APPRAISAL
OF
PROPOSED LIQUID WASTE DISPOSAL
BY UNDERGROUND INJECTION

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THE ANACONDA COMPANY
NEW MEXICO OPERATIONS
GRANTS, NEW MEXICO

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Proposed Liquid Waste Disposal

In the authorized operation of uranium milling and processing facilities, located in Valencia County of northwestern New Mexico, The Anaconda Company early recognized and was confronted with the problem of acceptable and safe disposal of mill tailings water.

Water from the mill tailings collects supernatantly as a pond within the confines of a naturally depressed disposal area immediately north and adjacent to Anaconda's Bluewater Plant. The Anaconda Company and all Federal and State agencies charged with the responsibility of safeguarding the public underground water supplies of the area were aware of the possibility of local pollution by seepage from this source.

Although a continuing and comprehensive program of monitoring the surrounding domestic water supplies, started in 1957, has not indicated pollution beyond Anaconda property, an extensive research program was undertaken by The Anaconda Company to investigate various methods of disposal for the liquid waste effluent of the mill. After much investigative study and many exhaustive large-scale applications in the field, it was indicated that the most feasible and practicable method of disposal would be to inject the effluent into permeable rock formations lying protectively below the potable water aquifers.

Again at great expense and with the cooperative study and surveillance of our progress and methods by the personnel of the New Mexico Department of Public Health, New Mexico State Engineer's Office, and the United States Geological Survey, a test well was exactingly constructed within the 2,500 feet of sedimentary rocks overlaying the basement granite and, by permit of the New Mexico state authorities and the United States Atomic Energy Commission, Division of Licensing and Regulation, was tested by injecting mill tailing water into the receptive rock formations underlying the potable water aquifers for a period of 90 operating days.

Now, in compliance with the instructions of federal regulation, The Anaconda Company seeks to obtain license to continue to dispose of its mill waste water into unrestricted areas by this deep-well injection method, and, in support of its intent and request, presents herein a condensed report with confirming and informative data.

In brief, the request of The Anaconda Company to adopt and continue the disposal of mill tailing water by deep-well injection is substantiated by:

1. The geological, hydrological, and engineering practicabilities of deep-well injection established during the permissive full-scale 90-day test.

2. The favorability of all injectivity data compiled as a result of preliminary pump-in and recovery tests.

3. The protective isolation of the disposal interval by (a) extensive and intervening anhydrite, selenite, and clay beds; (b) the indicated absence of transformational communication through fracturing in the barrier interval; and, (c) the triple steel and plastic cased and cemented construction of the well through and beyond the vertical extent of the potable water aquifers.

4. The favorable permeability and broad geological extent of the disposal interval.

5. The neutralizing and ion-exchange capacity of the rocks in the disposal interval.

6. The unsuitability of the formational waters within the disposal interval for domestic use.

7. The diminutive areas to be invaded by the mill waste fluid.

8. The unlikelihood of radioactive contaminates to enter the potable water aquifers and circumvent the monitoring pattern of control in concentrations that would endanger the public safety.

I. Sources, Quantities, and Kinds of Radioactive and Chemical Materials Involved

The Anaconda Company under authority and license of the United States Atomic Energy Commission began uranium milling operations in the Grants-Bluewater area in October of 1953. The present contract between The Anaconda Company and the Atomic Energy Commission, covering the production of uranium concentrate, expires on December 31, 1966. Therefore, the life expectancy of milling operations, for purposes of this proposal, is limited to the duration of that contract. Operations may continue, however, for a number of years beyond such expiration date, in the event of favorable market conditions for uranium concentrate.

Plant facilities consist of two separate mills: the Carbonate Mill designed for alkaline-leach treatment of high-lime ores; and, the Acid Mill designed for acid-leach treatment of low-lime sandstone ores. Operation of the Carbonate Mill was suspended on May 1, 1959. The total tonnage of solid tailings and the accompanying volume of waste water going to disposal were correspondingly decreased by this curtailment.

Present plant operations are limited to the Acid Mill and the ores now treated are derived almost entirely from deposits mined by the Company and located on the Pueblo of Laguna Indian Reservation. A diagrammatic flowsheet of this milling operation, together with typical pertinent chemical, radiological, and other related data, is shown on Plate XI.

The quantity of liquid waste discharged by the mill, averaged over a full one-year period, is approximately 1,058 gallons per minute. It contains approximate concentrations of radioactive and chemical constituents as noted in the following tabulation:

Analysis of Typical Liquid Waste Accumulation

Chemical Constituents	ppm
Chloride as Cl	1,350
Sulfate as SO_4	6,450
Nitrate as NO_3	100
Sodium as Na	1,050
Calcium as Ca	550
Magnesium as Mg	550
Iron as Fe	350
Manganese as Mn	450
Total Dissolved Solids	11,000
pH	2.7

Radiological Constituents	$\mu c/ml$
Gross Alpha	2.43×10^{-4}
Uranium-natural	1.61×10^{-5}
Thorium-230	2.70×10^{-4}
Radium-226	6.62×10^{-7}

The liquid waste available to the disposal well will vary within the approximate limits of 400 gallons per minute to 990 gallons per minute, assuming uninterrupted operation of the disposal well. These fluctuations in the injection rate will result from changes in the rate of tons of ore processed, and from the varying rates of solar evaporation. The amount of waste water available to the disposal well will also be affected by a steady loss of waste water to the waste solids. Solar evaporation may increase the concentrations of radioactive constituents; however, the individual gross amounts to be disposed of by injection will probably remain quite constant, except for losses, particularly of radium, by co-precipitation with $CaSO_4$ (gypsum) in the tailing pond.

II. Analysis and Evaluation of the Environment

The disposal well is located in the Southwest Quarter (SW1/4) of Section 8, Township 12 North, Range 10 West, New Mexico Principal Meridian, approximately two miles northeast of the plant, four miles northeast of the village of Bluewater, and nine miles northwest of the town of Grants. Note Plate V and Plate VI. The area at the well site is barren grazing land, with no dwellings within a radius of two miles. Surface ownership in the immediate vicinity rests with The Anaconda Company and access is restricted.

The San Jose River Valley in the Grants-Bluewater area is a small alluvium-filled plain, within which are several Recent volcanic surface flows. It is bounded on the south by the Zuni Mountains, which are a northwest-trending core of pre-Cambrian crystalline rocks. Sedimentary rocks dip north and northeast off the northeast flank of the mountains into the San Juan Basin, in successively younger strata ranging in age from what is believed to be Pennsylvanian through Upper Cretaceous. Note Plate VI and Plate VII for surface geology. Plate VIIA illustrates by cross section the local dip. The softer sediments have been eroded into troughs that are bounded by cuestas of more resistant rocks. The San Jose River Valley is one of these larger troughs, caused by the erosion of lower Triassic (Chinle Formation) shales.

The average elevation of the Zuni Mountains is about 7,000 feet, and the average elevation of the San Jose River Valley in the plant area is about 6,500 feet. Mount Taylor, an extinct volcano, is located about 18 miles east of the plant site. It has a maximum elevation of 11,389 feet, and its flanking foothill mesas have an average elevation of about 8,600 feet.

Rainfall throughout the area is directly related to altitude. In the San Jose River Valley, annual rainfall is seven to ten inches, while in the Zuni Mountains, the Mount Taylor foothill mesas, and the surrounding high cuestas the annual rainfall is from 14 to 18 inches. Approximate areal limits for these estimated quantities of rainfall are illustrated on Plate VI. The prevailing wind is westerly, with lesser periods of wind from the south, north, and east, in that order. The average annual wind velocity is about five miles per hour, with the greatest amount of wind occurring during the spring months. The average annual temperature is about 47° to 52° Fahrenheit.

Surface drainage into the San Jose River Valley is illustrated on Plate V. Updrainage from the town of Grants, the San Jose River and its tributaries are intermittent with periods of surface flow occurring only after thundershowers. Downdrainage--from Grants, the minimal surface flow is proportional to the amount of flow emanating from the alluvium in the form of springs, and the sewage effluent from Grants' sewage processing plant.

The principal aquifers in the Grants-Bluewater area are the alluvial valley fill and the sedimentary rocks of the Dakota Formation, Morrison Formation (Jurassic), Chinle Formation, San Andres Formation, Yeso Formation, Abo Formation, and what has been tentatively identified as the Madera Formation, in that descending stratigraphic order, as shown in the legend of Plate VII. The principal sources of potable water are found in the alluvium, Dakota, Morrison, Chinle and San Andes formations. The San Andres Formation (Permian), including the Glorieta, is the largest aquifer, and supplies the bulk of the water for industrial, agricultural and domestic uses.

The Yeso, Abo and Madera formations are stratigraphically below the San Andres, and contain, with the minor exception near their outcrops, saline and brackish waters unsuited to industry, agriculture, or human consumption.

The San Andres Formation is exposed to recharge over a wide area of the north flank of the Zuni Mountains, and potable water is found in this aquifer only in comparative proximity to this recharge area. Downdip (to the north and northeast) the quality of water in all aquifers deteriorates markedly with distance from their recharge areas. The recharge area of the Yeso, Abo and Madera formations is small. Recharge from Mount Taylor is probably significant to the runoff downstream from Grants and to the aquifers downdip north of Grants.

The combination of increased demands for water by the uranium industry and a current cycle of abnormally sparse precipitation has resulted in a pronounced lowering of the water level in the San Andres Formation. The agricultural industry is decreasing; consequently, the water demand is becoming less for farming purposes. Disregarding local cones of depression due to producing wells, the San Andres-Glorieta aquifer (San Andres Formation) has an average hydrostatic gradient decreasing to the southeast at a rate of about six feet per mile between Bluewater and Grants. It is assumed that the isolated Chinle aquifers have a hydrostatic gradient influenced by local withdrawal, but that their gradient between Bluewater and Grants, if undisturbed, would be similar to the gradient in the San Andres Formation.

The Yeso, Abo and Madera formations are assumed to have a gradient similar to, but much lesser in slope than, the gradient of the San Andres Formation.

III. Usage of Ground and Surface Water

Consumption of underground water in the Grants-Bluewater area is estimated to be about 4.3 billion gallons per year. Plate VI shows the location of the major users of this water, i.e., the Bluewater-Toltec Irrigation District, the five uranium ore milling plants, and the centers of population. The tabulation below shows the distribution of underground water consumption among the main users. The quantities shown are estimates made by The Anaconda Company and are only approximations.

Use	Aquifer		Approximate Gal. per Yr.	Per Cent of Total Used
Irrigation	San Andres-Glorieta	)		
	Chinle (negligible amt.)	)	1,954,972,850	45.2%
	Alluvium (negligible amt.)	)		
Total - Irrigation			1,954,972,850	45.2%
Uranium Industry				
Anaconda and Homestake Uranium Plants	San Andres-Glorieta		709,797,250	16.4%
Kermac and Phillips	Morrison	)		
Uranium Plants	Dakota	)	948,792,680	21.9%
Total - Uranium Industry			1,658,589,930	38.3%
General Consumption by Area Residents				
Town of Grants	San Andres-Glorieta	)		
	Chinle	)		
	Alluvium	)	419,750,000	9.7%
Village of Milan	San Andres-Glorieta		127,000,000	2.9%
Misc. Population -	San Andres-Glorieta	)		
Prewitt to McCarty	Chinle	)		
	Alluvium	)	125,580,000	2.9%
McCarty to Cubero	Dakota	)		
	Alluvium	)	41,975,000	1.0%
Total - General Consumption			714,305,000	16.5%
Total All Users			4,327,867,780	100 %

Surface waters used in the area consist mainly of an undetermined amount of precipitation runoff which is impounded in earthen reservoirs and used chiefly for watering livestock. Bluewater Lake, located approximately eight miles west of The Anaconda Company plant, was developed for irrigating farms in the Bluewater-Toltec Irrigation District. However, the water accumulation in the lake is seldom sufficient to economically justify its use in irrigation. In the area between Grants and Laguna (note Plate VI) the waters from the San Jose River and its intermittent tributaries are used, to a very limited extent, for irrigation.

IV. Proposed Method and Supporting Criteria of Disposal

A. Anticipated Operating Procedure:

The liquid waste from the mill will be impounded in a settling and holding reservoir. This waste water will be decanted from the reservoir, filtered to approximately 0.5 ppm undissolved solids, treated with a polyphosphate sequestering agent and a fungicide, and then pumped to the disposal well. The waste water will be released at the well collar in a closed system. Due to the disposal aquifers' static water level of 238 feet and high transmissibility, no surface injection pressures are thought to be necessary at the lower rates of injection. Low injection pressures, however, may be necessary at high rates of injection and during the latter period of the well's life, due to head losses in the well bore and at the immediate sand face.

B. Disposal Well Construction:

The disposal well was constructed with materials and by methods consistent with proper oil field and water well practices. The entire construction program, including the test injection was conducted with complete knowledge and approval of the agencies of the State of New Mexico charged with such supervision. Plate I illustrates the construction of the disposal well.

C. Geology and Hydrology of the Disposal Well:

Data obtained from the test well assist considerably in the geological evaluation of the proposed method of disposal. Plate II illustrates the rock types cored in the well. The local stratigraphic names and geologic age relationships for the rock units are also shown. Essentially the well may be divided into three intervals: the potable water interval (0 to 638 feet), the barrier interval (638 to 950 feet), and the disposal interval (950 to 1,778 feet).

1. Potable Water Interval:

The largest source of potable water in the area is the San Andres Formation which is composed of fractured San Andres limestone and the Glorieta sandstone. Numerous aquifers exist between the San Andres and the surface of the ground, and in general the quality of their waters is somewhat better than the waters contained in the San Andres-Glorieta aquifer. These shallow aquifers occur in the sandstones of the Chinle Formation and at the base of the surface alluvium. Transmissibility of water through the limestone facies of the San Andres-Glorieta aquifer is exceptionally high, because of the intense fracture and solution-channel systems present, and is believed to be many times greater than that of the disposal zones.

Plate III shows the chemical and radiological analyses of San Andres-Glorieta water and the interval which was isolated for sampling. Although the water sample was taken from the sandstone facies of the aquifer, it is believed that the quality of the water in the sandstone facies is nearly the same as that of the water in the limestone facies at any given locality. Plate IV shows the results of the drill-stem test on the interval 493 feet to 573 feet which reflects the formation pressure for the entire San Andres-Glorieta aquifer. The results of laboratory core analyses, for permeability (to air) and porosity of specific samples, are also shown on Plate IV.

2. Barrier Interval:

The barrier interval, which separates the potable water interval from the disposal interval, occurs between the hole depths of 638 feet and 950 feet. This zone is thought to extend over a relatively broad area. The presence and extent of this barrier interval, with its included evaporites, was determined by the interpretation of electric logs taken from the following wildcat oil tests:

Well	Location* Sec.	Twp.	Rge.	Distance from Disposal Well	Direction from Disposal Well
Dysart Federal #14-1	14	14N	10W	11 Miles	N
Great Western Hospah #1	1	17N	9W	32 Miles	NNE
Superior San Mateo Gov't #1-14	14	14N	8W	19 Miles	NE
Richfield Drought-Booth #1	4	15N	6W	31 Miles	NE
Humble Santa Fe-Pacific #1	20	14N	1W	55 Miles	NEE
Gore N.M.-Ariz. Land Co. #1	27	7N	4W	51 Miles	SE
Byron Gore Federal #1	26	7N	4W	52 Miles	SE
Larrazolo & Cornell Gottlieb #1	21	10N	9W	16 Miles	SSE
Tidewater-Mariano Dome #1	8	15N	13W	25 Miles	NW

* New Mexico Principal Meridian

Surface reconnaissance has also disclosed the presence of the evaporite sequence along outcrops approximately 11 to 12 miles south and southwest of the disposal well. The outcrops are at sufficient elevation to prevent any surface effects of the disposal operations. Plate IV shows the permeability (to air) and the porosity results obtained from laboratory analyses on core samples. Reference to Plate III and Plate IV will show the negative results of drill-stem tests and swabbing (pumping) tests for specific zones tested in this interval. Reference to Plate II will show the abundance of anhydrite ($CaSO_4$) and selenite ($CaSO_4 \cdot 2H_2O$). The aggregate thickness of anhydrite beds in the barrier interval amounts to approximately 29 feet. Estimated aggregate thickness of the selenite seams is about eight feet. The selenite occurs at random angles to the bedding and fills joints and openings. These occurrences illustrate the plugging ability of $CaSO_4$ when it occurs in a saturated concentration in ground water solutions. Invading waters would become saturated with $CaSO_4$ and further progress would be impeded by precipitation of selenite (gypsum). The presence of an aggregate thickness of approximately 11 feet of interbedded clays in the barrier interval will also tend to prevent vertical communication of ground waters.

Ion-exchange tests by The Anaconda Company and data obtained from other sources indicate the probability of reduction in radioactive constituents if the mill waste fluids should come into contact with the rocks of the barrier interval. Test data available do not indicate the upward migration of the waste fluid into the barrier interval. However, calculations using idealized conditions have been made simply to illustrate the beneficial effects that the rocks would have in removing radioactive constituents. Applying the ion-exchange capacity of the barrier interval to the full volume of mill waste water, it is indicated, as developed in Appendix A, that the soluble radium injected into the well would be captured within the first 0.006 inch of barrier interval rock. Furthermore, in a similar idealized illustration it is indicated that the acidity of the total quantity of mill water injected over a period of seven years would be completely neutralized by the first 15 inches of barrier interval rock and that within this depth the thorium-230 will be essentially removed from solution. The full development of this determination is also shown in Appendix A.

3. Disposal Interval:

The hole interval between 950 feet and 1,778 feet has been selectively perforated to allow for the injection of the mill waste fluid. The interval below 1,798 feet was plugged back because of the imperviousness of the rock. Reference to Plate I will show the location of the perforated zones within the over-all disposal interval. The zones were selected for perforating according to their permeability and porosity as determined by laboratory tests. Note Plate IV. Stratigraphy and lithology of the disposal interval may be seen on Plate II. The distribution of the injection flow into the perforated zones was determined by a spinner survey. Reference to Plate X will show the percentage distribution of the flow, and it will be noted that it is nearly constant for all rates of injection. The combined zones from 1,254 feet to 1,423 feet (Meseta Blanca) appear to be taking approximately 63 per cent of the total injected flow. The zone 1,088 feet to 1,132 feet is taking approximately 19 per cent of the total flow but because of its being a thinner sand bed, it is believed that this zone will carry the most advanced flood front. The perforated zones below 1,423 feet do not appear to be taking any injection fluid. Although some perforations may not be taking fluid because of plugging or other reasons, it is believed that, in the zone between 950 feet and 1,480 feet, approximately 420 feet of combined sandstones are taking the injection fluid.

The areal distribution of the principal disposal aquifer, the Meseta Blanca, has been investigated. This unit outcrops approximately

12 miles and 14 miles southwest and south respectively from the disposal well site and is also evidenced in electric logs taken from the following oil test wells:

Well	Location* Sec.	Twp.	Rge.	Distance from Disposal Well	Direction from Disposal Well
Dysart Federal #14-1	14	14N	10W	11 Miles	N
Great Western Hospah #1	1	17N	9W	32 Miles	NNE
Superior San Mateo Gov't #1-14	14	14N	8W	19 Miles	NE
Richfield Drought-Booth #1	4	15N	6W	31 Miles	NE
Larrazolo & Cornell Gottlieb #1	21	10N	9W	16 Miles	SSE
Tidewater-Mariano Dome #1	8	15N	13W	25 Miles	NW

* New Mexico Principal Meridian

The chemical and radiological quality of the water samples taken from the disposal interval may be seen on Plate III. The waters were found to be unsuitable for domestic appropriation. The formation static water levels as interpreted from the drill-stem tests in the disposal interval may be seen on Plate IV.

The salinity of the ground water in the disposal aquifers indicates the likelihood of extremely slow or negligible water movement.

Removal of radium-226 by ion-exchange, with the disposal interval rocks, was investigated by two methods, the Schollenberger-Simons Method on pulverized clay core samples and the direct flooding of a segment of core with the mill waste fluid. The exchange capacities for samples tested by the Schollenberger-Simons Method may be seen in Appendix B. A brief description on the laboratory core flood test and an illustration showing the generalized peripheries, under various assumed conditions, for radium-226, using these laboratory ion-exchange data, is also set out in Appendix B. Although the laboratory data and the generalized illustrations have their practical limitations it is indicated that the disposal interval environment will very effectively remove radium-226 from the mill waste fluid.

Reduction of dissolved thorium-230, from uranium mill acidic wastes, to permissible levels has been demonstrated by the National Lead Company. Its findings indicate that neutralization of the acidic waste fluids to a pH of about 7 will result in the precipitation of nearly all of the soluble thorium-230. Laboratory data that demonstrate the neutralizing effect of the disposal interval rocks upon the mill waste fluid and an idealized illustration showing the relatively insignificant invasion radii of the acidic (less than pH 7) phase that would result from the injection of mill waste fluid are shown in Appendix B.

In order to provide a means for the detection of direct cross-formational communication, a monitor well was constructed into the San Andres Formation adjacent to the disposal well. Appendix B sets out data and analyses of water samples taken from the monitor well.

Operation of the disposal well was precisely observed during the 90-day test period. Records were kept of the water levels within the well bore to show both injection build-up pressures and recovery fall-off pressures that occurred during active injection and during periods of shutdown. These data were plotted on semilogarithmic graph paper and analyzed for apparent disposal interval transmissibility, well-bore damage, injectivity, and reservoir life expectancy.

No apparent cross-formational flow is indicated either in the monitor well samplings or in the studies that have been made of the injection and recovery curves of the disposal well.

These and all other data pertinent to the disposal project have been examined by the officially concerned New Mexico state agencies and by the Albuquerque office of the Ground Water Branch of the United States Geological Survey.

The extent of radiological penetration within the disposal interval will be relatively small over the expected life of present milling operations. Considering the probable irregularities in the pattern of dispersion of the mill waste fluid in the disposal interval, the affected area is expected to be less than four square miles. Reference to Plate VIII will show the idealized radii to the waste fluid periphery under maximum assumed conditions of flow and restricted dispersion from the disposal well. The post-injection movement of radioactive materials is not expected to be appreciable because of the preponderance of ion-exchange sites and neutralizing constituents within the disposal interval rocks.

V. Procedures to be Observed to Minimize the Risk of Unexpected or Hazardous Exposures

The Anaconda Company plans to continue its present water monitoring program as outlined in Plate IX. The locations of the monitor wells or springs, as the source may be, are illustrated on Plate VIII. The analyses of water samples taken from these sources will be forwarded to the New Mexico Public Health Department for their perusal. As a part of this monitoring program a water well was constructed adjacent to the disposal well for the sole purpose of observing the chemical and radiological behavior of the San Andres-Glorieta water in the immediate area. This well is referred to on Plate IX as Monitor Well No. 1, and further reference to it has been made in Appendix B.

The water levels on the North Well, Berryhill Sec. 5 well, and Monitor Well No. 1 (Note Plate VIII and Plate IX) will be taken at appropriate intervals to monitor pressure buildup. Water levels on specific wells in the Grants-Bluewater area are normally taken by the United States Geological Survey as a part of their ground water program. The pressure build-up curve in the disposal well will also be developed as injection of mill waste fluid continues.

It is believed that this monitoring program is adequate to detect any intermingling of mill waste water with the potable waters, well in advance of any hazardous, radiological concentrations at points of appropriation.

APPENDIX A

Barrier Interval -- Laboratory Data and Development of Idealized Calculations Illustrating the Favorable Characteristics of the Rocks Relative to the Removal of Radium-226 and Thorium-230 from the Mill Waste Water

Radium-226, Ion Exchange by Schollenberger & Simons Method:

The following table lists the laboratory results of ion-exchange tests on samples of claystone taken from the barrier interval. Sample locations are shown graphically on Plate II.

ION-EXCHANGE DETERMINATIONS BY SCHOLLENBERGER & SIMONS METHOD

Sample Number	Well Footage	Laboratory MEQ NH4/gram	Calculated grams Ra/cu.ft.*
P1	625	0.087	669
P2	627	0.057	438
P2A	648	0.041	315
P2B	654	0.124	954
P2C	667	0.122	938
P3	694	0.073	561
P4	704	0.094	723
P7	810	0.006	46
P8	812	0.349	2,684
P9	859	0.350	2,692
P10	862	0.024	185
P12	917	0.076	584
		Average	899

* Sp. Gr. 2.40, 150 lbs./cu.ft.

DESCRIPTION OF METHOD OF SCHOLLENBERGER AND SIMONS (SOIL SCIENCE, VOL. 59, PP. 13-24, 1945) USED BY DR. H. WALTON, PETROLEUM RESEARCH CORPORATION.

1. The sample is pulverized and saturated with a weighed portion of ammonium acetate solution. This removes all replaceable adsorbed ions by replacement with the ammonium ion.

2. Sample is filtered out and treated with ethyl alcohol to remove the excess ammonium acetate, leaving a residue of ammonium clay.

3. The ammonium clay is treated with sodium hydroxide and steam distilled in a suitable apparatus allowing the liberated ammonia gas to

be condensed in a normal acid solution. Titration of the normal acid determines the amount of ammonium ion associated with the clay and hence the ion exchange capacity in milliequivalents per gram of clay or rock.

It should be pointed out that the Schollenberger-Simons Method as applied here, does not simulate actual field conditions, and that, therefore, the above table probably does not reflect true ion-exchange capacities of the rocks for radium. The table is presented merely to illustrate a qualitative relationship between the rocks and cations, specifically radium cations. However, these clays even though they may have a comparatively small ion-exchange effect because of the relatively limited exposure of contact area to the injected fluid as a result of low rock porosity, will have a significant removal effect on certain cations in the mill waste fluids simply because of their great mass in comparison to the number of exchangeable cations in solution.

Calculations, of a theoretical nature, illustrating the insignificant depth of barrier interval rock required to capture by ion exchange the radium injected into the disposal interval for seven years using the results from the foregoing table as the basis for the calculations, are shown here.

*Premise:

(1) Daily output of soluble radium from milling, averaged over one full year: 40×10^{-4} grams.

(2) Uniform vertical formation transmissibility of the barrier interval and uniform invasion by the injected mill waste fluid.

(3) Ion-exchange capacity of the barrier clays determined by laboratory test:

899 gm Ra/cubic foot.

(4) Radius of injected mill waste fluid flood front in seven years: 1,400 feet.

(5) Average clay content of barrier rock: 3.5%.

* Certain conditions are assumed and/or generalized.

Calculations:

(1) Total radium available:

40×10^{-4} gm x 365 days x 7 years = 10.2 grams

(2) Ion-exchange capacity of barrier rocks after reducing test value by an arbitrary factor of 10,000:

$$\frac{899 \text{ gm Ra}}{10{,}000} \times 3.5\% = 31 \times 10^{-4} \text{ gm Ra/cubic foot}$$

(3) Volume of rock required to capture all of the radium:

$$\frac{10.2 \text{ gm Ra}}{31 \times 10^{-4} \text{ gm Ra/cu.ft.}} = 3.29 \times 10^{3} \text{ cubic feet}$$

(4) Area of barrier interval exposed to waste fluid for vertical transmission:

$$3.14 \times (1{,}400)^2 = 61.5 \times 10^5 \text{ square feet}$$

(5) Depth of barrier interval required to capture by ion exchange the radium entering the disposal well:

$$\frac{3.29 \times 10^3}{61.5 \times 10^5} = 0.0005 \text{ foot} = 0.006 \text{ inch}$$

The foregoing calculation emphasizes the importance of the ion-exchange relationship.

Thorium-230, Precipitation by Neutralization:

Data are available which indicate that thorium-230 is precipitated and thus removed from acidic mill waste fluids by neutralization. The barrier interval contains an estimated aggregate thickness of 18.4 feet of limestone. Limestone ($CaCO_3$) whether in consolidated limestone beds or disseminated in other rocks will neutralize acidic mill waste fluids. It is possible to show, by theoretical calculation, that the amount of barrier interval rock required to neutralize the mill waste fluids is not appreciable when compared to the total rock volume available. Such calculation follows, illustrating the depth of barrier interval rock required to neutralize to a pH of 7 all of the waste fluid injected and precipitate thorium-230 from the mill waste fluid:

*Premise:

(1) Concentration of available acid in mill waste fluid: 0.02 lb./gal. (assumed to be entirely sulphuric).

(2) Rate of injection into well: 990 gal./min. for a period of seven years.

(3) Radius of injected mill waste fluid flood front at the end of seven years: 1,400 feet.

(4) Neutralizing capacity of the 325.6-foot barrier interval, calculated by assuming that the known 18.4 feet of limestone contained in it is disseminated throughout (specific gravity 2.6):

9.5 lbs. acid per cubic foot of barrier interval. (Generalizing that neutralization results in a pH of 7.)

Calculations:

(1) Total amount of available acid injected:

$$990 \text{ gpm} \times 1{,}440 \text{ min.} \times 365 \text{ days} \times 7 \text{ years} \times 0.02 \text{ lb./gal.} = 72.85 \times 10^6 \text{ lbs.}$$

(2) Volume of rock necessary to neutralize total amount of acid:

$$\frac{72.85 \times 10^6}{9.5} = 7.6 \times 10^6 \text{ cubic feet.}$$

(3) Area of barrier interval exposed to vertical migration:

$$3.14 \times (1{,}400)^2 = 6.15 \times 10^6 \text{ square feet.}$$

(4) Depth of barrier interval to neutralize the acidic phase (less than pH 7) of the mill waste fluid:

$$\frac{7.6 \times 10^6}{6.15 \times 10^6} = 1.23 \text{ feet} = 15 \text{ inches.}$$

* Certain conditions are assumed and/or generalized.

APPENDIX B

Disposal Interval -- Laboratory and Field Data and Supplemental Idealized Calculations Illustrating the Radial Periphery of Radium-226 and Thorium-230

Radium-226, Ion Exchange by Schollenberger & Simons Method:

The following table lists the laboratory results of ion-exchange tests on samples of claystone taken from the disposal interval. Reference to Plate II will show the location of the core intercepts of these samples.

ION-EXCHANGE DETERMINATIONS BY SCHOLLENBERGER & SIMONS METHOD

Sample Number	Well Footage	Laboratory MEQ NH_4/gram	Calculated grams Ra/cu.ft.*
P13	1035	0.059	454
P14	1215	0.182	1,400
P15	1238	0.193	1,484
P16	1549	0.092	707
P17	1574	0.145	1,115
P18	1591	0.145	1,115
P19	1622	0.118	907
P20	1666	0.128	984
P21	1708	0.162	1,246
P22	1766	0.102	784
		Average	1,020

* Sp. Gr. 2.40, 150 lbs./cu.ft.

As mentioned in Appendix A, the Schollenberger-Simons Method, as applied here, does not simulate actual field conditions. However, the actual ion-exchange capacities of the rocks of the disposal interval, even if much less than those shown in the table, would be adequate in view of their tremendous volume. Reference is made here to Appendix A for an idealized development and illustration of the significant effect that rocks, with similar exchange capacity, will have on the radium-226 injected. Although Samples Nos. P16 through P22 were taken from points below the zone of injection, as indicated by the spinner survey, the results are shown in the table for illustrative purposes.

Radium-226, Ion Exchange by Core Flooding:

The core flood test for radium removal from the injected fluid was conducted in the laboratory on a 9.5 inch length of core which was lithologically similar to the entire Meseta Blanca interval. A volume of 58,570 cubic centimeters of mill waste fluid was injected and passed through the core. Selected samples of this effluent were assayed and compared for radium content. The core was also assayed for residual radium. Based on the results of this test, and assuming an average specific gravity of 2.6 for the disposal zone rocks, it appears that approximately 9.66×10^{-8} grams of radium per cubic foot of rock could be expected to be removed by ion exchange from the mill waste fluid passing through the rock. The following table illustrates the idealized radii of dispersion of radium-226, under various assumed conditions, based on the ion-exchange value of 9.66×10^{-8} grams per cubic foot. Only two disposal zones were chosen to illustrate the invasion by radium-226. These two zones combined take about 82 per cent of the total injected flow. The radium has been prorated according to the distribution of the flow.

Limiting Radii of Radium-226 Dispersion
Seven-Year Period of Injection

Radial Dispersion	360°			
% Rock Porosity Used	100%		60%	
Rate of Injection	400 gpm	990 gpm	400 gpm	990 gpm
Zone A	383 ft.	383 ft.	493 ft.	493 ft.
Zone B	305 ft.	305 ft.	394 ft.	394 ft.

Radial Dispersion	90°			
% Rock Porosity Used	100%		60%	
Rate of Injection	400 gpm	990 gpm	400 gpm	990 gpm
Zone A	765 ft.	765 ft.	986 ft.	986 ft.
Zone B	610 ft.	610 ft.	787 ft.	787 ft.

Zone A interval = 1,088 ft. - 1,132 ft., the zone of maximum penetration of fluids. Average rock porosity = 16%.

Zone B interval = 1,254 ft. - 1,480 ft., the zone of maximum fluid flow. Average rock porosity = 22%.

The repetition of radii for the different injection rates is explained by the fact that there will be a near constant quantity of radium, though at varying concentrations, going to the disposal well. The fluctuations in the concentration of soluble radium-226 will be caused primarily by solar evaporation and co-precipitation with $CaSO_4$, in the tailing pond. Plate VIII illustrates the location of the idealized periphery of the radium dispersion for the maximum anticipated injection rate, utilizing 60 per cent of the total disposal rock porosity available.

Thorium-230, Precipitation by Neutralization:

The neutralizing capacity of the rocks in the disposal interval was found, by laboratory tests, to be sufficient to readily neutralize, within a short distance, the invading mill waste fluid. Inserted hereinafter is a tabulation showing the core samples tested, calcium carbonate content, magnesium carbonate content, hole footage represented by the core sample, and the calculated pounds of acid (assumed to be entirely sulphuric) neutralized by a cubic foot of the sample tested. The amount of acid consumed by minor rock constituents, the difference in equivalent weights of the available acid, the calcium carbonate, and the magnesium carbonate, and any chemical buffering effect that may develop during the reaction, are not accounted for in this tabulation and subsequent illustrations. Plate II shows the location of the core intercepts of the core samples listed in this table.

PARTIAL CHEMICAL ANALYSES OF DISPOSAL WELL CORE SAMPLES TO DETERMINE ESTIMATE OF CALCIUM AND MAGNESIUM CARBONATE CONTENT

Sample No.	Depth Ft.	Per Cent 1/ Calcium Carbonate	Per Cent 1/ Magnesium Carbonate	Per Cent 1/ Core Acid Soluble	Per Cent 1/ Core Acid Insoluble	Footage, Sample Represents 2/	Pounds of H_2SO_4 Neutralized Per Cu.Ft. 3/
1A	953.4	4.85	1.76	10.26	89.74	22	11.08
5A	997.8	1.25	4.42	11.84	88.16	40	9.51
8A	1028.9	6.46	2.88	15.02	84.98	37	15.66
10A	1064.7	2.60	2.93	8.24	91.76	20	9.27
12A	1102.5	9.50	2.62	13.62	86.38	41	20.33
14A	1124.8	2.55	3.56	10.82	89.18	15	10.25
17A	1182.5	3.70	2.55	15.77	84.23	36	10.48
19A	1206.5	0.98	1.86	11.49	88.51	39	4.76
21A	1267.4	7.50	5.38	15.81	84.19	56	21.60
26A	1322.0	2.60	2.59	7.55	92.45	44	8.70
29A	1351.6	1.15	1.00	4.86	95.14	27	3.61
31A	1383.4	1.25	0.59	3.69	96.31	35	3.09
34A	1412.7	1.12	1.03	3.99	96.01	35	3.61
38A	1450.8	1.10	1.10	4.39	95.61	35	3.69
41A	1489.9	5.70	7.94	17.11	82.89	7	22.87
42A	1523.7	5.20	5.14	14.38	85.62	9	17.34
43A	1558.3	0.48	0.66	5.63	94.37	15	1.91
44A	1613.4	7.85	6.11	18.62	81.38	14	23.41
46A	1637.5	14.59	11.65	31.98	68.02	9	44.00
47A	1718.7	1.90	1.83	6.93	93.07	16	6.26
48A	1773.8	0.90	1.55	4.56	95.44	11	4.11
				Weighted Average			7.77

1/ Dry weight basis; samples dried @ 180° F. for 30 minutes.
2/ Footages assigned through examination of permeability and porosity log.
3/ Generalized basis; (1) One pound of carbonates will neutralize (pH=7) one pound of H_2SO_4, in weak solutions.
(2) Sand grain specific gravity = 2.6, density = 167.7 lb./cu. ft.
(3) All available acid is assumed to be sulphuric.

Utilizing the results from the foregoing table it was determined by test that approximately 388.5 gallons of mill waste fluid could be neutralized to a pH of 7 by each cubic foot of disposal interval rock. The following tabular presentation illustrates the idealized radii of the periphery of the acidic phase of the injected mill waste fluid, under various assumed conditions and using the figure of 388.5 gallons of waste fluid per cubic foot of rock. Certain conditions are assumed and generalized.

Radii to Neutral Front Where pH of Acidic Injection Fluid Has Been Raised to Approximately 7 and the Thorium-230 Has Been Essentially Removed. Seven-Year Period of Injection.

Radial Dispersion	360°			
% Rock Porosity Used	100%		60%	
Rate of Injection	400 gpm	990 gpm	400 gpm	990 gpm
Zone A	72 ft.	114 ft.	93 ft.	147 ft.
Zone B	58 ft.	91 ft.	75 ft.	118 ft.

Radial Dispersion	90°			
% Rock Porosity Used	100%		60%	
Rate of Injection	400 gpm	990 gpm	400 gpm	990 gpm
Zone A	145 ft.	228 ft.	187 ft.	294 ft.
Zone B	116 ft.	183 ft.	150 ft.	236 ft.

Zone A interval = 1,088 ft. - 1,132 ft., the zone of maximum penetration of fluid. Average rock porosity = 16%.

Zone B interval = 1,254 ft. - 1,480 ft., the zone of maximum fluid flow. Average rock porosity = 22%.

Zone A + Zone B = 82% of total injection flow.

Reference to Plate VIII illustrates the location of the periphery of neutralization for the maximum anticipated injection rate, utilizing 60 per cent of the total disposal rock porosity available.

In support of the thorium-230 precipitation-by-neutralization concept, reference is made to the following report:

Winchester Laboratory Topical Report 112
January 1960
National Lead Company, Inc.
For the
U. S. Atomic Energy Commission
Under Contract AT(49-6)924

San Andres Monitor Well:

A monitor well, located approximately 300 feet southeast of the disposal well, was completed into the San Andres-Glorieta aquifer during the 90-day injection test. During the latter part of the injection test, and again after a period of three weeks since termination of the test, water samples were taken from the monitor well. A comparison of chemical and now available radiological analyses of these water samples and of water samples taken from the same aquifer in the disposal well, is presented here. This comparison does not indicate pollution in the monitor well samples as a result of the test injecting.

	Disposal Well	Monitor Well No. 1		
Chemical Analyses	January 1959 ppm	March 15 1960 ppm	April 5 1960 ppm	June 1 1960 ppm
SO_4	636	689	680	668
NO_3	2	14	25	23
Cl	158	141	145	150
Na	186	231	233	190
Ca	185	208	215	212
Mg	65	68	67	71
Fe	Nil	Nil	Nil	Nil
Mn	Nil	Nil	Nil	Nil
K	---	5	13	---
pH	7.5	7.1	6.9	7.4
Total Dissolved Solids	1,608	1,685	1,726	1,739

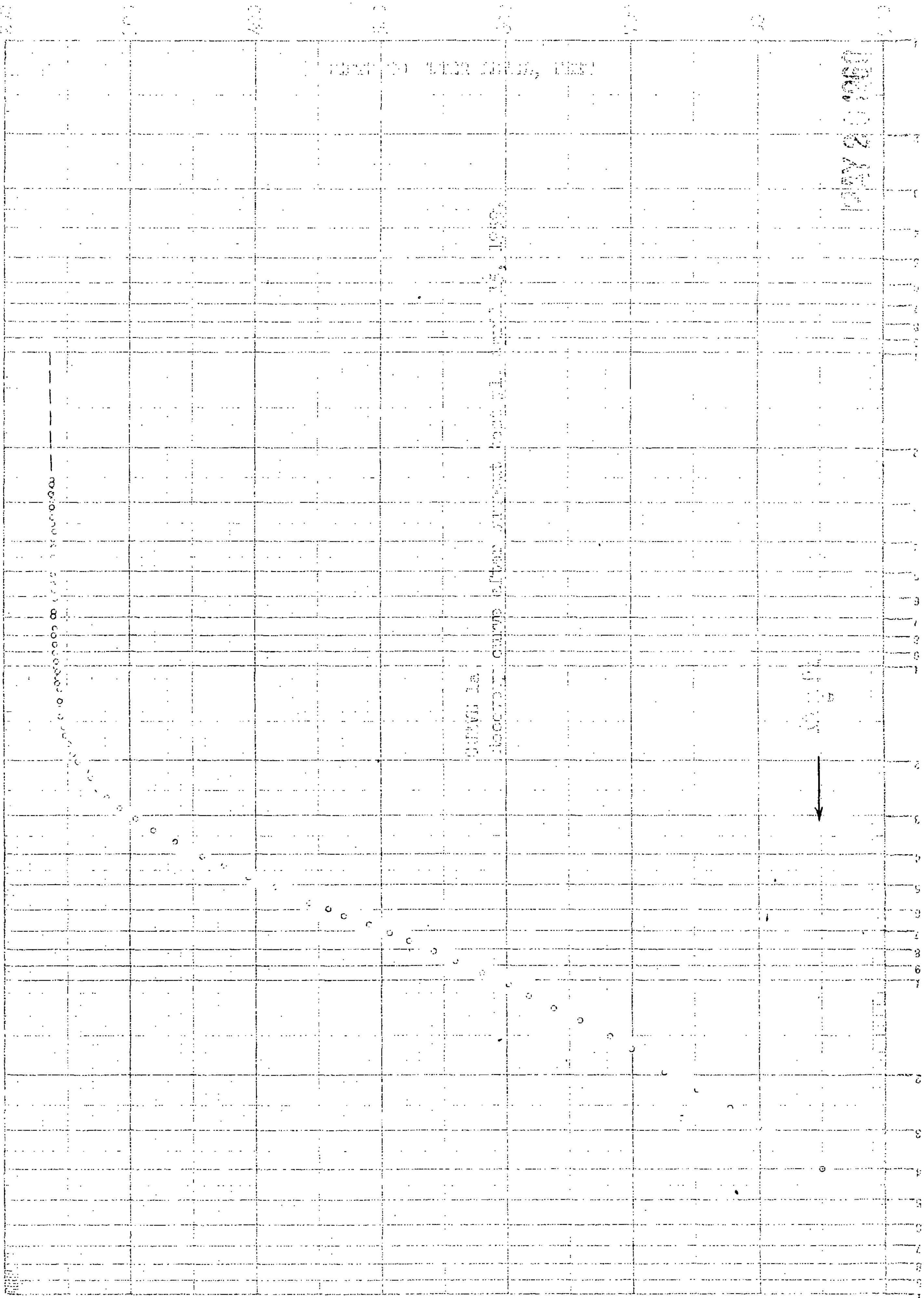
Radiological Analyses	Tracerlab, Inc. $\mu c/ml$	Tracerlab, Inc. $\mu c/ml$	Tracerlab, Inc. $\mu c/ml$	Tracerlab, Inc. $\mu c/ml$
Gross Alpha	95×10^{-9}	122×10^{-9}	162×10^{-9}	Not Available
Gross Beta	43×10^{-9}	17×10^{-9}	23×10^{-9}	" "
Th-230	-------	31×10^{-9}	Not Available"	"
Ra-226	0.7×10^{-9}	2.9×10^{-9}	" "	" "
U-Nat.	3.9×10^{-9}	25×10^{-9}	" "	" "

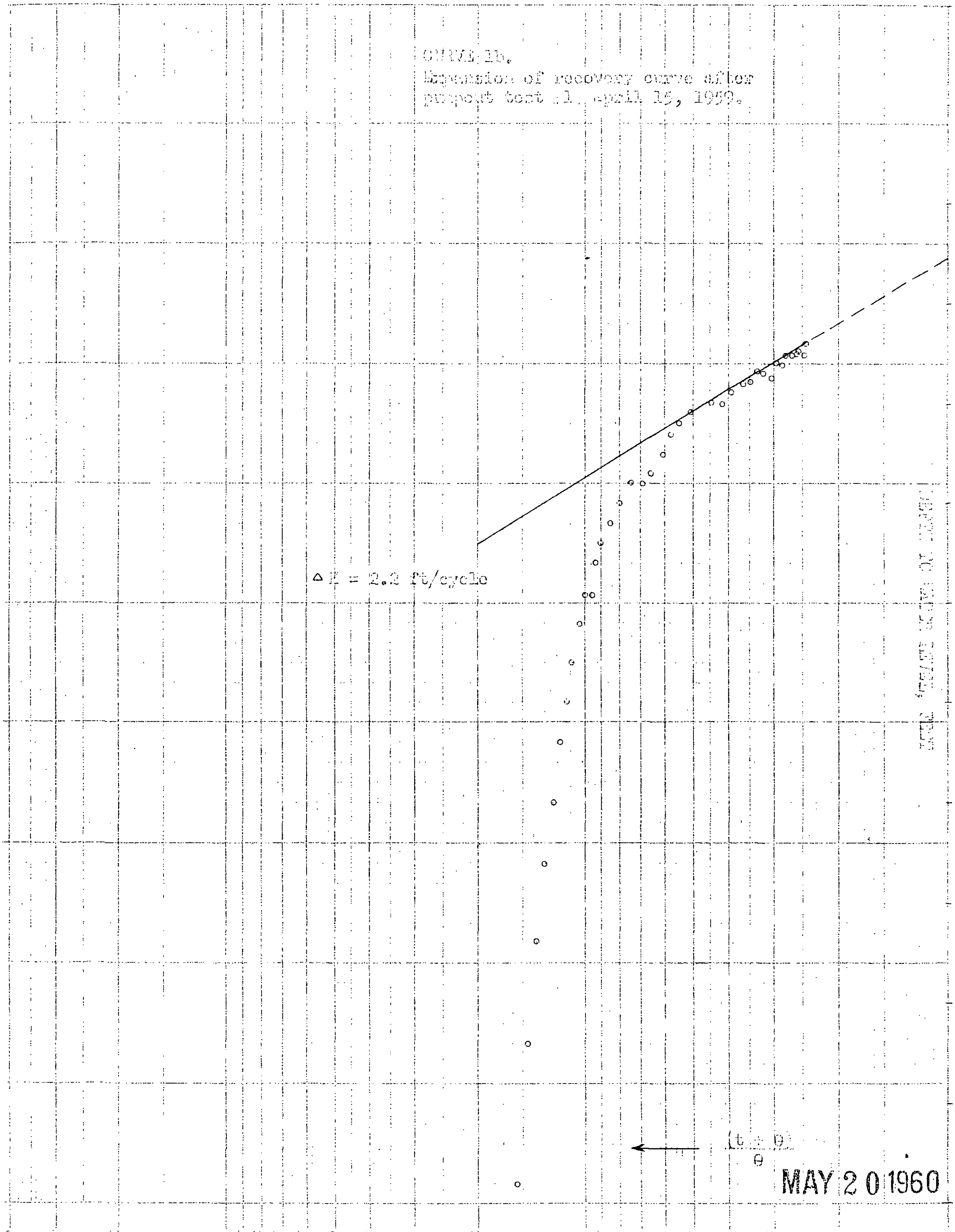
	N.S.&E.C.* $\mu c/ml$
Gross Alpha	20×10^{-9}
Gross Beta	14×10^{-9}

* Nuclear Science and Engineering Corporation duplicate sample for April 5, 1960.

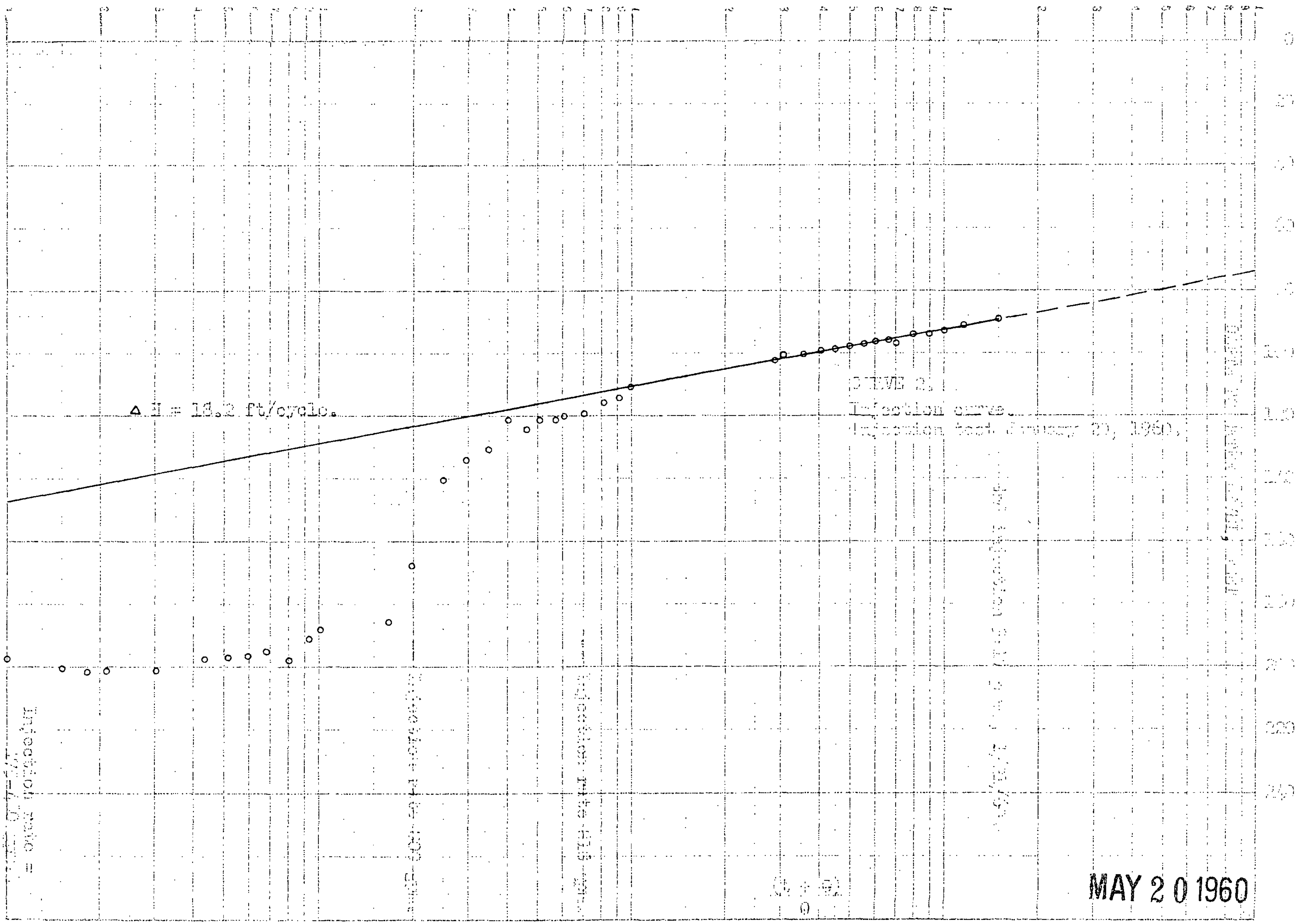
Ninety-Day Test, Injectivity and Recovery Data:

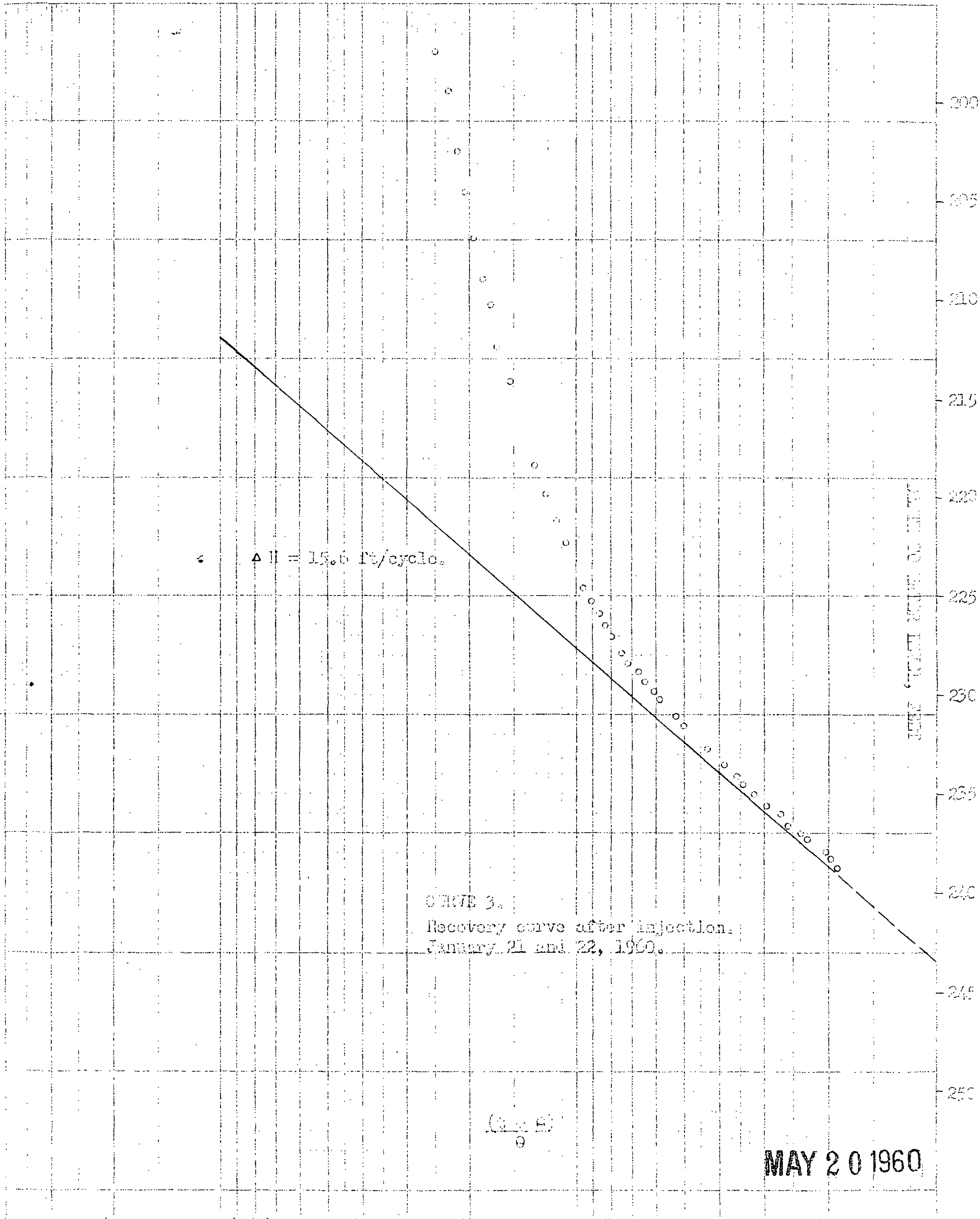
Following are semilogarithmic plots of injection and recovery water levels, a summary of the results calculated from them, and the methods of calculation. Numerous similar curves covering the balance of the 90-day test are omitted for simplicity. Curve 1 was obtained from a pump-out test conducted at the completion of the construction of the test disposal well. The potable water aquifer has a transmissibility greatly in excess of the disposal aquifers and any leakage or communication to it during injecting by way of channels would result in an increase of apparent disposal aquifer transmissibility. It is evident from the curves that the apparent transmissibility of the disposal aquifers has not increased during the test injection.





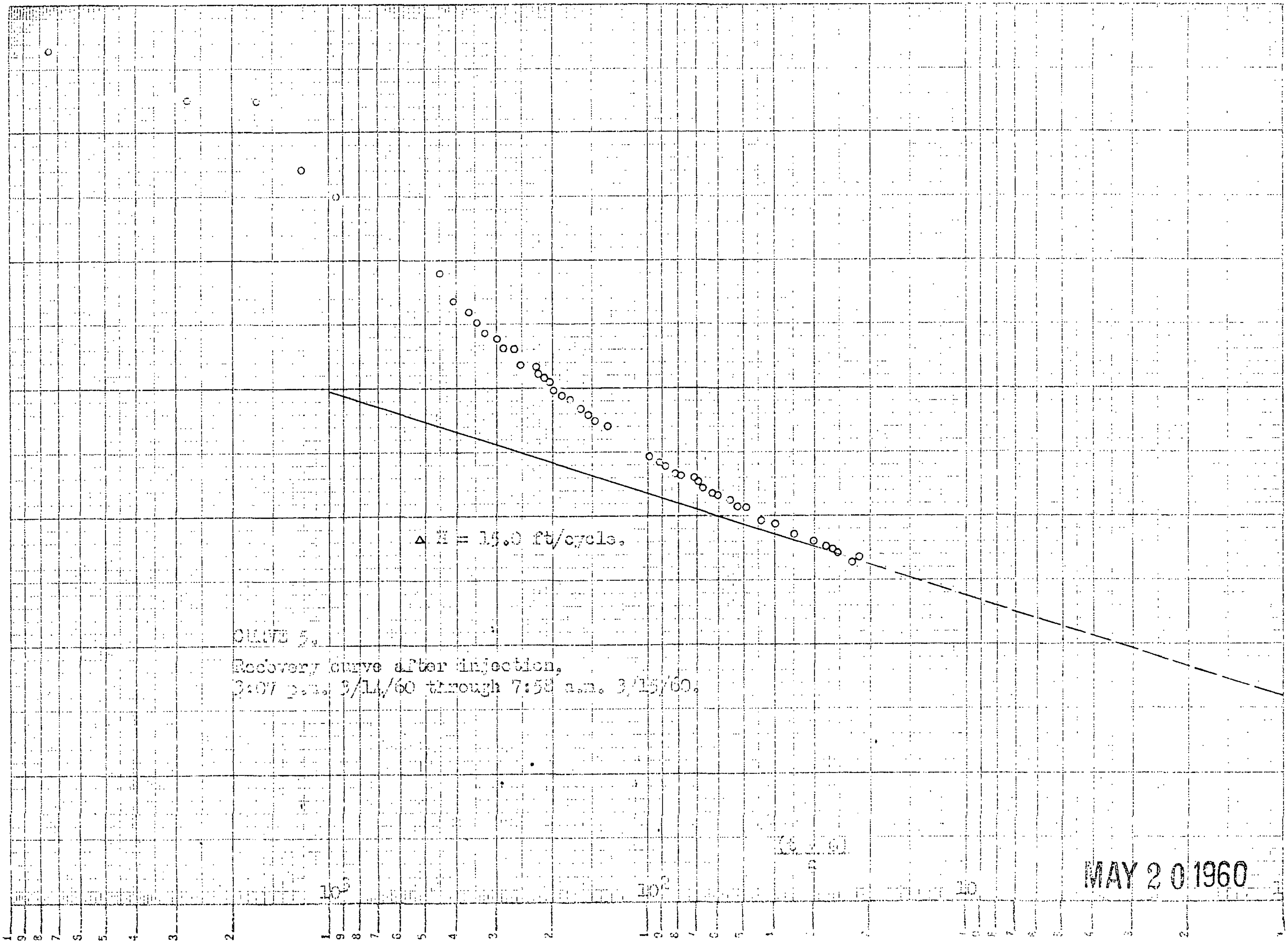
CURVE 1b.
Expansion of recovery curve after pumpout test #1, April 15, 1959.


Δ H = 13.2 ft/cycle.
Injection curve.
MAY 20 1960



CURVE 3.
Recovery curve after injection.
January 21 and 22, 1960.


MAY 20 1960


Δ H = 15.0 ft/cycle.
CURVE 5.
Recovery curve after injection,
3:07 p.m. 3/14/60 through 7:58 a.m. 3/15/60.
10^3
10^2
10
1
190
200
210
220
240
MAY 2 0 1960

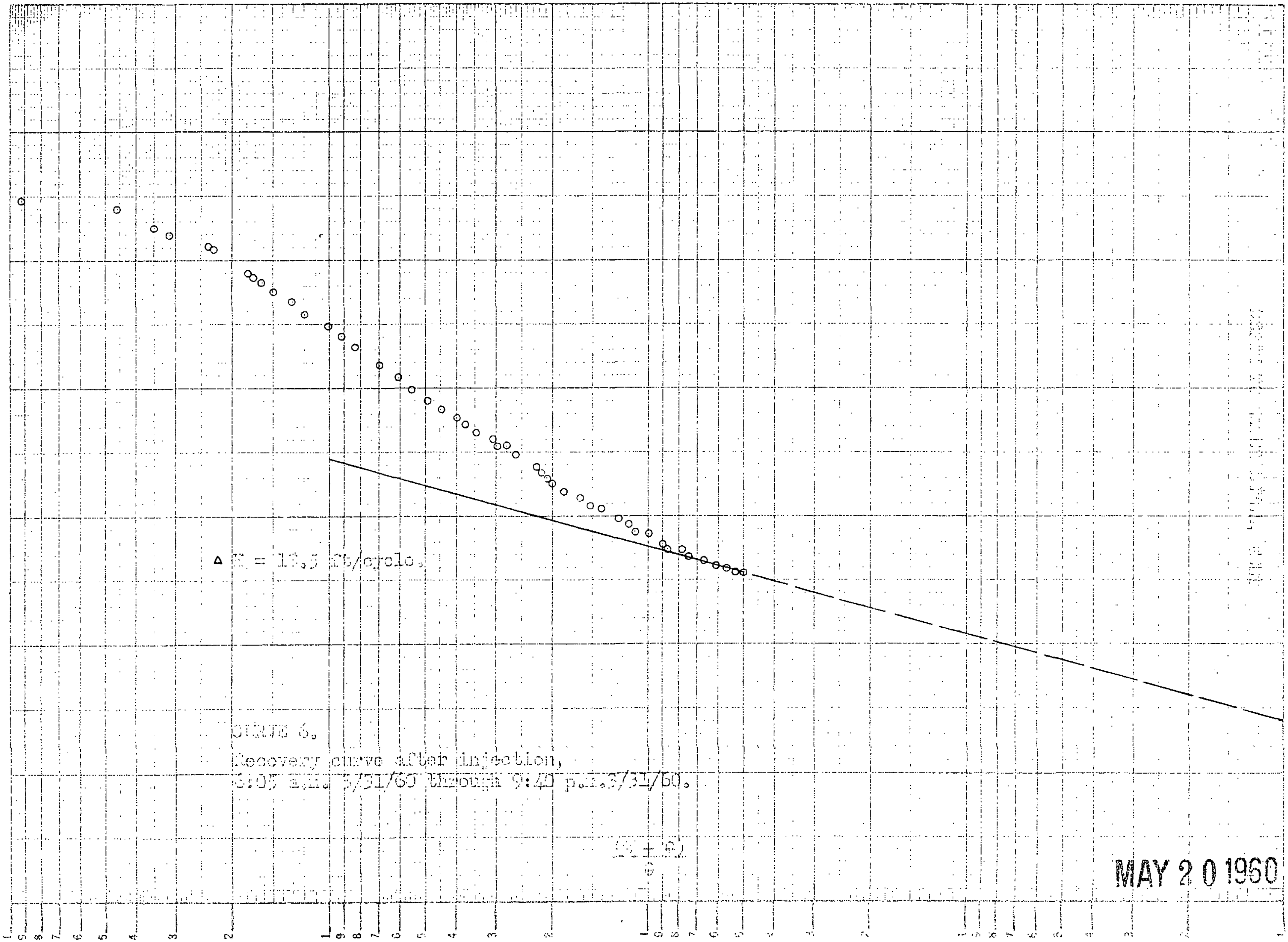


FIGURE 6.
Recovery curve after injection,
8:05 a.m. 3/31/60 through 9:40 p.m. 3/31/60.

Summary from Injection and Recovery Curves

Description	Rate gpm	Slope (ΔH) feet/cycle	Apparent Transmissibility kh/μ md ft/cp	U.S.G.S. T units	Injectivity gal/min/ft	H_s-H_f, feet Head Differential
CURVE 1.a. RECOVERY 4/15/59	100	2.2	585,000	11,700	-----	-----
CURVE 1.b. - Expansion of Curve 1.a.						
CURVE 2. INJECTION 1/20/60	818	18.2	578,000	11,600	5.065	161.5
CURVE 3. RECOVERY 1/21/60	818	15.6	675,000	13,500	5.346	153.0
CURVE 4. INJECTION 2/27/60	380	15.1	324,000	6,480	2.92	130.0
CURVE 5. RECOVERY 3/14/60	380	15.0	326,000	6,530	2.82	135.0
CURVE 6. RECOVERY 3/31/60	382	18.5	266,000	5,330	2.87	133.0

Transmissibility Calculations:

$$\rho g\,(H_o - H_w) = -\frac{q\mu}{4\pi kh}\,Ei\left(-\frac{r_w^2\,f\mu c}{4\,kt}\right)$$ [1,2]

where H_o = static water level

H_w = flowing water level at well bore

q = injection rate

μ = fluid viscosity

k = permeability

h = sand thickness

r_w = well bore radius

c = liquid compressibility

t = time

f = porosity fraction

ρ = density of fluid

g = acceleration of gravity

$$Ei(-x) = -\int^{\infty} \frac{e^{-u}}{xu}\,du$$

1/ Horner, D. R.: "Pressure Build-Up in Wells," Proc. Third World Petroleum Congress, Section 11, E. J. Brill, Leiden, Holland (1951).

2/ Theis, C. V.: "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground Water Storage," Trans. AGU (1935), 16, 519-524.

PLATE XI

DOCKET NO. 40-665
File Copy

THE ANACONDA CO.

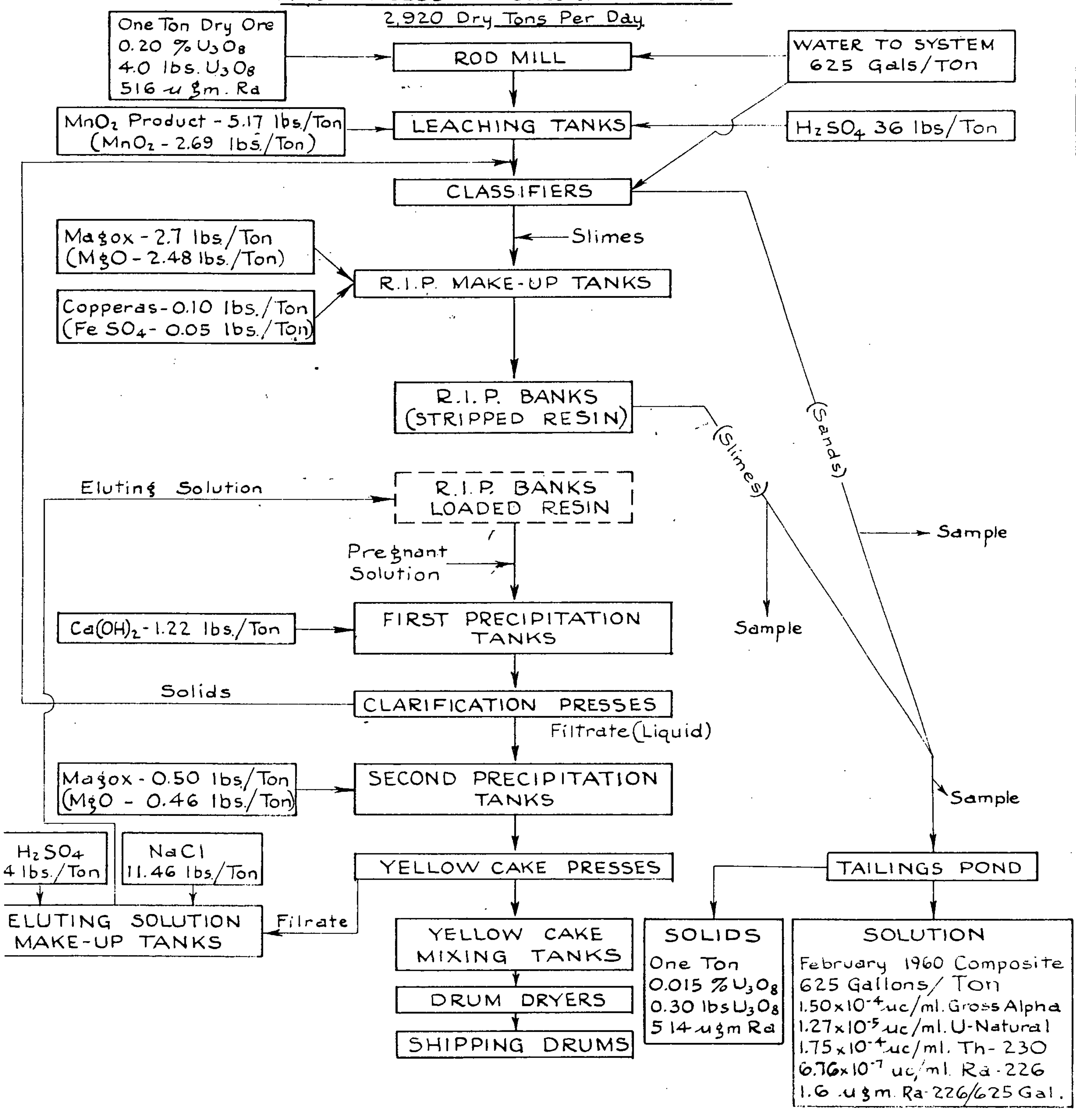
NEW MEXICO, OPERATIONS

FLOW DIAGRAM

ANACONDA URANIUM OXIDE LEACHING MILL

ACID PROCESS — CHLORIDE ELUTION

2,920 Dry Tons Per Day



MAY 20 1960

ote:
Quantities indicated above are typical only.