in the contaminated zone, however.

The total amount of fission products and uranium in the ground water was also calculated periodically. Plate 2, an index map of the waste disposal areas within the 200-East area, shows the extent of the beta-gamma ground water contamination at six-month intervals, and the uranium contamination extent as of November, 1947 and July 1, 1949. Plate 6 shows the chronologic contamination contour (isoactivity) maps for these periods. Plate 5 is a summary of the total amounts of fission-products-contaminated water, fission products, and uranium-contaminated water present in the 241-B-361 area from November, 1947. The uranium analyses in the individual samples varied considerably throughout the low levels encountered; therefore accurate trends were difficult to establish

200-EAST AREA CONTAMINATION DIAGRAMS

221-B AND 224-B BLDG. WASTE DISPOSAL

241-B-361 REVERSE WELL AREA

RADIOACTIVITY IN GROUND WATER

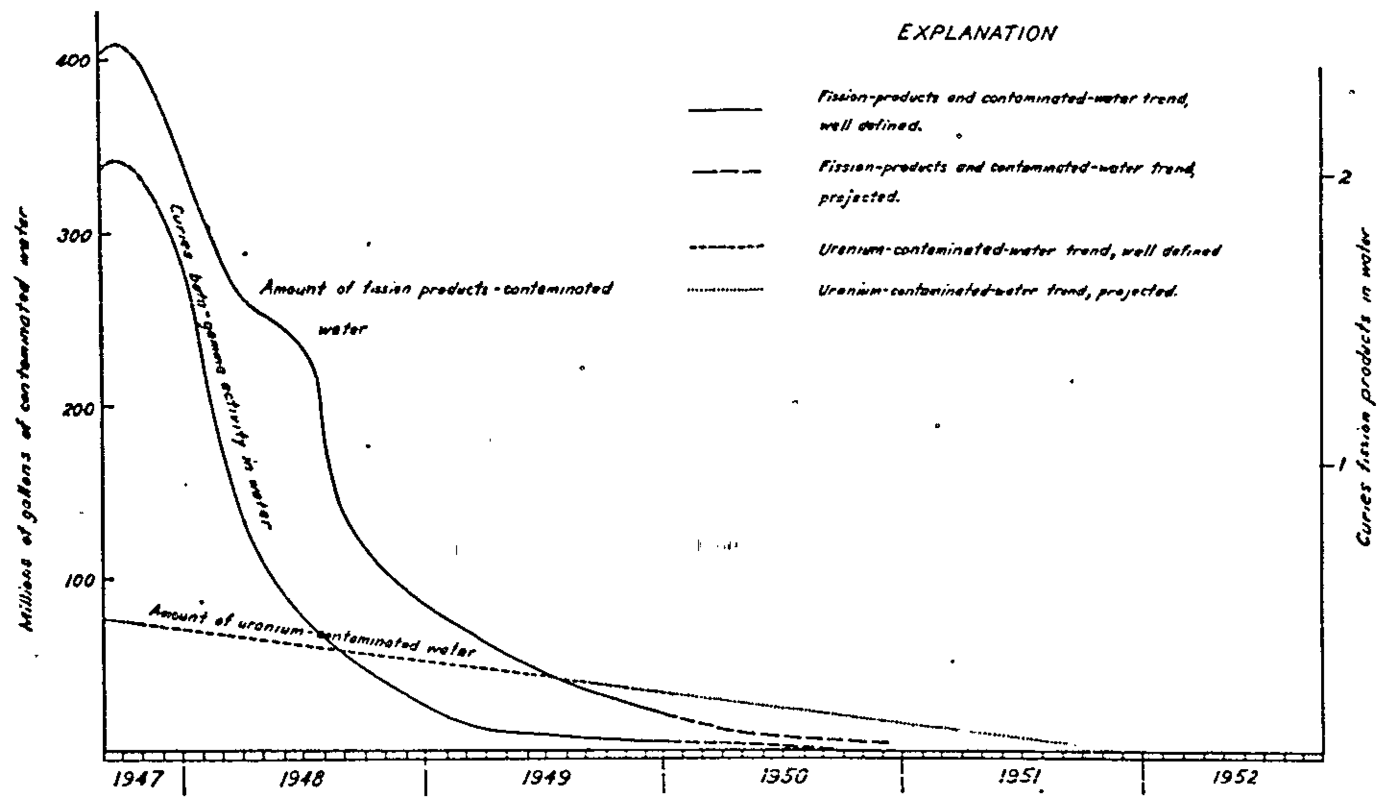

PLATE 5

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and only the two uranium contamination contour maps are presented. The amount of uranium present in the ground is obviously constant, although the amount within the uranium-contaminated zone decreases owing to diffusion and dilution of some of the contaminated water to below the significant level. The curve for the amount of uranium in the significantly contaminated zone thus parallels the curve for the total amount of uranium-contaminated water, and is not presented.

The above calculations were made on the basis of sediment porosity of 15 percent and a depth of water to basalt of 60 feet. Numerous porosity tests on samples from the 361-B area, including samples obtained with the sand-pump bailer, gave porosities ranging from 13 to 25 percent. Porosities in the ground may be slightly lower; however careful settling and packing of the sediments resulted in porosities presumably not significantly different. The figures may be a maximum, but the relative decrease of activity owing to dilution and to decay will be the same.

Movement of the Ground Water

The activity trends in the water from the individual wells points out another fact of considerable significance. The order of level of activity of the water in the individual wells is the same as at time of completion of the wells and initial sampling. This indicates that the contamination and therefore the ground water has not moved an appreciable amount at least since November, 1947. This fact is similarly corroborated by the uranium-contaminated zone. The fission-product-contaminated zone and the uranium-contaminated zone, moreover, have steadily and regularly decreased in size and level of activity with the passage of time, but have not changed their relative positions with respect to each other or with respect to the reverse well or the observation wells.

The ground water beneath the 200-East area is thus not moving, but such was

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not always so. Contamination in November, 1947, had clearly spread southeastward from the reverse well at least as far as 361-B-8, 2500 feet from the reverse well, although it had spread only a short distance beyond 361-B-2, 500 feet from the reverse well in the opposite direction. Ground water conditions obviously changed during the period of use of the reverse well. Plate1 shows the ground water table in the vicinity of the 200 areas and the reason for this change. A ground water mound lies about one mile east of the 200-East area, directly beneath the discharge swamps for the 221-B building effluent wastes and the power house wastes. This mound results from the large and constant volumes of water discharged on the ground since beginning of operations of 200-East area and can be roughly accounted for by the recorded volume of water discharged from the two buildings since beginning of operations (about 2,600,000,000 gallons up to January, 1950).

The ground water mound lies athwart the natural northeast direction of movement of the ground water, and thus changed the direction of movement of the water from northeast to south beneath the 200-East area. Radioactive wastes at beginning of operations were probably discharged slightly above the ground water table through the 241-B-361 reverse well, and such activity as penetrated to the ground water moved slowly eastward with the water. The ground water mound east of the area slowly rose until the ground water was forced to move southeastward around the mound and until the bottom of the well was immersed in the ground water. Continued build-up of the mound turned the drainage direction at right angles to its original course, and essentially stopped the movement of the water and the contained activity.

This fact is important. If highly active wastes are discharged into the ground or percolate to the ground water, then a means exists by which those

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wastes can be effectively held in location until such times as the decay plus the natural ground water dilution and diffusion will reduce the activity below the significant level. A greater reduction of the activity level can be accomplished by introducing clean water into the contaminated zone either through wells as can be done with the 241-B-361 reverse well area contaminated zone, or by percolation through the ground, if the depth is not too great and if the sediments are adequately permeable. The contamination of the ground water in the 241-B-361 area was inadvertent, but the fortuitous placing of the effluent swamps resulted in a combination of events that proved ideal for the study of the behavior of the radioactive wastes within the ground water. If the effluent swamp were north or south of the 200-East area, instead of to the east, the body of contaminated water might never have been detected, and would now probably lie between the 200-East area and Route 2S.

Continued discharge of effluent wastes to the swamps will result in an increased flow of the ground water to the south in the area beneath the 200-East area. The mound is apparently no longer rising and may be reaching a height equilibrium. The rate of movement of the ground water may therefore be expected to increase. Careful and periodic sampling of the ground water will be maintained until the level of activity is below the significant level.

5-6 CRIB AND TILE FIELD

The 5-6W crib in the 200-East area is 14 feet square, 7 feet high, and consists of a network of 6-inch by 6-inch timbers with the bottom open and the top and sides wrapped with heavy tar paper. The tile field, built on a bed of coarse gravel about two feet thick, consists of a main lateral 180 feet long and six secondary laterals each 50 feet long. The 361-B settling tank was bypassed and the crib system tied directly to the waste lines, because the

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settling tank was nearly filled with sludge from the 8,100,000 gallons of wastes that had passed through it to the 241-B-361 reverse well. The 5-6 crib was therefore used as a combination settling tank and crib, although it was not designed for the double purpose, and although elimination of settling tanks was known to increase the problems and the activity of wastes disposed to ground.

Nine 150-foot test wells were drilled near the crib and in the tile field prior to using this disposal unit (Plate 2). Well 361-B-13, located 12.7 feet from the center of the crib, was drilled at an angle of 85° toward the center and bottomed directly beneath the crib (see Plate 7, section A-A'). More information as to the potential downward movement of the waste liquids is obtainable particularly in this area of high permeability than from the wells drilled vertically 18 feet or more from the crib center. This was the first attempt on the project to drill a well at an angle with a standard percussion well-drilling machine. The initial step was to bury a 12-foot section of "starter" pipe at an angle of 85°. A shorter drilling stroke and more frequent driving of the casing were the only differences between drilling this inclined well and a vertical well. Four test holes for checking the drainage of the tile field were also drilled and bottomed at the same elevation as the tile field.

The more efficient rod and plunger "suction" type or "sand pump" bailer was used for the first time in this area on the recommendation of the U.S. Geological Survey, as previously explained.

A total of 18,400,000 liters of wastes containing approximately 95 grams of plutonium and 2050 curies of fission products was discharged to the crib between August, 1948, when the unit was placed in operation, and January 1, 1950. Sludge in the wastes rapidly decreased the capacity of the crib and acid was added to the unit to keep it in operation. This aided materially in increasing

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the volume of wastes that could be absorbed by the crib. Eventually the crib became sealed with sludge and overflow into the tile field began in November, 1948, after about 4,000,000 liters of waste were discharged to the crib. No liquid or activity was found in the tile field test holes, which were inspected periodically to check the drainage of the tile field, until April, 1949, at which time 7 inches of liquid was found in Test Hole No. 2. A sample of this liquid analyzed 11.5 microcuries (fission products)/liter and 9,000 alpha dis./min./liter. Sediment samples from the three dry test holes showed a maximum fission product contamination of 0.9 microcurie/kilogram. Fission products contamination is thus at least 150 feet from the crib in the direction of the tile field. Liquid was found in Test Hole No. 2 at all inspections between April, 1949, and October 6, 1949, but was dry on October 20. The fission products activity of the liquid varied from 0.6 to 51 microcuries/liter and the alpha activity from 1000 to 12,400 dis./min./liter. A sediment sample taken from the hole October 20, had 152 microcuires of fission products/kilogram and alpha contamination of 943,000 dis./min./kilogram of sediments. The liquid found in Test Hole No. 1 in May, 1949, analyzed 2,200 alpha dis./min./liter and the fission products activity 1.3 microcuries/liter. Other than this, Test Hole No. 1 was always free of liquid. Maximum alpha contamination on the sediments from Test Hole No. 1 was 35,400 dis./min./kilogram and maximum fission products contamination was 1.2 microcuries/kilogram of sediments. Fission products contamination in the sediments from the other two test holes was less than 1.0 microcurie/liter and has shown no significant increase. Since initial sampling in January, 1949, and up to January, 1950, 59 sediment samples and 12 liquid samples were obtained from the test holes and analyzed for contamination.

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Had a settling tank been included in the present 5-6W waste disposal system, most, if not all the difficulty with the crib would have been prevented. The disadvantages of by-passing settling tanks are as follows: (1) The life of the waste disposal unit is greatly shortened. (2) Wastes of far higher activity are discharged to the ground than would otherwise be the case. (A sample of the 241-B- 2nd cycle sludge had 5000 times the fission products activity as the supernatant.) The effect of the sludge on the ground is as yet unknown, however the possibility of contamination of the ground water is materially increased. (3) The necessity of introducing acid to the crib to maintain the crib's capacity is a practice that cannot be justified in view of the risk of increased transmissibility of active materials. (4) Possible future recovery of certain valuable constituents is prohibited.

Test Well No. 13 (drilled at an angle of 85° towards the crib and bottoming beneath the center of the crib) was found filled with sediments to within 24 feet of the surface in April, 1949. Acid used to clear sludge from the crib corroded the casing and permitted wastes discharged to the crib to wash sediments into the well. A sample of the sediments from this well had 1830 microcuries of fission products/kilogram and alpha contamination of 14,800,000 dis./min./kilogram of sediments. A rough calculation and comparison between the activity in the waste liquid and the volume of sand and gravel necessary to contain that amount of liquid, indicates that about 60 times the activity of fission products is concentrated in the sand and gravel as is present in the waste liquid that would saturate that sand, and that about 100 times the plutonium is present as in the waste liquid. The activity at a point beneath the edge of the crib where the sample was taken from 361-B-13 thus had 120-150 times the activity of sediments 17 feet from the point of injection to the ground (Test

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Hole No. 2).

The fact that the well casing is corroded and filled with sediments means that some waste liquids were introduced into the ground at a depth of 150 feet, or within 150 feet of the water table. The behavior of these high level wastes in the ground is not known, particularly as a combination of sludge and solutions. Therefore, an accelerated schedule of sampling the water wells around the crib (wells 361-B-1,2,5, and 9) was instituted to determine if these wastes are or will be penetrating to the water table. No evidence has been found to date from wells 361-B1, 361-B-2, 361-B-5 and 361-B-9 that such is or may be occuring. A sudden influx of activity has clearly not taken place. If rises in the activity levels should appear, decay curves will be determined to prove the presence of elements of shorter half-life than are present in the originally contaminated water. Sediment samples obtained in October, 1949, from the bottom of all the 150-foot wells but 361-B-13 in the 5-6 crib and tile field area showed no significant alpha or beta-gamma contamination at that depth.

The replacement unit planned for the 5-6 wastes is that of 2 cribs in series. Modified cribs are again planned in preference to tile fields owing to the large ground area required for installation of tile fields as compared to cribs. Two sets of 2-cribs systems can be placed in the area occupied by one crib and tile field, a smaller area of ground is contaminated per system and closer control is maintained over the contamination spread. Open louvers in the cribs and a coarse gravel bed beneath the crib are planned to permit seepage of the waste liquid out of the crib as it fills with such sludge as may be discharged to it.

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241-B AREA

224-B Waste Crib

No plutonium or fission product contamination was found in any of the samples from the three wells drilled to depths of 150 feet and only 18 feet from the center of the 201-B tank crib (224-B waste crib) in May, 1947. Neither were any contaminants found in the ground water at a depth of about 240 feet below the surface in well 224-B-4 or in well 241-BY-2. About 3,300,000 liters of waste were discharged from the 201-B tank to the crib prior to drilling. This waste contained approximately 600 grams of plutonium and approximately 800 curies of fission products at the time it was jetted to the 201-B tank. About 3 grams of plutonium and 4 curies of fission products were jetted to the ground, as estimated from 46 analyses of what passed from the 201-B tank and on a long term figure of what went into the tank. Contamination may have channelled out laterally from the crib and not been detected by any of the three test wells, but at the rate of discharge (100 gallons/minute) all the liquid could have easily moved downward and never reached the area drilled. Samples of the sediments from the 4 wells in this area indicate high permeability of the sediments to a depth of at least 200 feet. The 241-B 2nd cycle crib shaft (H.I. Shaft) confirmed this conclusion, both by observations made during construction and during operation. The 201-B contaminated zone was therefore probably completely within the circle formed by the three crib wells at the time of drilling. The nearly 1000 water samples taken from 13 water observation wells within the 200-East area up to January 1, 1950, indicated that no radioactive contamination has reached the water table except from the 241-B-361 area; therefore the wastes from the 201-B tank crib and the 241-B 2nd cycle crib and tile field are probably above the water table. The possibility cited by Piper (14, p. 94) that a

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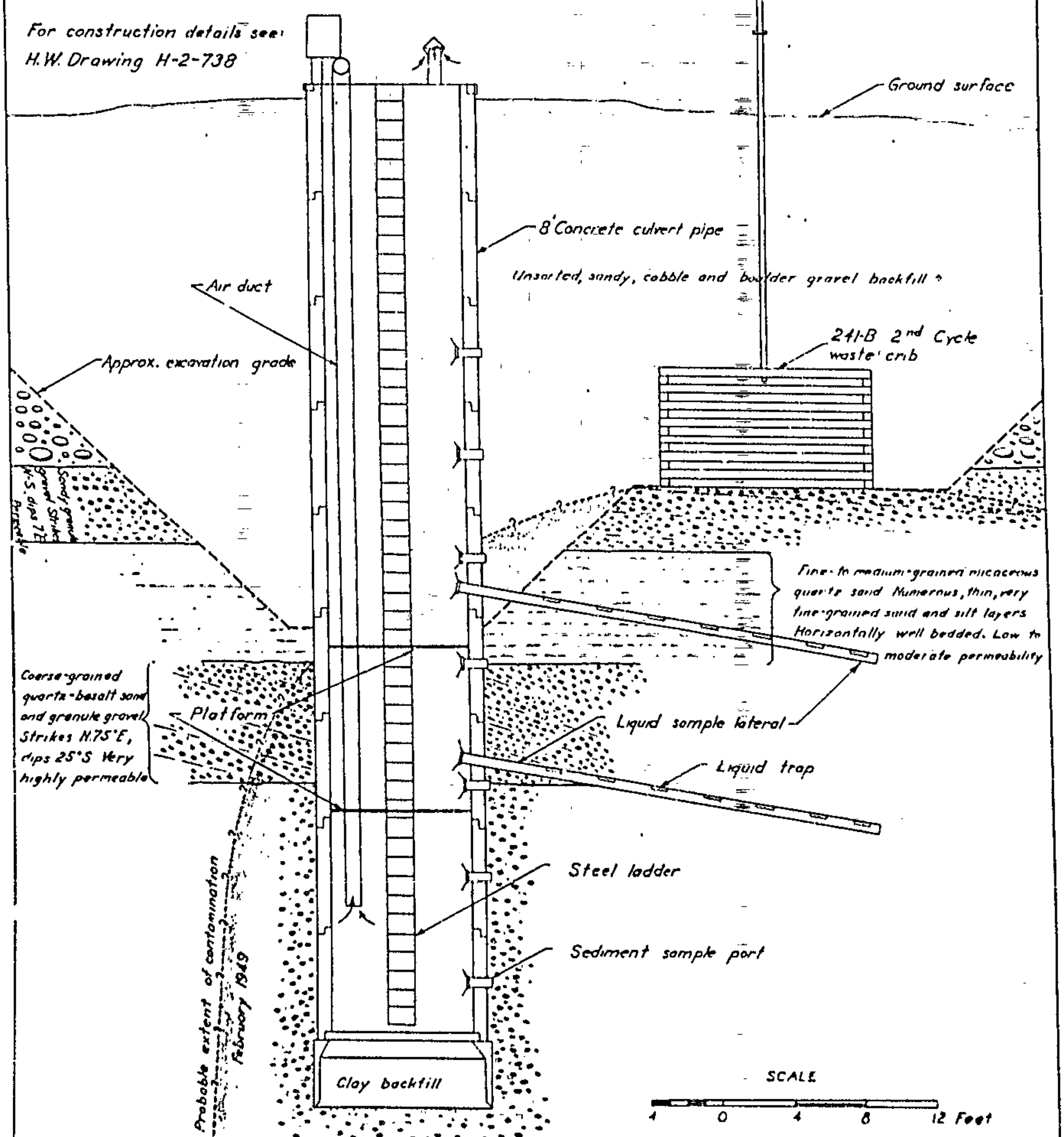
200-E AREA WASTE DISPOSAL

241-B 2ND CYCLE CRIB AREA

H.1 SHAFT



By HGR & REB AUGUST 1949

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"very considerable fraction of the 'second-cycle' wastes intentionally infiltered in the two 200 areas may have reached the regional water table" is contra-indicated by the sampling evidence in the 200-East area, although a small amount conceivably could penetrate to the ground water in a limited area and not be detected. Undetectable contamination in water is certainly innocuous, provided there is no subsequent superefficient concentration in a biological material used as food.

A total of 22,300,000 liters (5,900,000 gallons), containing a recorded 2180 grams of plutonium and 4000 curies of fission products were jetted to the 201-B and 204-B tanks between May, 1947 and January 1, 1950. About 10 grams of plutonium and 20 curies of fission products were estimated jetted from the 201-B and 202-B tanks to the 201-B tank crib, based on analyses previously mentioned. The direction that these wastes or contaminants moved is not known. Presumably they followed the wastes discharged prior to May, 1947. The three wells adjacent to the crib were cleaned out and deepened from a depth of 150 feet to 153 feet to determine if activity had penetrated to that depth. No activity was detected by the laboratory analyses of the samples. Additional information will be obtained from this area by additional wells and by use of the casing sampler, described in a later section of this report.

The 201-B tank was removed from service in October, 1948. Sludge from the 7,400,000 liters of 221-B wastes and 10,200,000 liters of 224-B wastes nearly filled the tank (56,500 gallon capacity) and was in danger of flowing to the No. 1 crib. The 204-B, 203-B, and 202-B tanks were connected in series and to the No. 1 crib. Waste liquid, first added to the 204-B tank in October, 1948, overflowed from the 202-B tank to the No. 1 crib in December, 1948.

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2nd Cycle Crib, Tile Field and Shaft

A shaft 55 feet deep (see Plate 8) for collecting liquid and sediment samples was installed 20 feet from the 241-B 2nd cycle crib. The shaft consists of prefabricated concrete sections, 8 feet in diameter, 6 feet 2 inches high, and 9 inches thick. Steel laterals six inches in diameter and 22 feet long were installed in holes in the walls of the sections 10 feet and 20 feet beneath the crib and were carefully emplaced in order to disturb the sediments as little as possible. Openings in the tops of the laterals permitted liquid to enter and collect in sample cups. Other holes were made in the shaft wall facing the crib and covered with removable caps sothat sediment samples could be obtained at periods during operation.

A discharge rate of 20,000 gallons per day (50 gpm) into the 2nd cycle crib saturated the sediments on the side of the shaft nearest the crib and caused liquid to seep into the shaft through the joints. An increase in the jetting rate to 30,000 gallons a day saturated the sediments on the far side of the shaft as well and liquid seeped into the shaft from all sides. This seepage was removed by a pump installed on the bottom platform of the shaft and which pumped the liquid back to the crib. Special coveralls, rubbers, rubber gloves, hats, and masks were necessary protective equipment for persons operating within the shaft because of the radioactive seepage. Readings up to 4 rep/hr. at 2 inches were obtained on the contamination on the bottom of the shaft.

About 7,500,000 liters of wastes containing approximately 7 grams of plutonium and 12 curies of fission products were discharged to the unit between March, 1948, when the 2nd cycle crib was placed in operation and January 1, 1950. Samples obtained from the shaft and analyzed in a radiochemical laboratory included 105 liquid samples, 4 sludge samples, and 7 sediment samples. The liquid samples collected at a depth of 20 feet beneath the crib had approximately the same fission product activity (0.5 uc/liter) as the samples collected from 10 feet beneath the crib, and showed no increase in activity during jetting from each tank except in the case when sludge was inadvertently jetted to the crib from the 104-B tank in August, 1948. A sudden decrease in the crib capacity led to the discovery that about 15 inches of radioactive sludge was in the crib. Some of the sludge was washed to a depth of at least 20 feet beneath the crib, for a small amount was collected in the sample cups at that depth. Considerable sludge was obtained from the upper lateral cups and some sludge was washed into the shaft. The downward movement of this sludge will be followed by means of additional liquid and sediment samples from the shaft and by well samples.

The plutonium activity in this sludge was 990 micrograms/kilogram of sludge, roughly 1,000 times as high as the supernatant, and the fission products activity was 9,000 microcuries/kilogram of sludge, roughly 5000 times as high as the fission products in the supernatant. Clearly much of the activity in the wastes is thus concentrated. Citric and hydrochloric acid were used in attempts to help clear the crib, but results were not significantly successful. The tile field was therefore put into service receiving the overflow of waste liquids from the crib. This incident clearly demonstrates the necessity for adequate and thorough settling tanks in a waste disposal system and also demonstrates how most of the activity in the waste solutions is removed in sludge in the settling tanks.

The average alpha contamination of the supernatant jetted to the crib was approximately 135,000 dis./min./liter; however 64 of the liquid samples obtained from the shaft laterals prior to the jetting of sludge had less than

1,000 dis./min./liter alpha activity and the average alpha activity of the other four samples was 17,500 dis./min./liter (based on 10 milliliter samples). Very little plutonium therefore penetrated to a depth greater than 10 feet below the crib except in the sludge. Plutonium in the wastes is therefore demonstrably initially retained on the sediments within a short distance of the disposal unit even though large volumes of wastes may move downward from that unit. Previous work in the 231, 361-T, and 201-B crib areas, and the indicated lateral spread of the water from this crib indicates that the horizontal spread of plutonium was probably not greater than 20 feet from the unit. The fission products activity decreased by a factor of 3.4 within 10 feet of the bottom of the crib and showed no appreciable decrease within the next 10 feet. This probably correlates with the strata in the shaft area, as shown on Plate 8, which shows a highly permeable gravel bed at a depth of 10 to 20 feet beneath the crib, and directly underlying a less permeable bed of sand and silt.

The sediments 18 feet beneath the crib showed an increase in beta-gamma activity from 0.13 microcurie/kilogram to 0.33 microcurie/kilogram between the 1,930,000 and 5,090,000 liters discharge of radioactive wastes. No alpha contamination was detected on the sediments.

Radioactive sludge, with an activity far higher than that of the supernatant liquid, was thus discharged to the ground in the 241-B 2nd cycle crib area as in the 5-6 crib area. The high permeability of the sediments in both areas is conducive to the downward movement of such sludge as well as the waste liquids, particularly as the sludge is readily soluble. The large number of wells to water within the 200-East area will serve as a constant check on the penetration of additional wastes to the ground water table.

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241-BX and 241-BY Areas

Seven 150-foot monitor wells were drilled in the 241-BX tank farm (see Plate 2). No plutonium or fission products contamination was found in any of the samples from the wells. All the wells are sealed at the bottom with cement and perforated between depths of 40 feet and 100 feet.

Six 150-foot monitor wells and one 275-foot water observation well were drilled in the 241-BY tank farm (see Plate 2). All the 150-foot monitor wells are sealed at the bottom with cement and perforated between depths of 40 feet and 100 feet. No impermeable strata that might be expected to retard or prevent liquid moving directly to the water table were found in this area. The water observation well was drilled to furnish a means of obtaining ground water samples for the detection of contamination which might be the first indication of storage tank failure. Samples from the completed well show the ground water to be free of contamination at this location, up to the time of this report.

200-WEST AREA

Considerable information was obtained from the 200-West area since publication of the earlier report by Brown and Ruppert (2) based on additional drilling, water table studies, reanalysis of waste volumes data and activity released to ground, additional sample analyses and observations of the waste disposal units. In addition, more accurate records are maintained of wastes discharged to ground than was previously the case.

The impermeable silt and clay bed discussed in the previously published report as the upper part of the Ringold formation was explored further and was found in all wells in the 200-West area drilled to a depth of at least 100 feet and in two wells outside the area boundaries. It therefore probably underlies the entire 200-West area. The probable form and distribution of the bed is shown on Plates 9 and 10, as determined from samples and drillers' logs from the 361-T, 231, 241-TX and 234-5 areas, and from the drillers' logs from the wells in the 241-T and

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the 241-U tank farms, and the 241-U-361 and 241-T-361 reverse wells. Drillers' logs of wells 241-T-361A and 222-T-110 are sketchy and no indication of the bed was noted. Well 222-U-110 was too shallow to encounter the bed. The bed is probably a local lacustrine deposit (shallow lake or river flood-plain deposit) on an erosion surface, represented by a prominent caliche zone (calcium carbonate) immediately beneath the silt-clay bed. The bed is now believed to be a part of the terrace gravel series above the Ringold formation, and not a part of the Ringold formation, which lies at somewhat greater depth, as indicated on Plate 10. The erosion surface and the overlying silt-clay bed dip westward at an angle of 1-3°, rather than dipping to the north at an angle of 1° as does the Ringold formation in the White Bluffs. The bed was not found in wells outside the area to the north and southwest, but was identified in well 45-69.5, near the Meteorology Tower, at a depth of about 30 feet, which is the depth calculated from the 231, 241-T, and 361-T areas.

The silt-clay bed is extremely important for as discussed in the earlier report by Brown and Ruppert (2) and in a later report by Brown (4), it supports a perched water body beneath the 221-T effluent swamp and forms at least a temporary barrier to the downward movement of liquids and radioactive wastes throughout nearly the entire 200-West area.

The perched water body beneath the 221-T effluent swamp probably pinches out between the 241-T 2nd cycle tile field and the 241-TX tank farm as indicated in Plate 10. The location of the southern edge of the perched water table was determined by the projection of the line from the edge of the swamp through those wells in the 241-T area recorded as "holding" water during drilling, and by the depth to and angle of dip of the 201-T tank crib fission products and plutonium-contaminated zones (about 5° S.). The perched water body extends to unknown

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though probably comparable distances in other directions. To the north and west the perched water body may extend to the undergound margin of the impermeable bed, for no trace of that bed was noted in well 49-79, less than a mile to the northwest of the discharge swamp. The 241-T tank farm undoubtedly terminates the water table to the southeast, for the tank farm observation wells were drilled to depths of 150 feet and were perforated from a depth above the silt-clay bed to the well bottom. Thus, such water as penetrates to the 241-T tank farm probably enters the casings above the silt-clay bed and passes out of the casings near the well bottoms, from which points it rapidly seeps through the permeable gravels to the natural water table at a depth of about 240 feet. The depth to and extent of the perched water table in the 241-T tank farm area is thus not known.

A second perched water body is probably present beneath the discharge swamp in the southwest corner of the 200-West area, but its extent and depth are not known owing to insufficient wells in that part of the area and lack of knowledge of the depth and attitude of the silt-clay bed, which probably extends under this part of the area. The extent of this perched water body is certainly less than that of the perched water body beneath the 221-T discharge swamp, for the daily volume of water discharged to it is about 600,000 gallons, in contrast to the more than 1,000,000 gallons discharged to the 221-T swamp.

Waste liquids discharged into the ground above this probable perched water body will presumably spread laterally along the upper surface of that ground water body in the same manner that the 201-T tank radioactive wastes spread toward the 241-TX tank farm. These wastes may actually float on the perched water table, or the radioactive materials may be deposited in the capillary fringe above that water body, as suggested in the earlier report by Brown and Ruppert

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TABLE 4

Summary Figures, 200-West Area Waste Disposal Units, January11

Unit	Total Volume Waste in Liters Dec. 1, 1947	Jan. 1, '50	Recorded Radioactivity (Amounts Approximate) Dec. 1, 1947	Jan. 1, '50	Radioactivity Discharged	In Use
231-W-150 (reverse well) 6", 150' deep	1.0×10^6	same	*50 g Pu	same	To ground	No, sealed with sludge
231-W #1 & #2 cribs 12' x 12' x 4'	26.8×10^6	same	*340 g Pu	same	To ground	No, sealed with sludge
231-W trenches 150' x 8' x 2'	9.5×10^6	30.8×10^6	10 g Pu	75 g Pu	To ground	Yes
234-5 #1 & #2 cribs 12' x 12' x 14'	----------	3.8×10^6	-----	60 g Pu	To tank	Yes
241-T #1 & #2 cribs (201-T tank cribs) 12' x 12' x 4'	4.5×10^6	13.3×10^6	500 g Pu 70 (?) c F.P.	1460 g Pu 200 (?) c F.P.	To tank	Yes
241-T-361A (reverse well) 8", 206' deep	11.3×10^6	same	3350 g Pu 2800 c F.P.	same same	To tank	No, sludge in tank
361-T #1 & #2 cribs (5-6W) 12' x 12' x 4'	8.7×10^6	32.6×10^6	111 g Pu 4 g Pu 2800 c F.P. None direct to ground	111 g Pu (to 10-24-47) 160 g Pu 2800 c F.P. 5100 c F.P.	--to tank-- --to ground-- --to tank-- --direct to ground	Yes

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TABLE 4 (cont.)

Unit	Total Volume Waste in Liters Dec. 1, 1947	Jan. 1, 1950	Recorded Radioactivity (Amounts Approximate) Dec. 1, 1947	Jan. 1, '50	Radioactivity Discharged	In Use
241-T #3 crib & Tile Field (2nd cycle) 12' x 12' x 7'	1.9×10^6	11.2×10^6	2 g Pu 3 c F.P.	25 g Pu 230 c F.P.	To ground	Temporarily suspended
	63.7×10^6	130.8×10^6				

*Revised value based on additional data reviewed and studies made since publication of Document HW-9671 dated May 3, 1948, entitled "Underground Waste Disposal at Hanford Works".

(2, p. 18). Information on the extent and depth of the silt-clay bed and the probable perched water body above it as well as the ground water mound beneath it will be obtained from wells to be drilled in the near future in the 241-S crib and tank farm areas and in the vicinity of the proposed Redox swamp.

Waste liquids in other waste disposal areas within the 200-West area will generally move down the dip of the sediments above the silt-clay bed. This was noted in the earlier report, which pointed out that the radioactive contaminatio in the 361-T area, the 241-T area and the 231 area moved in a direction between south and west. Examination of the sediments in numerous excavations throughout the 200-West area shows that they (at least to a depth of about 50 feet) dip up to 30° S. to SW.

Additional data were added and revisions made in Table 1 of the previously published report to make Table 4, "A Summary of the 200-West Area Waste Disposal Units", of this report. The estimate of the amount of plutonium discharged to reverse well 231-W-150 and the 231 number 1 and 2 cribs was lowered from the earlier figure, based on additional analyses and studies (18). Fission products activity and plutonium listed in the original table under "recorded radioactivity" is that amount discharged to the system, as was stated, in some instances to a storage tank some time prior to discharge to the ground, in other cases to a settling tank and then to the ground, and in still other cases directly to the ground, as indicated in Table 4. The fission products activity, moreover, was not corrected for radioactive decay. Information obtained on the approximate half-life of some of the wastes since publication of the previous report makes possible a rough estimate of the activity present in the ground at any time. Data from several waste units has confirmed the belief that much of the activity is removed from solution in the settling or storage tanks where it is concen-

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trated on the sludge, and that much of the activity is deposited directly beneath the crib in areas inaccessible to drilling. The ratio of calculated to recorded activity, therefore, represents essentially a ratio of the effectiveness of the settling or storage tank and/or the sediments directly beneath the crib in removing the activity not accounted for, and should not be interpreted as evidence that substantial amounts of the released activity totally escape from the combined system of tank, crib and sediments below, and get to the ground water. The probability that significant activity escaped from those waste disposal areas drilled is extremely remote, although present data will not permit a complete denial of this opinion.

The following reasons are cited as evidence for the belief that no radioactivity has penetrated from the crib or trench waste disposal units to the ground water in the 200-West area:

1. Eighty-eight water samples were taken from the two water observation wells within the 200-West area and from the four wells immediately outside the area boundaries, up to January 1, 1950. None showed radioactivity above the significant or reporting level. If significant amounts of radioactive materials from the 231 cribs or trenches, the 201-T tank cribs, or the 2nd cycle cribs penetrated to the ground water, such contamination should have been detected in the 231-2 or 224-T-4 wells routinely sampled. Well 241-T-361, reopened early in October, 1949, showed ground water contamination at that point, undoubtedly from the 241-T-361A reverse well. Eighty-seven samples were taken up to January 1, 1950, from this well for alpha and beta-gamma counts, fission products analyses, decay curves, fluorophotometer, TTA and other extraction analyses. Additional wells are planned for the vicinity to

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determine the extent of contamination. Additional wells are also planned for other parts of the 200-West area for routine monitoring of the ground water.

2. Sediment samples obtained during drilling operations from the 361-T crib area contaminated zone alone numbered 539, those from the 231 No. 1 and 2 cribs, the 231-W-150 reverse well and the 231 sump cribs totaled 358, and 364 were obtained from the 201-T tank cribs and 2nd cycle crib and tile field area. Some of the last named were obtained prior to use of the 2nd cycle crib; however, some of those wells in the 2nd cycle crib and tile field area encountered contamination from the 201-T tank cribs. All samples showing contamination by field check were analyzed in a radiochemical laboratory and the results of the analyses plotted on plan maps and on a series of interlocking cross sections. Contamination contour maps and sections (isoactivity drawings) were drawn, followed by additional horizontal and vertical contamination profile and assay sections, for both the plutonium and fission product-contaminated zones. Only then were calculations made of the probable amounts of activity present in the drilled areas. The pattern of the spread of activity in all cases was unmistakable for the decrease in alpha and beta-gamma activity away from the crib, both laterally and downward, was clearly shown in every plan map, section, profile and assay section. Similarly the activity levels toward the cribs increased along curves diverging smoothly and greatly from straight-line functions. The contamination assay plan maps, sections and profiles presented in the earlier report by Brown and Ruppert (2) were only a few of several dozen such diagrams that were drawn but not presented in the interests of brevity. Contami-

nation maps and sections, drawn during drilling operations, were used as the basis for locating additional wells. The extent, depth, and level of activity in areas to be drilled were predicted by this means and were later confirmed, proving the reliability of the data analysis and confirming the accuracy of the sampling procedure. Control in the lower and in the outer parts of the contaminated zones was felt to be adequate and accurate enough to indicate that no contamination had escaped. The greatest error in calculating the amount of activity present in the ground lay in the inability to obtain samples from directly beneath the cribs, where activities are far higher than elsewhere (see 5-6 crib and tile field discussion).

3. Samples were obtained in October, 1949, of the sediments from the bottoms of wells 361-T-1 through 13. Contamination was found on only two sediment samples, those obtained from 361-T-5 (75' deep) and 361-T-6 (102' deep). Of these wells, 361-T-5 did not originally penetrate completely through the fission products contamination zone, and well 361-T-6 penetrated less than 20 feet beyond it. About 0.08 microcurie of beta-gamma activity/kilogram of sediment was detected on each sample (significant level 0.05 microcurie/kilogram). No significant alpha contamination was detected in any of the samples taken. Samples from the bottom of the 6 wells penetrating through the silt-clay bed showed no significant contamination whatsoever.

4. The early effluent sampling data cut off at a much higher level than has been used in Health Instrument Divisions investigations (3,16). Conservatively, effluents below the then used limit were assumed to be at the limit. This grossly overestimated the recorded activity as shown by re-

fined material balances.

5. A considerable fraction of the effluent activity was retained in settling tanks where such were used (see discussion on 241-T-361 area, 241-B-361 (5-6) area, 241-B 2nd cycle crib area, 201-B tank crib areas). Sludge to which access was possible invariably showed very high specific activity relative to the effluent (241-B 2nd cycle crib and 241-B-361 (5-6) crib). Analyses of samples of the wastes on discharge from the buildings indicated that the activity of the wastes was considerably higher than the activity following passage through either a storage or settling tank, where radioactive decay and/or settling of the sludge significantly decreased the activity levels.

6. The silt-clay bed previously discussed has effectively supported at least one ground water body and is proven to underlie all the radioactive waste disposal areas in the 200-West area. The fine-grained sediments are clearly more effective removers of both alpha and beta-gamma activity than the coarser fractions (2,20), apparently due to the surface area of the rock particles exposed to the waste solutions per unit volume of those sediments. Moreover, the clays, particularly those derived from volcanic materials, are recognizably effective in processes involving ion exchange phenomena. The finer-grained sediments, and particularly the clays, are therefore more ideal than other sediments for removal of activity by either simple surface (physical) fixation or by ion exchange. The possibility of transmittal of radioactive waste liquids through the bed which is as much as forty feet thick is difficult to explain, although admittedly not impossible. Radioactive materials might locally penetrate beneath the silt-clay bed by some such means as

following the peripherally disturbed areas around the well casings although the possibility of such seems very small. Such materials should still be removed from solution prior to penetration to the water table, for processes operating to remove activity beneath the crib should certainly function at greater depth.

Some of the activity now in the ground may someday be released to move downward, although laboratory tests and field observations to date have not demonstrated how this might occur under natural conditions, nor has the incomplete evidence to date indicated that such is actually taking place. If such activity should be released and move downward, then it should again be deposited on sediments at greater depth, as indicated by Thorburn (20).

361-T Area

An analysis of the 22-foot level sediment samples from wells 361-T-3 and 361-T-6 for uranium and plutonium by ether extraction, TTA, and flurophotometer methods, showed that less than one percent of the alpha activity was due to uranium.

A fission products decay curve, plotted from June, 1947 to November, 1949, for a sample of the sediments from the 22-foot level of well 361-T-6, shows that the half-life of the activity during this period was approximately 400 days. During this period the activity decreased to 22 percent of the original count.

The results of fission products analyses made on the 22-foot and 37-foot level sediment samples from well 361-T-6 are shown in the following table:

Element	Beta-gamma Activity (microcuries/gram of sediments) 22-foot level	37-foot level
Ce	98.5	.32
Y	19.2	.32
Sr	19.2	.48
Ru	2.4	11.5
Cs	57.6	3.68
Rare earths (other than reported)	2.4	.32
Total	240	16

The above results were not corrected for back scatter nor self absorption caused by the use of a finite amount of carrier.

The decay curve for the fission products, and the fission products analyses give a means by which a rough estimate of the amount of beta-gamma activity in the ground at any one time can be estimated. These estimates suggest that the amount of beta-gamma activity in the ground in the 361-T area is nearly constant, and has been so for about one year in spite of the constant additions of radioactive wastes. In other words, at the present accumulation of activity (about 2400 curies), the radioactive decay just equals the periodic increments. Additional decay curves will be determined from samples to be obtained from this and other areas to verify the indication and to determine the equilibrium amounts in the other waste disposal areas.

241-T-361 Reverse Well Area

The 241-T-361 reverse well contaminated zone was not explored during the earlier drilling operations in the 200-West area. The 241-T-361A reverse well, used for waste disposal, was originally drilled to a depth of 206 feet, after the 241-T-361 well, drilled to a depth of 287 feet, reportedly encountered the ground water table. The 241-T-361A reverse well was perforated from a depth of 104 feet 6 inches to a depth of 204 feet, and put into service June 21, 1945.

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Because sand entered the well through the perforations, two cribs were installed (361-T No. 1 and 2 cribs) and tied into the reverse well through an overflow pipe. On August 15, 1946, overflow into the cribs was noted, and on October 17, 1946, the reverse well and settling tank were by-passed. During this period an estimated 3,000,000 gallons of waste containing more than 2800 curies of beta-gamma activity and 3350 grams of plutonium was sent to the settling tank, and the overflow sent to the reverse well.

The 241-T-361A reverse well therefore discharged radioactive wastes into the ground beneath the silt-clay bed that underlies the 200-West area and within 75 feet of the present ground water table (see Plates 9 and 10). The possibility that contamination had penetrated to the water table was therefore good, and exploration was indicated.

Well 241-T-361, 27 feet from the 241-T-361A reverse well, originally was reputed to have penetrated to the ground water. The rise of the water table owing to the effluent discharge into the swamps in the northwest and southwest corners of the area presumably raised the water table to a point where water samples could be taken from the 241-T-361 well. This well was inspected, found dry and filled with sediment to a depth of 271 feet from the ground surface. The well was reopened in October, 1949, cleaned out and deepened. The casing could not safely be driven deeper (5); therefore the well was drilled as an open hole to a depth of 325 feet, about 38 feet beyond the bottom of the casing. Caving of the sides of the well and washing in of sand through the casing perforations made further deepening not feasible. Water was encountered at a depth of 278 feet, (elevation 430 feet) seven feet higher than originally reported in the well logs of the 241-T-361 well. The average annual rise of the water table at this point owing to the effluent discharge thus is about 1 3/4 feet a year.

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No contamination, either beta-gamma or alpha, was found on the sediments although the 241-T-361A well is only 27 feet away. Alpha and beta-gamma contamination above the probable natural level of activity were found in water samples taken from the well, the alpha contamination averaging about 70 dis./min./liter and the beta-gamma activity about 3500 micro-microcuries/liter. These compare with a presumed natural alpha activity level of 5.9 dis./min./liter, based on 82 analyses of water from six wells in and about the area, and 11.7 micro-microcuries/liter of beta-gamma activity based on 89 samples from the same six wells. Samples analyzed by fluorophotometer indicate that all the alpha activity in the 241-T-361 well is due to uranium, not plutonium.

The early samples taken from well 241-T-361 during drilling operations contained lower alpha and beta-gamma activity than those samples taken at later periods. All the samples were taken at the ground water surface; therefore the increase in activity in the water suggests that the activity is predominantly on the surface of the water. The early samples were obtained by thoroughly bailing the well; therefore the lower activity of these samples suggests mixing of the highly contaminated water at the water surface with the much less contaminated water at greater depth. This phenomenon of activity floating on the surface is analagous to the action of the activity in the 201-T tank crib area, except that the elements present in the ground water are those least likely to be retained on the sediments, whereas apparently all the elements, including plutonium, were floated on the surface of the perched water body in the 201-T tank crib area, and then deposited on the sediments.

The presence of radioactive contamination in the ground water at this point only 27 feet from the 241-T-361A reverse well indicates that movement of the ground water has not been great, as in the 241-B-361 ground water contaminated zone; otherwise the activity should be some distance east of the reverse well.

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The 200-West area ground water mound is still rising as indicated by well 224-T-4, which indicates that the ground water mound has not reached its maximum height, and that the maximum rate of movement of water is yet to be attained.

Sluffing of the walls of the open hole and flow of sand through the casing perforations have slowly filled the well. On October 27, two weeks after completion of drilling, the well was open to a depth of 297 feet and thus had filled to a depth of 28 feet. On November 4, it was filled to a depth of 294 feet and had apparently stopped filling with sand. Two wells in the 361-T crib area will be deepened to water to provide additional points for monitoring the ground water. Five wells will also be drilled east of the reverse well, down the slope of the ground water mound in the indicated direction of movement.

241-T Area

The 8,800,000 liters of wastes discharged to the 201-T and 204-T tanks between December 1, 1947 and January 1, 1950, contained an estimated 960 grams of plutonium and 130 curies of fission products. Approximately 4 grams of plutonium and one curie of fission products were estimated jetted from the 201-T and 202-T tanks to the 201-T crib (224-T waste crib), based on analyses previously mentioned. The 201-T tank was removed from service and the 204-T, 203-T, and 202-T tanks connected in series and to the No. 1 crib. No additional wells were drilled in this area and no contamination detected on the water samples from well 224-T-4, located approximately 200 feet from the No. 1 crib.

About 11,200,000 liters of radioactive wastes containing about 25 grams of plutonium and 230 curies of fission products were discharged to the No. 3 (2nd cycle) crib and tile field up to May 5, 1949, when jetting was temporarily dis-

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continued owing to the availability of considerable storage space. Thirty-four sediment samples were obtained from the bottom of well 241- T-1 at a depth of 20 feet beneath the crib to check the downward migration of activity. No alpha activity was detected on any of the samples, and the maximum beta-gamma activity was 0.1 microcurie/kilogram of sediment.

Well casings 241-T-2,3,4,5 and 9 around the No. 3 (2nd cycle) crib contain open holes or perforations. Wells 241-T-2,3,4, and 5 have two perforations at a depth of 30 feet from the ground surface, and two at a depth of 35 feet from the surface. These perforations, 2½ inches long and 1/4 of an inch wide, were made during attempts to obtain sediment samples in September, 1947. Casings 241-T-2 and 5 also have a 1-inch diameter hole at a depth of 35 feet from the surface and well casing 241-T-9 has a 1-inch diameter hole at a depth of 45 feet from the ground surface. These one-inch holes were drilled with the casing sampler, and were not plugged by the machine. In one instance the sampler auger hit a rock and shifted the entire machine, so that the lead plug used to seal the drilled holes was not properly inserted. In the other instances the motor armature short-circuited and the sampler did not complete its cycle. Concrete was used to seal the well bottoms and prevent the introduction of radioactive wastes into the ground at depths of 150 feet. Radioactive waste seeped through the perforations and was found in wells 241-T-2,3, and 5, 18 feet from the center of the crib, and in well 9 which is 28 feet from the center of the crib. The maximum fission products contamination was as follows:

18 feet from the crib	1.1 microcuries/liter
28 feet from the crib	0.5 microcurie/liter

The activity due to fission products in the liquid samples obtained 18 feet from the crib was approximately 4 percent of the activity of the original wastes and the activity due to fission products in the liquid samples obtained 28 feet

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from the crib was approximately 2 percent of the original. No plutonium was detected in the sediment samples from 20 feet beneath the crib or in the liquid samples obtained 18 feet from the crib. The plutonium-contaminated zone, accordingly, probably lies within the 36-foot diameter circle formed by the four wells nearest the crib and is less than 20 feet thick. The value of angled wells, such as the 361-B-13 well, to get under such cribs is apparent.

The wells which contain liquid indicate that the waste liquids are moving in the same southwesterly direction as was noted in the earlier drilling in the vicinity of 201-T tank crib.

Some waste liquids undoubtedly will move downward along the sides of the well casing, in the sediments disturbed by the drilling and casing driving operations. Following initial settling and sorting of the sediments, and washing of fine material into the peripheral zone, the permeability of the zone will probably be similar to that of the surrounding sediments, and in some cases may be less. The decrease of permeability with use was noted in the 241-B 2nd cycle crib shaft, already discussed.

Four shallow test holes were drilled for observation purposes in the tile field. No contamination was detected on sediment samples obtained from the bottom of the test holes and no liquid was found in any of the holes.

No contamination was detected by the analyses of water samples from well 224-T-4 at a depth of approximately 234 feet beneath the ground surface. A Leupold and Stevens Water-stage recorder was installed on this well to determine the effect of the 200-West area effluent water discharge on the water table.

<u>241-TX Tank Farm Area</u>

Well 241-TX-9 was the first of nine 150-foot monitor wells drilled in the tank farm (see Plate 9). No contamination was detected by the field check of the

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5-foot sediment samples from this well, the closest to the 241-T area from which contamination may have spread.

The well locations were determined by the presence and attitude of the silt-clay bed as predicted from its location in the 241-T area, the 361-T area, and the 231 area. The wells were located down the dip of the bed from the tanks to be monitored, in such a pattern that liquid from any tank will be collected by one of the wells as the liquid moves down the dip of the impermeable silt-clay bed. The silt-clay bed was encountered exactly as predicted in all the wells drilled in the 241-TX area. All the wells penetrated below the silt-clay bed, were sealed at the bottom with cement, and were perforated from a level slightly above the bottom of the tanks down to the surface of the impermeable silt-clay bed.

The 241-TX wells were watched closely for evidence that the perched water body, originally noted early in 1948 beneath the 241-T area, was present in the 241-TX area. No significant change of moisture content, or inflow of water into any of the wells was noted above the silt-clay bed, nor, as has been mentioned, was any contamination noted in well 241-TX-9. Therefore, the perched water body which apparently influenced the deposition and spreading of the radioactive contaminants beneath the 201-T crib and the 2nd cycle crib and tile field, probably pinches out short of the TX tank farm area as indicated in Plate 10. The possibility exists, however, that increased discharge of effluent water to the 221-T swamp will extend the perched water body until liquid enters the 241-TX monitor wells. The planned 1st cycle evaporation process for the 241-T area contemplates the discharge of an additional estimated 250,000 gallons of non-radioactive water to the T-plant swamp. The results of increased discharge will be carefully watched in the T-plant swamp area, in the perched water body and in the ground water mound.

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234-5 Area

The eleven 150-foot test wells drilled in the crib and tile field area penetrate the silt-clay bed that underlies the entire 200-West area, and indicate that the ground water in this area is also safeguarded from radioactive wastes discharged above the bed. One test well also penetrates the center of each of the two cribs and bottoms 20 feet beneath the cribs. Sediment samples are routinely obtained from the bottom of these two wells and analyzed to check the downward movement of contamination, as in the 241-T 2nd cycle crib. The radioactive waste tile field for this area is constructed of ordinary farm drainage tile and is covered by a maximum of only four feet of earth, which will create several problems when the liquid wastes pass through the cribs to the tile field. Capillary action may bring some radioactive contamination to the ground surface from the tile field level in the same manner that caliche is deposited at the ground surface by ground water elsewhere in the general region. The surface sediments will be sampled regularly, therefore, when the tile field begins to receive such wastes in order to detect such capillary rise of contamination. Vegetation that grows in the tile field area will also be checked periodically, inasmuch as the roots of many desert plants, some of which are known to concentrate radioactivity, penetrate far beyond this depth. This vegetation check will help delimit the area to be surface sampled and together with the surface sampling will also determine the extent of the tile field being used. Preliminary sampling, to determine the natural activity level of the plants growing in the tile field area, is completed.

231 Area

No additional wells were drilled in the area and no contamination was detected in water samples from well 231-2 at a depth of approximately 244 feet beneath

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the ground surface. The 19,700,000 liters of wastes discharged to the 231 trenches between December 1, 1947, and January 1, 1950, contained approximately 65 grams of plutonium. Several wells are to be drilled in the vicinity of the disposal trenches to determine the extent of contamination spread.

Effluent Discharge Swamps

A number of problems were and will be created by the continually increasing discharge of effluent (non-radioactive) wastes to the ground. Most of these problems are discussed in those sections of this report to which they directly apply. The problem has been thoroughly and well analyzed by Parker and Piper (16) although their figures for discharge of liquid to the various areas contain some errors of importance. For purposes of unity, the problems are briefly summarized here so that a full understanding of them may be obtained.

The ground water mounds or ridges shown on Plate 1 have been demonstrated by Parker and Piper to be the result of the effluent discharge in the 200-East, 200-North, and 200-West areas. The relation between the areas of discharge and the mounds is clear cut and obvious; moreover the amount of water estimated to be in the mounds is roughly equal to the recorded volumes discharged during the approximately five years of plant operation. Plate 1 represents the conditions as they existed only in October, 1949, for changes in the height and extent of these mounds are continuous. The ground water mound beneath the 200-East area has shown no recent significant rise as indicated by several observation wells, but has shown lateral spread, especially to the north. The ground water mound beneath the 200-West area is rising at a rate of about 2½ feet a year, and is also spreading to the west, north and east. No indications were noted, however, that the rate of ground water movement has increased in the vicinity of either the 241-B-361 or 241-T-361A reverse wells.

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The ground water mounds beneath the 200 areas will increase in height until a point is reached, at which the radial flow outward from the center of the mounds will exactly equal the downward seepage of water from the waste disposal areas. A new set of conditions will then be imposed on the ground water system, resulting in a materially increasing rate of flow of water from the mounds outward, and with it such radioactive materials as may be in solution or suspension Eventually the ground water table in the area between the 200-East and 200-West areas will be raised to form essentially a ground water plateau. The form and height of this will be determined by the permeabilities of the various sediments, the increment rate and the location of new disposal areas. Continued observation of the ground water table is planned.

Perched water bodies, as previously explained, are a problem of increasing importance, particularly as the volume of effluent wastes added to the ground in the 200-West area increases. Not only is this a problem related to radioactive waste disposal, but it easily can become of consequence to present and future installations, both buildings and tank farms (4).

Areas capable of absorbing larger quantities of effluent water need to be defined. The T-plant swamp, now receiving 1,000,000 to 1,500,000 gallons per day, is scheduled to receive an additional 250,000 gallons per day from the proposed 1st cycle evaporation process. Additional volumes of water may well cause the swamp to overflow and drain northward beyond the perimeter fence, particularly during periods of low evaporativity, such as in the winter. This and similar swamps should be adequately diked to maintain a constant area under water to prevent activity that may be in the water from being precipitated on the ground as dust from where the wind will carry it over the surrounding region. The discharge of significantly greater volumes of water to the ground in this area will

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cause significant changes in the perched water table that may result in its extension into the 241-TX tank farm and into other facility areas.

The swamp in the southwest corner of the area has a smaller areal extent than the T-plant swamp owing to the smaller volume of water discharged to it, and to the fact that neither of the two ditches feeding it are lined for a total length of about 5000 feet (see Plate 9). A considerable volume of water, therefore, seeps into the ground from these ditches, and a considerably smaller volume of water is discharged to the swamp than if the ditches were lined or were shorter. About 590,000,000 gallons of water was discharged to this swamp to January, 1950. About 20 acres of ground is available within this swamp area to an elevation of 656 feet, above which overflow to the west will occur. Comparison between the volumes of waste discharged to the two swamps and the approximate acreage covered by water indicates that about 150,000 gallons per acre per day seeps into the ground. The 231, power-house and laundry swamp is thus capable of an indicated maximum of about 3,000,000 gallons of water per day. Redox plant wastes, estimated to total 2,500,000 gallons per day, will be discharged in a separate swamp about 3500 feet south of the 200-West area (see Plate 1), at a point where a perched water body, if created, will not interfere with operations of the area. Excess capacity available in the present swamp area is reserved for the possible future use of the U-plant buildings.

The Redox wastes will be discharged onto sediments probably correlatable with the Touchet beds, which floor Cold Creek Valley, rather than the Ringold formation. The sediments in Cold Creek Valley closely resemble those deposits from the type locality at Touchet, are unconsolidated, are characterized by cut and fill bedding, are uniformly highly micaceous silts and very fine-grained sands, contain no caliche and are non-calcareous. Sedimentary dikes are extreme-

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ly common in the sediments exposed, and erratic boulders of foreign rock types, common at the type locality of the Touchet beds, are locally extremely abundant in many parts of Cold Creek Valley.

No serious problems are anticipated in connection with the 200-East area ground water mound, for no perched water tables are known or believed to exist within this part of the project area, and the ground water mound is east of the area. Total volume of water discharged to date into the 200-East area swamp is about 2,600,000,000 gallons. Material increases in the volumes of water discharged to the ground will raise the mound to greater heights and will cause a more rapid movement of the ground water, but should result in no other complications.

300 AREA

Three wells were drilled outside the 300 area to determine the degree of spreading of contamination in the ground water between the 300 area waste ponds and the river. One well was completed at a depth of 70 feet, the other two at depths of 75 feet each, but all penetrated 30 feet into the ground water. No fission products contamination was detected on any of the sediments from the wells and the maximum alpha contamination detected was 8200 dis./min./kilogram on the 65-foot sample from well 303-1. Maximum contamination detected in water samples from the wells was 40 micro-microcuries of beta-gamma activity/liter and 640 alpha dis./min./liter. Most of the alpha activity is due to uranium; however, trace amounts of plutonium were detected in some water samples and significant amounts occasionally are found in the principal waste lines into the pond. Water samples are taken and analyzed from the wells on a routine basis to detect changes in the activity and to compare these with changes in the river and ground water level. A continuous, routine program will be maintained to determine the changes in activity levels with time and with changing conditions.

Completion of the McNary Dam at Umatilla, Oregon, will markedly influence waste disposal practices in the 300 area. The river will be raised to a maximum predicted elevation at highest flood stage of about 368 feet at the 300 area, which is the present mean or "normal" river elevation at 100-F area. The river at the 300 area will normally be about 7 feet higher than at present, and during flood stage may be raised to record heights. The effect of such a rise must be considered in waste disposal planning, in both this and other areas that may be constructed in the future. The 300 area disposal pond is recognized as an inferior and potentially hazardous temporary expedient in any case, justified only (if at all) by the relatively low activity of all components except uranium.

A series of ten wells are being drilled in the vicinity of this area for a detailed ground water study preparatory to revising the waste disposal system for this area and the proposed Works Laboratory area.

<u>321 Building Waste Crib</u>

Well 321-1, approximately 4 miles north-northwest of the 300 area at coordinates approximately S 6000 E 3500, was completed at a depth of 117 feet and penetrated 30 feet into the ground water. The well was drilled to supply water to flush the tank truck used to transfer 321-building, hexone-bearing, radioactive wastes from the 300 area to the 321 cribs and to provide a means of sampling the ground water for radioactive contamination. The cribs consist of two buried stainless steel tanks which were inverted and placed on concrete footings. Sixty-three pounds of uranium were discharged to the crib during its period of use. No contamination was detected in the water samples from the well.

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The crib is no longer in use owing to cessation of operations requiring waste disposal to the crib.

100 AREAS

107-F Waste Disposal Trench

This well is located between the river and the 107-F waste disposal trench and approximately 250 feet from the latter. It was completed at a depth of 67 feet and penetrated 25 feet into the zone of ground water. The well was drilled to determine if contamination were present in the ground water and were moving to the river, as the result of 8,000,000 gallons of low activity beta-gamma waste liquids placed in the trench. No significant alpha contamination was detected in these wastes. No contamination was detected on the sediment samples from the well and none has been detected in water samples obtained from the well to date.

108-B Crib

The 108-B crib receives the cooling water from the P-10 production process and also the drainage from the decontamination hoods. Three wells were drilled to depths of 90 feet each within 40 feet of this crib and penetrated 30 feet into the ground water. The water samples analyzed from the wells the first three months following drilling (March, April and May, 1949) showed beta-gamma contamination. Maximum beta-gamma contamination in the wells was 730 micro-microcuries/liter. The level of contamination decreased with the rise in river level and subsequent rise in the water in the wells until the water samples from all the wells were free of contamination. The contamination probably emanates from leaks in the 105-B cooling water discharge line which passes about 50 feet east of the crib, for the flow of water from the river into the gravels pre-

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sumably forced the contamination away from the wells. Sodium (14.8 hr. half-life) and phosphorous (14.3 day half-life) are the most hazardous components in the pile effluent. The half-life of the activity will be checked to prove the source of contamination, as soon as the level of activity rises. No radioactive wastes are known to have gone to the crib, and no P-10 product was found in the samples analyzed to date.

A Leupold and Stevens water-stage recorder was installed on 108-B-3 well to monitor the water level changes and to compare them with the river level changes. Samples of the ground water are taken from the three wells every week and the level of activity plotted against water level, to determine the effect of change in river level on contamination in the water from the wells.

A group of wells are planned for the 100 areas to determine the feasibility of underground waste disposal of relatively small amounts of low activity radioactive wastes from the Health Instrument Biology Division animal farm and of large volumes of cooling water effluent that conceivably might become contaminated with fission products, plutonium and uranium.

EARTH MATERIALS EXPERIMENTS

A number of experiments have been made on the fixation and retention of radioactive materials on soil materials, and on different types of sediments. Some of these have been previously referred to (10,12,15). Other experiments have been made by additional personnel along the same lines, the results of which have been summarized in memoranda or have been verbally discussed with the authors. To date, however, no comprehensive or planned study has been made of the many phases of the subject as yet unexplored. Such experiments are planned when personnel adequately trained in soil physics and chemistry can be obtained and adequate laboratory space provided.

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All information obtained to date, both from laboratory experiments and from empirical observations indicates good to excellent (though obviously incomplete) retention of activity on earth materials. The notable exception to these observations are the anions, ruthenium, the alkali metals and uranyl ion, all expected to be exceptions. Other ions, as indicated by comparisons between the 361-T-6 fission products analyses and the 241-B-361 fission products analyses are demonstrably retained on the sediments, at least under the conditions existent during the nearly five years that some of the waste disposal units have been in operation. Plutonyl ion may conceivably be transmitted under certain conditions so that the complexing of plutonium is probably one of the ultimate risks assumed in underground waste disposal. However, to date, plutonium appears to be one of the elements most quickly and easily removed from solution and most thoroughly retained on the sediments. Probably one of the old- no-longer-used disposal units should be excavated to assay the pattern of retention on earth materials and to correlate the results obtained with the results of the drilling program. The 231 No. 1 crib zone would obviously be most ideal, for the contaminated zone is small and at moderate depth. The complete lack of radioactive fission products will also greatly simplify the problem. Moreover, the long period of time since the crib was used (February, 1947) suggests that the moisture content of the sediments would be at or near specific retention. The value of this procedure is reduced considerably by the very poor accountability of input materials, by the large volume of contaminated or potentially contaminated sediments that must be handled and by the hazards involved.

A series of tests by Overstreet and Jacobson (15) on fission products fixation on sediments pointed out a number of facts of value to the waste disposal problem. Waste liquors from W-6 were poured through a series of nine soil

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columns, as undiluted wastes, diluted 1:10, 1:100, 1:1000. Control soil from Clinton afforded the highest retention of activity at all dilutions, attaining a maximum of 96 percent retained. Sediments from various parts of the Hanford Works area gave varying results ranging from a minimum of 25 percent retained at no dilution, to 94 percent retained at dilution of 1:100. A control sample of quartz foundry sand from Illinois gave consistently the lowest retention value, ranging from zero percent for the undiluted wastes to a maximum of 29 percent for the dilution of 1:100. Wastes of a dilution of 1:100 were universally more readily retained by the sediments, followed by dilutions of 1:1000 and 1:10 of nearly equal retention, and lastly by the undiluted waste liquors. No figures are cited showing the elements retained, nor the elements passed through the columns.

These tests strongly indicate that the principal means of retention of the fission products activity is by ion exchange, for the quartz sand, one of the most inactive compounds present in the sediments, gave the lowest retention of radioactivity. The Clinton topsoil on the other hand, with a high percentage of clay, most completely removed the activity from the solutions. Samples from the Hanford Works area removed amounts of activity intermediate between the two extremes. The types of clay occurring in the Hanford Works area are particularly good for ion or base exchange processes, for they belong largely to the montmorillonite group, derived from volcanic rocks. The clay bed beneath the 200-West area thus provides an impermeable floor consisting of material with a high base exchange capacity and thereby probably effectively limits the downward movement of the radioactivity as well as the waste liquids. Other processes undoubtedly affect the retention of activity, but appear less important. Base exchange processes are reversible with changing conditions; therefore, the

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assumption that the principal means of removal of activity is by base or ion exchange admits the possibility of later removal of some of the activity under changed conditions, which are probably unlikely in the natural course of events. Such conditions as might contribute to a reversal of the ion exchange process are currently being investigated and will be further investigated by laboratory tests.

Fixation, as Overstreet and Jacobson (15) points out, may be on soil particles (as ion exchange), in capillaries (as water of specific retention), and as water of hydration (chemically combined). Thus, considerable amount of radioactivity may be immobilized in solution in the sediments or the movement at least greatly retarded. A larger factor of safety is thus introduced than if the base exchange capacity alone is considered in the immobilizing of radioactivity, particularly in the event of unscheduled discharge of radioactive wastes to the ground. The porosity, permeability (ability of material to transmit water), specific retention (the water-retaining capacity) and the actual moisture content of the sediments are therefore important in determining the volume of the waste liquids that will be immobilized in the sediments. Overstreet and Jacobson (p.5) state that the dry composite soil from the 200-West area T-tank farm will immobilize 10 gallons of solution per cubic yard, which indicates a retention of 5 percent by volume.. The methods used in determining this amount were not stated.

Three samples from well 34-51.5 (about three-quarters of a mile south of 200-East area) were tested for water content. The samples were obtained with a drive core sampler devised by C.H. Row of the Transportation Division well drilling force, and which permitted the recovery of so-called "undisturbed" or "drive" samples from as much as three feet below the bottom of the hole being

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drilled. The samples were obtained from depths of 221-222 feet, 250-252 feet, and from 275-278 feet. All were dusty dry when removed from the sampler, although obtained only a few inches below the depth of drilling and the drilling water. The samples moreover absorbed moisture from the air on exposure. Following sampling, the samples were sealed in one-pint glass sample jars with screw-cap lids. Portions of each sample were weighed, oven dried, weighed again and then screened. No significant amount of water could be detected in any of the three samples. All three samples, on the basis of the mechanical analyses, were classed as silty sand, which may be expected to contain as much as 10 percent of water by volume as specific retention. Certainly these samples should be visually damp if the moisture content were at specific retention, for the percentage of very fine sand, silt and clay totalled more than 25 percent of the sample by weight. Coarser sediments obviously will have a moisture content not greater than that of these samples. Moisture equivalent tests were also made by Overstreet and Jacobson (p.3), in which the moisture equivalent of sediments in the Hanford Works area was calculated to range from about three to eight percent by weight. Moisture equivalent is an arbitrary ratio that is sometimes useful in estimating specific retention and is the ratio of the weight of water which the sediments, after saturation, retain against a centrifugal force 1,000 times the force of gravity, to the weight of the soil when dry.

A series of soil column experiments by R.C. Thorburn of the Health Instrument Development Division were recently completed and are summarized in a published paper (23). The results obtained are not conclusive nor more than indicative, nor were the tests more than additional checks of retention of plutonium and fission products under somewhat more carefully controlled conditions and with fewer variables than the earlier tests by Healy and Kay. Thorburn's conclusions although adnittedly based on only one series of experiments, confirm the earlier work of Healy and Kay and the field observations of Brown and Ruppert. His experiments suggest that:

1. The sorption properties of some of the sediments underlying the Hanford Works area are independent of the moisture content of those sediments, at least for the elements Sr^{90}-Y^{90} and Ce^{144}-Pr^{144}.
2. The fission products tested (Sr^{90}-Y^{90} and Ce^{144}-Pr^{144}) are generally removed within a short distance of the point of injection into the sediments and that the finer-grained sediments absorb a greater amount of activity per gram of sediment.
3. The pH of plutonium-bearing solutions is quite important in the sorption of Pu by the sediments as suggested by Healy (10), and that the sorption increases with decreasing pH. Sorption of plutonium is also increased by decreasing the velocity of the solutions and thereby increasing the time the solution is in contact with the sediment particles, as suggested by Brown and Ruppert (2, p.19) on the basis of empirical observations.
4. The effect of calcium and magnesium carbonates on the elution rate of Pu absorbed on soil was not significantly different from the elution rate with water, particularly in the concentrations that might be naturally expected.
5. The Pu eluted from soil by water would reabsorb on the soil at a lower horizon instead of traveling as an unabsorbable slug.

The extremoly dry nature of the sediments at depth as well as at the surface was also confirmed by the results of an electrical resistivity survey by a special U.S. Geological Survey field crew in October, 1948. Four lines were run

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in areas deemed most favorable in the vicinity of the 200 areas. All failed completely to detect changes in the rock types, reportedly owing to the extremely dry nature of the rocks, and the consequent inability of the instrument to detect significant changes in the resistivity of the sediments and the basalt bedrock.

FUTURE DEVELOPMENT

An analysis of the results obtained during the two-year drilling and waste disposal observation period clearly indicates a program of further investigation. Observation of the contaminated ground zones about the waste disposal units must be continued by all means possible, and observation of the ground water contaminated zones must also be continued as in the past.

An electrically-driven, side-wall or casing sampler, designed and built to obtain sediment samples through the casing of an 8-inch well, was discarded. Continuously successful operation of the sampler was not attained owing to the lack of a suitable electric motor. The mechanics of sample taking were proven effective, however, for sediment samples that averaged ten grams in weight were obtained in eight of the fifteen sampling runs made by the sampler. An air-driven casing sampler is designed, incorporating the drill for perforating the casing, the sample tube inclosing the rotating sample auger, and the piston for sealing the drilled hole with a machined lead plug. Most of the bad features of the electrically-driven sampler are eliminated. The build-up of activity on the sediments in the contaminated zones can thus be followed more closely by the use of this specially constructed equipment.

Five wells are scheduled to be drilled to water in the 241-T-361A reverse well area ground water contaminated zone. Two wells in the 361-T crib area will

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also be deepened to the ground water table to further explore the zone of ground water contamination. Monitoring of the ground water will then proceed as in the 241-B-361 reverse well area. Well 241-U-361, used for water table measurements to date, is being reopened to permit sampling of the ground water at that point and to determine the level of activity of the uncontaminated ground water prior to construction of the Redox plant. Additional wells to water will be drilled to the south of the 241-U-361 well, in the vicinity of the 241-R proposed tank farm and cribs, and between the area boundaries and the proposed Redox effluent swamp. These wells will permit more thorough monitoring of the ground water, will permit an accurate analysis of the effect of the discharge swamps on the ground water, and in addition to numerous shallower wells throughout the area will aid in determining the exact form and gradient of the silt-clay bed underlying the area.

Fifteen wells are planned for the waste disposal areas in both the 200 areas to re-explore and re-evaluate the crib areas. These wells will supplement the information obtained by use of the casing sampler, will obtain samples from greater distances from the cribs to check for lateral spread of activity, and will explore a few critical areas in greater detail. Included in this group will be several inclined wells to explore the areas directly beneath several of the cribs.

The need for additional wells in those areas previously drilled is briefly summarized in the following chart, which includes all the waste disposal units now in use.

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Waste Disposal Area	Total Wastes Discharged at Time of Drilling (liters)	Total Wastes to Jan. 1, 1950 (liters)	Percentage Increase Since Previous Drilling
200-West Area			
201-T tank crib	3,440,000	13,300,000	286%
241-T (2nd cycle)	None	11,200,000	
361-T cribs	8,700,000	32,600,000	275%
231 sump cribs	8,450,000	30,800,000	264%
234-5 cribs	None	3,800,000	
200-East Area			
241-B (2nd cycle)	None	7,500,000	
201-B tank crib	4,000,000	22,300,000	458%
5-6 cribs	None	18,400,000	

The smallest increase was that for the 201-T tank and 231 cribs, where more than 2.5 times the volume of wastes were discharged to the cribs as were discharged prior to drilling. The 201-B tank crib received 4.5 times the volume of waste that it had received at the time of drilling. The increase of fission product activity in the ground is far less than this as explained earlier in which a suggested equilibrium mass or amount of fission product activity is attained whereby the loss by radioactive decay equals the periodic increments. Data to be obtained from these proposed new wells will supplement existing knowledge concerning the mechanisms involved in present waste disposal methods. This information will also determine the accuracy of predictions made on the basis of previous drilling operations and should indicate whether or not such extrapolation is possible with the information that is currently available on the mechanisms of underground waste disposal. Both a time and a volume extrapolation will thus be tested.

The changing levels of activity of the sediments as the disposal units are used will be followed by analyzing samples obtained: (1) through the well casings with the sampler, (2) from the bottom of wells which bottom 20 feet beneath the 241-T 2nd cycle crib, and the No. 1 and No. 2 cribs of the 234-5 buildings, (3) from the bottom of the test holes in the 5-6W, the 241-B and T 2nd cycle tile fields, and the 241-TX tile field, and (4) from the blanks in the walls of the H.I. Shaft.

Routine sampling of the water in all the wells penetrating to water or to be drilled to water both in and outside the operating areas will be maintained as in the past. The constant monitoring of the water table both by water-stage recorders and by tape surveys will also be continued and expanded as necessary.

A large-scale series of laboratory tests are indicated, proposed or in operation, to supplement the empirical data obtained from field observations of the waste disposal operations. Foremost among these tests is a series of soil column experiments to be performed when space and manpower become available, to accurately determine the degree of fixation of the different radioactive materials in the sediments, and to determine their behavior under all possible conditions that might arise. A special laboratory is proposed to coordinate the empirical results obtained from the drilling and field studies with the theoretical results obtained from the laboratory test, and to apply the results of geologic studies to specific waste disposal problems.

A group of additional wells are proposed to be drilled in the area between North Richland and the vicinity of the 200 areas, and in Cold Creek Valley, to further extend the ground water and geologic study and to more adequately cover the fringe areas that may be affected by present or future waste disposal practices. Coincident with this and continuing well beyond it will be a continuation of the complete and thorough study of the areal and regional geology, aimed at obtaining a complete and comprehensive picture of the underlying conditions throughout the entire project area and surrounding region, both to greater depth and to a greater lateral extent.

A hand-dug and hand-timbered shaft 150 to 200 feet deep is also proposed to explore the area between the 200 areas and to obtain undisturbed samples on which numerous physical tests can be made, including permeability, porosity, specific gravity, and specific retention. The drive sampler devised by C.H. Row and discussed earlier has, however, eliminated much of the need for such an expenditure. Such a facility may be of considerable value after adequate laboratory facilities and personnel are available to conduct the necessary tests.

CONCLUSIONS

A total of 210,000,000 liters of radioactive wastes (55,500,000 gallons) were discharged to the ground up to January 1, 1950, containing about 800 grams of plutonium and 7400 curies of fission products activity. Of this total, only some of the wastes discharged to the 241-T-361A and 241-B-361 reverse wells is demonstrated to have penetrated to the water table. In no case whatsoever is plutonium known to be traveling in the ground water even though plutonium-bearing wastes were injected directly into the ground water in one instance and in another were injected within 75 feet of the water table. Such fission products as penetrated to and are traveling in the ground water are demonstrably largely of half-lives of a year or less. Evidence suggests that no hazardous condition has been or will be created by the present waste disposal practices, but close observation of the waste disposal units must be maintained by all means available to prevent the creation of a hazardous condition and to control such a condition if one should inadvertently be created.

Although present waste disposal practices appear adequate and feasible, these methods are clearly only temporary, for the possibility always exist that a

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hazard may be created that cannot be adequately controlled. Therefore, all possible means of more complete and efficient waste disposal methods must be considered toward the ultimate, if practically unattainable, goal at which no radioactive materials shall be released to the ground.

R. E. Brown

H. G. Ruppert

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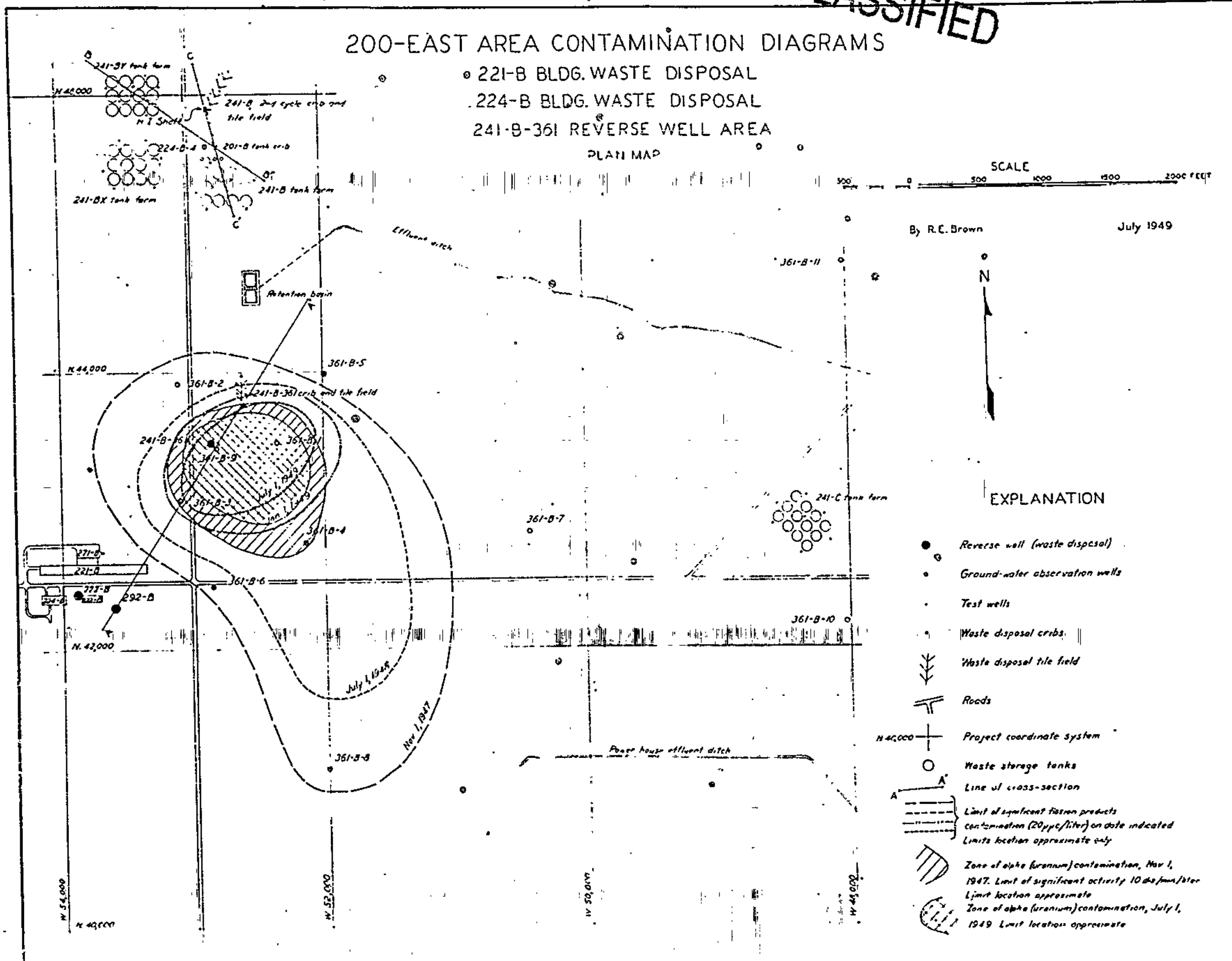

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PLATE 6

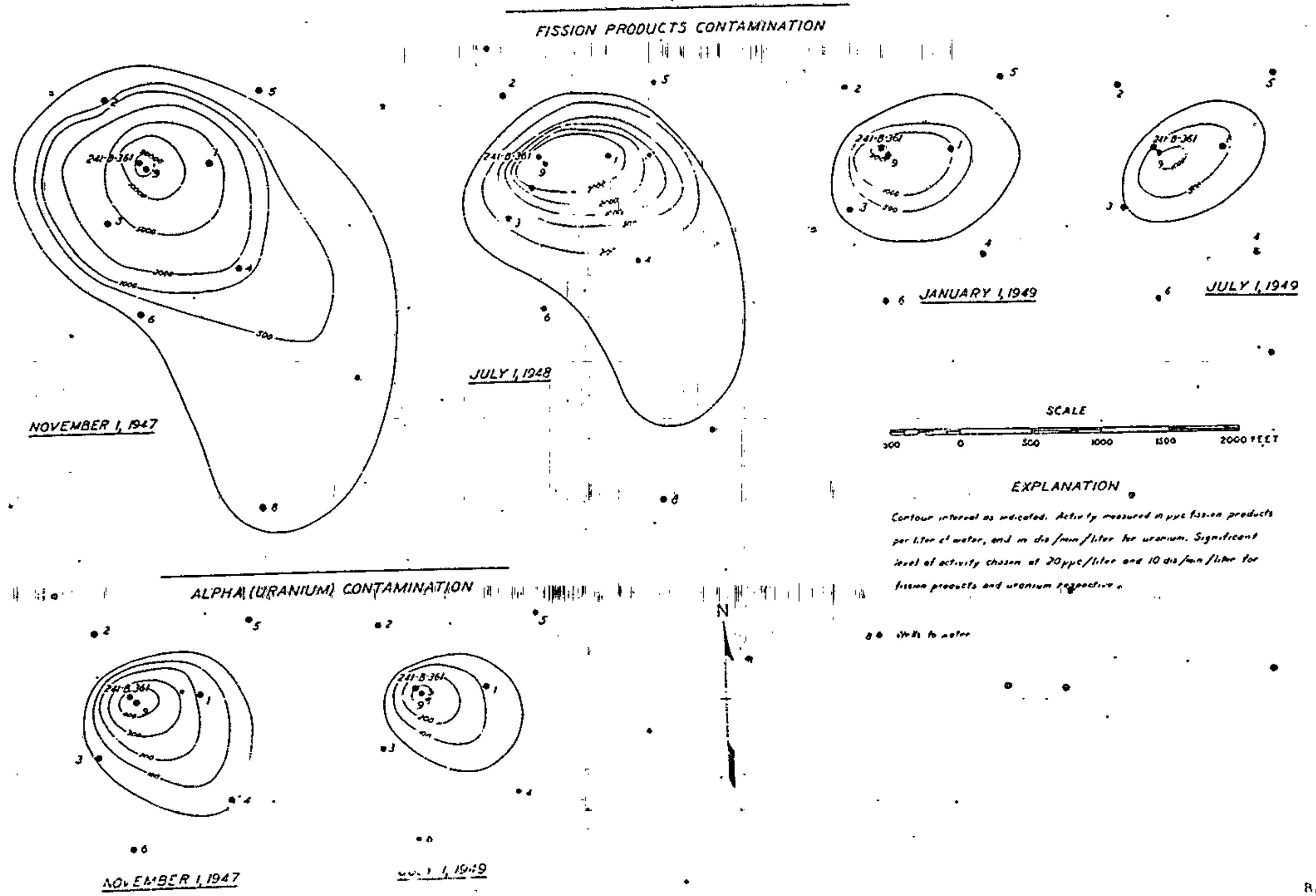
200-EAST AREA CONTAMINATION DIAGRAMS

224-B AND 221-B BLDG. WASTE DISPOSAL

241-B-361 REVERSE WELL AREA

CHRONOLOGIC CONTAMINATION CONTOUR (ISOACTIVITY) MAPS

GROUND WATER CONTAMINATION



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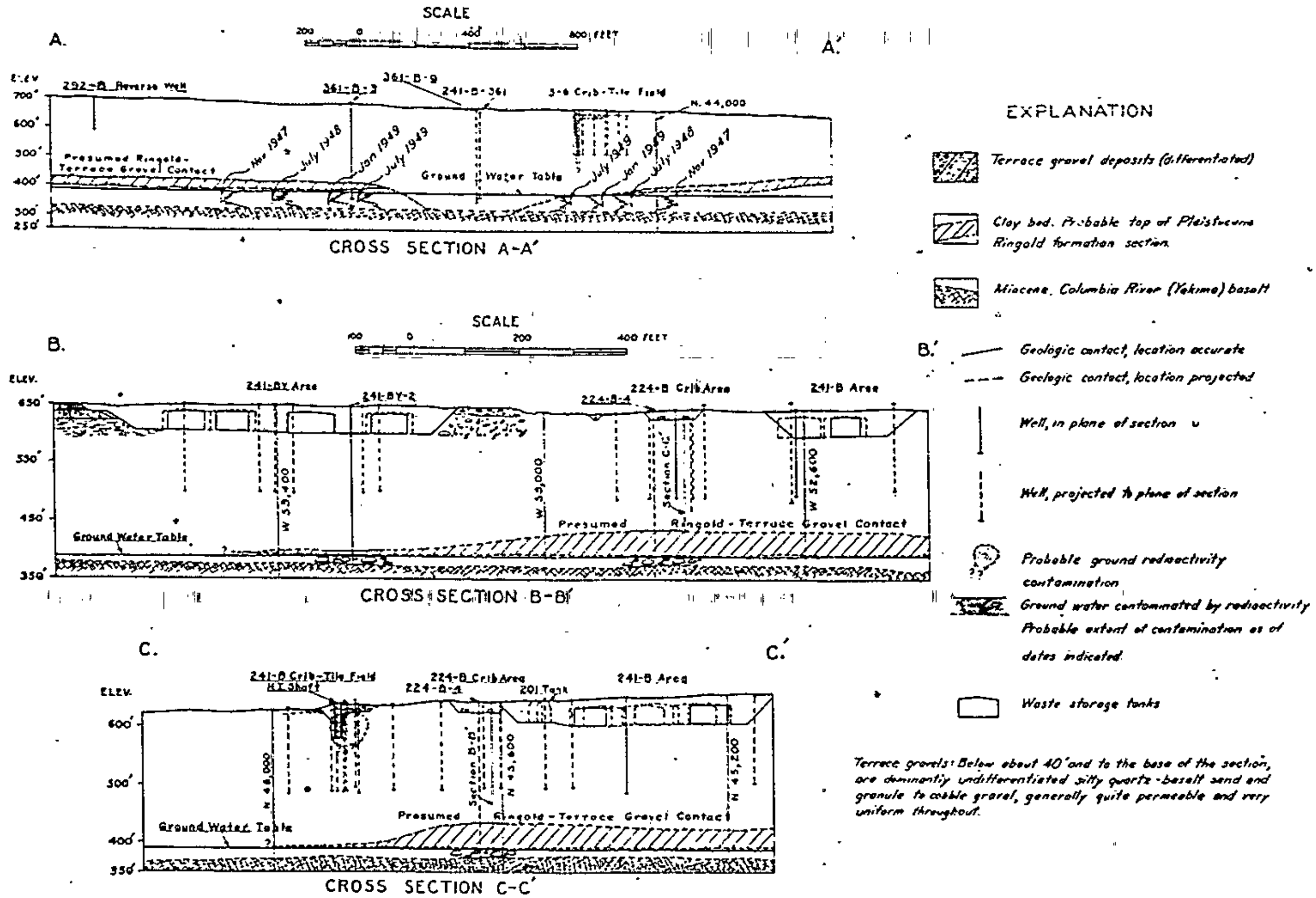
200-EAST AREA WASTE DISPOSAL DIAGRAMS

SECTIONS SHOWING GENERAL GEOLOGIC AND HYDROLOGIC FEATURES OF PART OF THE 200-EAST AREA

Datum is Mean Sea Level



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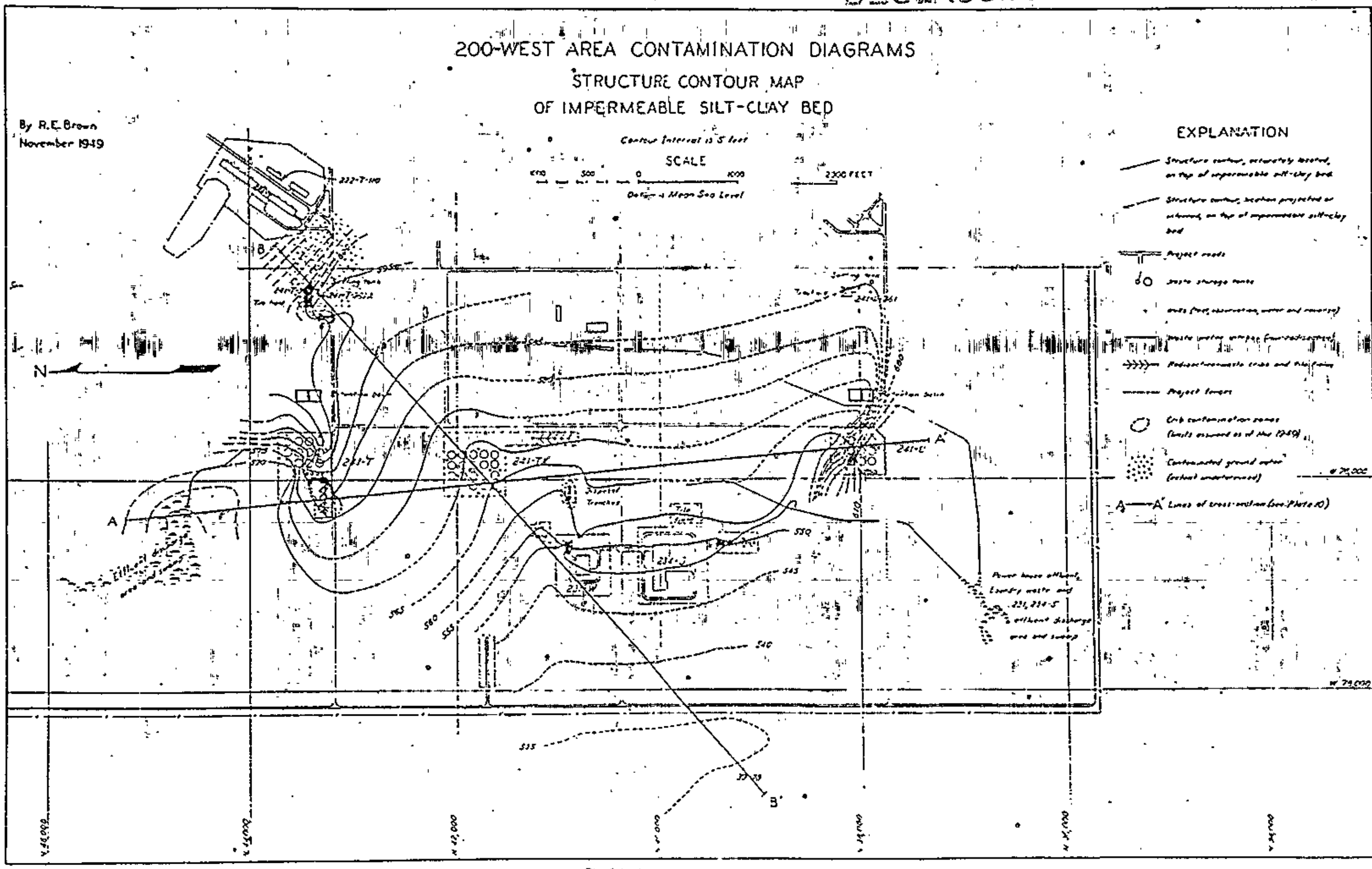
200-WEST AREA CONTAMINATION DIAGRAMS
STRUCTURE CONTOUR MAP
OF IMPERMEABLE SILT-CLAY BED
By R.E. Brown
November 1949
Contour Interval is 5 feet
SCALE
2000 FEET
Datum is Mean Sea Level
EXPLANATION
Project roads
Waste storage tanks
Project fences
Lines of cross-section (see Plate 10)
N
A
A'
B
B'
241-T
241-TX
241-U
231-Z
222-T
560
555
550
545
540
535
W 75,000
W 74,000
N 42,000

200-WEST AREA WASTE DISPOSAL DIAGRAMS

SECTIONS SHOWING GENERAL GEOLOGIC AND HYDROLOGIC FEATURES OF PART OF THE 200-WEST AREA

SCALE

500 0 1000 2000 FEET

Vertical scale is 2 times horizontal scale as indicated

Datum is Mean Sea Level

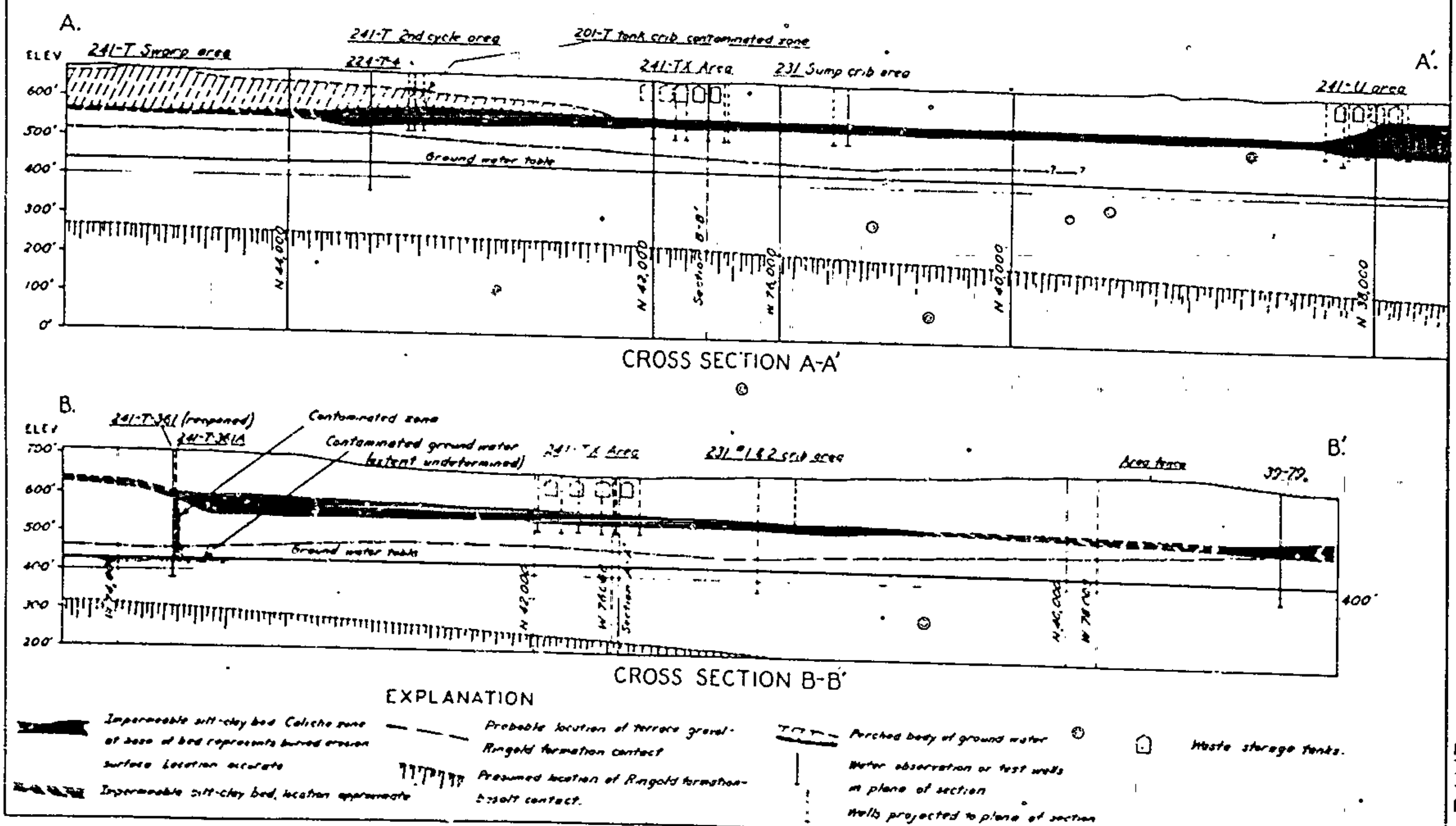

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PLATE 10

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