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# GASBUGGY

## GROUND WATER SAFETY EVALUATION


TELEDYNE ISOTOPES
PALO ALTO, CALIFORNIA


A GOVERNMENT-INDUSTRY EXPERIMENT

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# GROUND WATER SAFETY EVALUATION - PROJECT GASBUGGY

by

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# ABSTRACT


The most likely path for hydrologic transport of radionuclides from the Gasbuggy Site to possible water-use points is through the Ojo Alamo Sandstone. Groundwater in the Ojo Alamo Sandstone flows westward. The point at which groundwater in the Ojo Alamo Sandstone could mix with other water is along the San Juan River near the mouth of Los Pinos River, 38 kilometers northwest of the Gasbuggy Site. Based on available data, groundwater flowing from the Gasbuggy Site will take 5900 years to reach the confluence of the San Juan and Los Pinos Rivers. At the Gasbuggy Site, the total dissolved solids, sodium, and sulfate content of the groundwater occur in concentrations higher than acceptable for irrigation or domestic use.

Tritium, strontium-90, and cesium-137 will decay to concentrations below the appropriate concentration guides (CG) for the general public before reaching the San Juan River. Tritium will travel a maximum of 2100 meters in no more than 309 years before decaying to a concentration of $1 \times 10^{-3}$ $\mu$Ci/ml (the CG for tritium). Because of their high $K_d$ values, $Sr^{90}$ and $Cs^{137}$ will migrate no farther from the cavity than 320 meters and 3.5 meters, respectively, in 1,000 years. By this time, both nuclides will have decayed to well below the CG.

## A C K N O W L E D G E M E N T S

This unclassified report was revised in July 1970, by G. Lewis Meyer, Hydrogeologist, and Mendell M. Bell, Geologist, TELEDYNE ISOTOPES, Las Vegas Office, Las Vegas, Nevada. The manuscript was typed by Karen L. Cathie, Secretary.

# I. INTRODUCTION

The Project Gasbuggy nuclear explosive of 26 kilotons design yield was detonated on Sunday, December 10, 1967, at 1230:00 Mountain Standard Time.

The explosive was emplaced at 4240 feet below ground surface, 1770 feet from the West line and 1218 feet from the South line in Section 36 of Township 29 North, Range 4 West, in Rio Arriba County, New Mexico, about 55 air miles east of the city of Farmington, New Mexico. The geodetic coordinates are: Latitude -- 36°40'40.4" North; and Longitude -- 107°12'30.3" West. The elevation of surface ground zero was 7204 feet above Mean Sea Level.

The detonation occurred in the Lewis Shale formation of the San Juan Basin about 40 feet below its contact with the gasbearing Pictured Cliffs sandstone formation.

Palo Alto Laboratories of Teledyne Isotopes is under contract AT(29-2)-1229 to the Nevada Operations Office, U. S. Atomic Energy Commission (NVOO), to evaluate possible hydrologic contamination that may result from underground nuclear detonations. This report is based on data from investigations which were performed to determine the possibility of radiocontamination of natural water supplies by Project Gasbuggy. This report was revised in July 1970 to incorporate revised information and current nomenclature.

## II. REGIONAL ENVIRONMENTAL CONDITIONS

### 2.1 Geologic Setting

The Gasbuggy Site is in the northeastern part of the San Juan Basin, a structural depression in the Colorado Plateau physiographic province. The province is characterized by broad, gentle folds and flexures developed in sedimentary rocks that range in age from Paleozoic to Tertiary.[3] The rocks of the San Juan Basin are chiefly sandstone and shale.[4]

The San Juan Basin is a semi-circular area, 240 kilometers north-south by 150 kilometers east-west (Figure 1). The basin is a structural depression with as much as 5000 meters of sediments deposited near the center of the basin. Contemporaneous and post-depositional deformation resulted in the accumulation of a relatively thick sequence of younger rocks in the center of the basin with successively older rocks exposed toward the margins. The primary structure of the basin is a gentle downwarp with a relatively small uplift near the western edge. Structural features that may influence groundwater movement include randomly oriented joints throughout the basin[6] and scattered northward-trending dike swarms in the northern part of the basin.[5]

The thickest section of Tertiary rocks is southwest of the GASBUGGY Site. The thickest section of older rocks is more than 50 kilometers to the northwest (Figures 2 and 3). The sedimentary sequence at the GASBUGGY

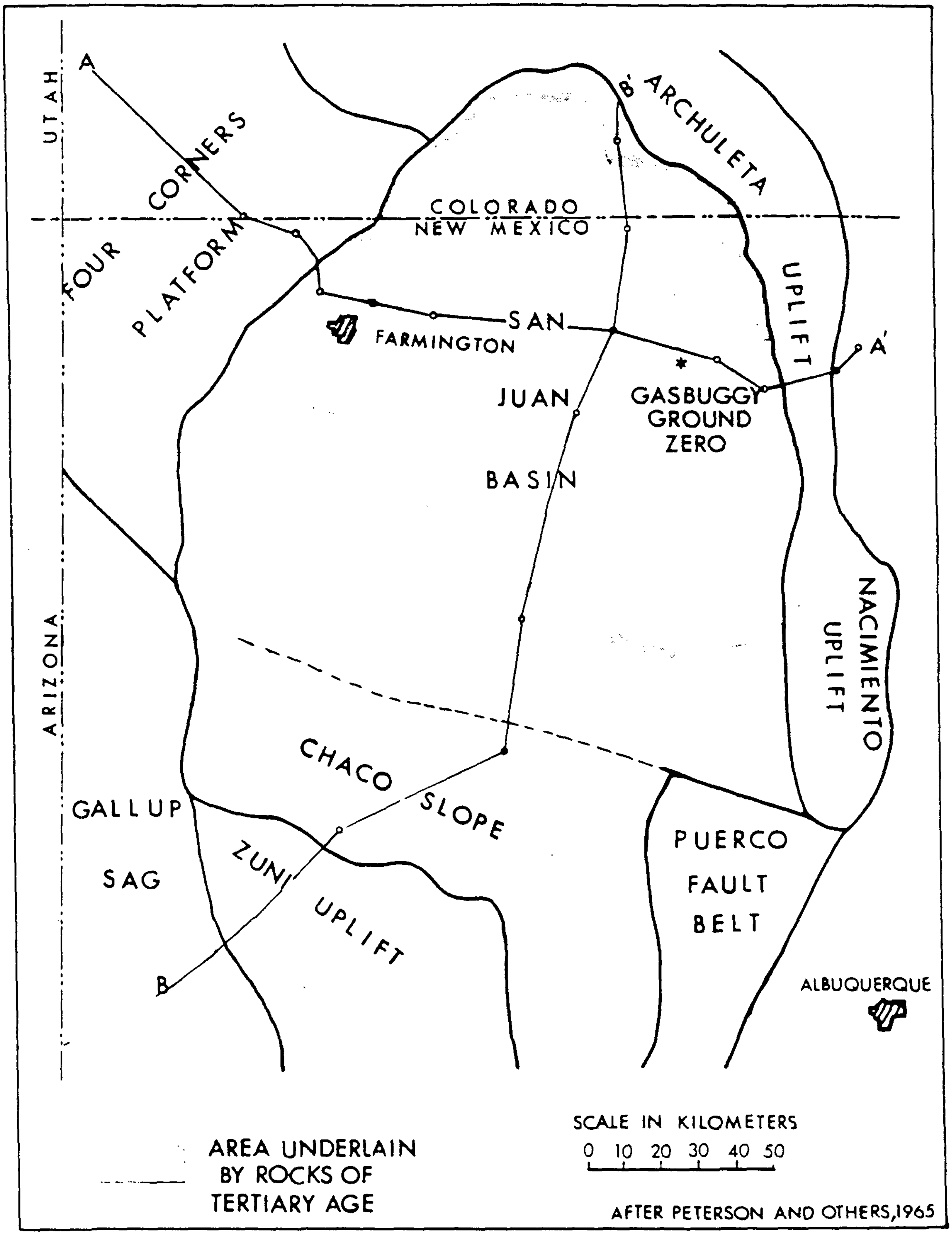



Figure 1: Index Map of San Juan Basin Showing Regional Tectonic Features and Locations of Cross Sections

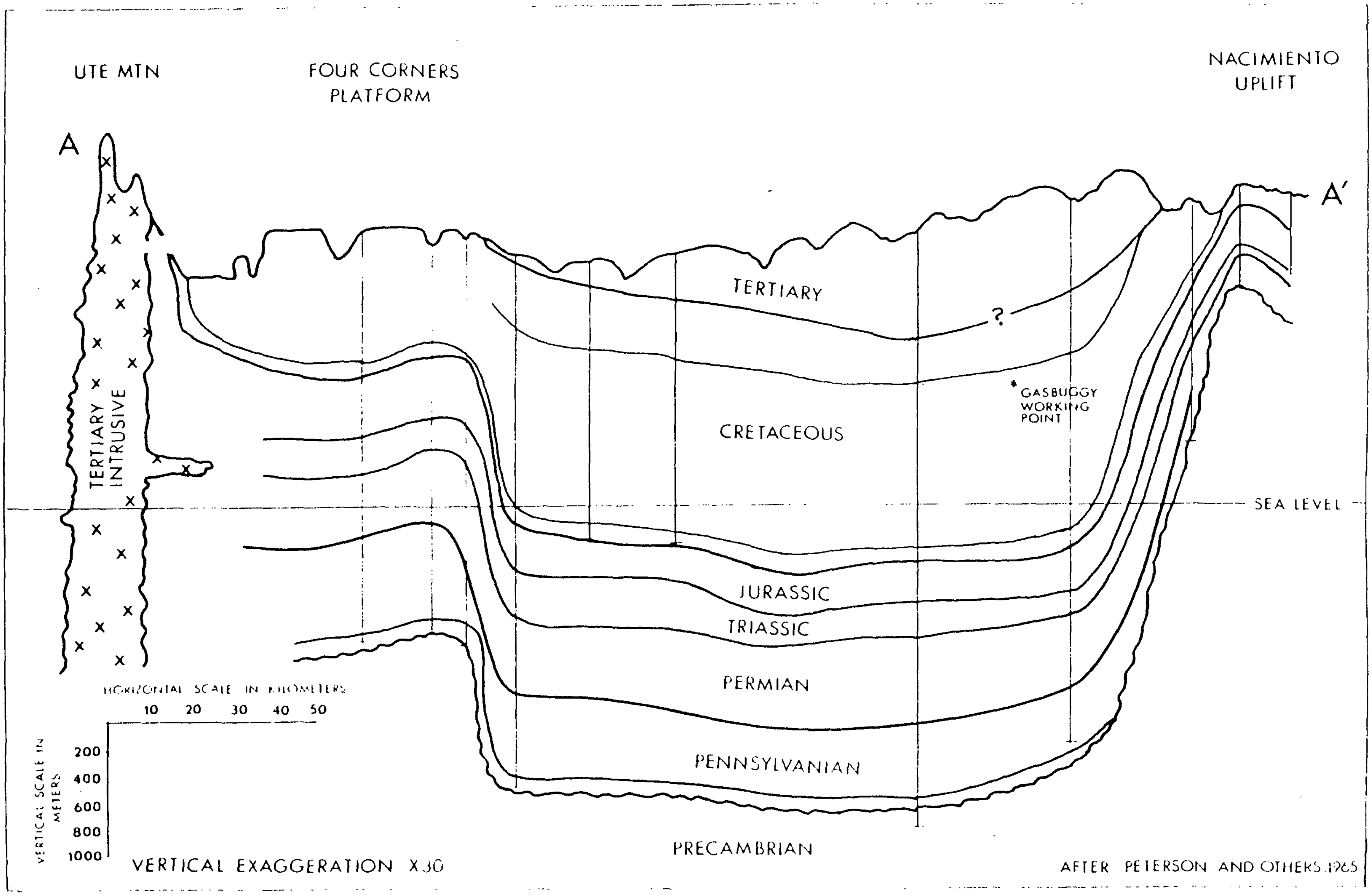



Figure 2: East-West Geologic Cross Section of the San Juan Basin

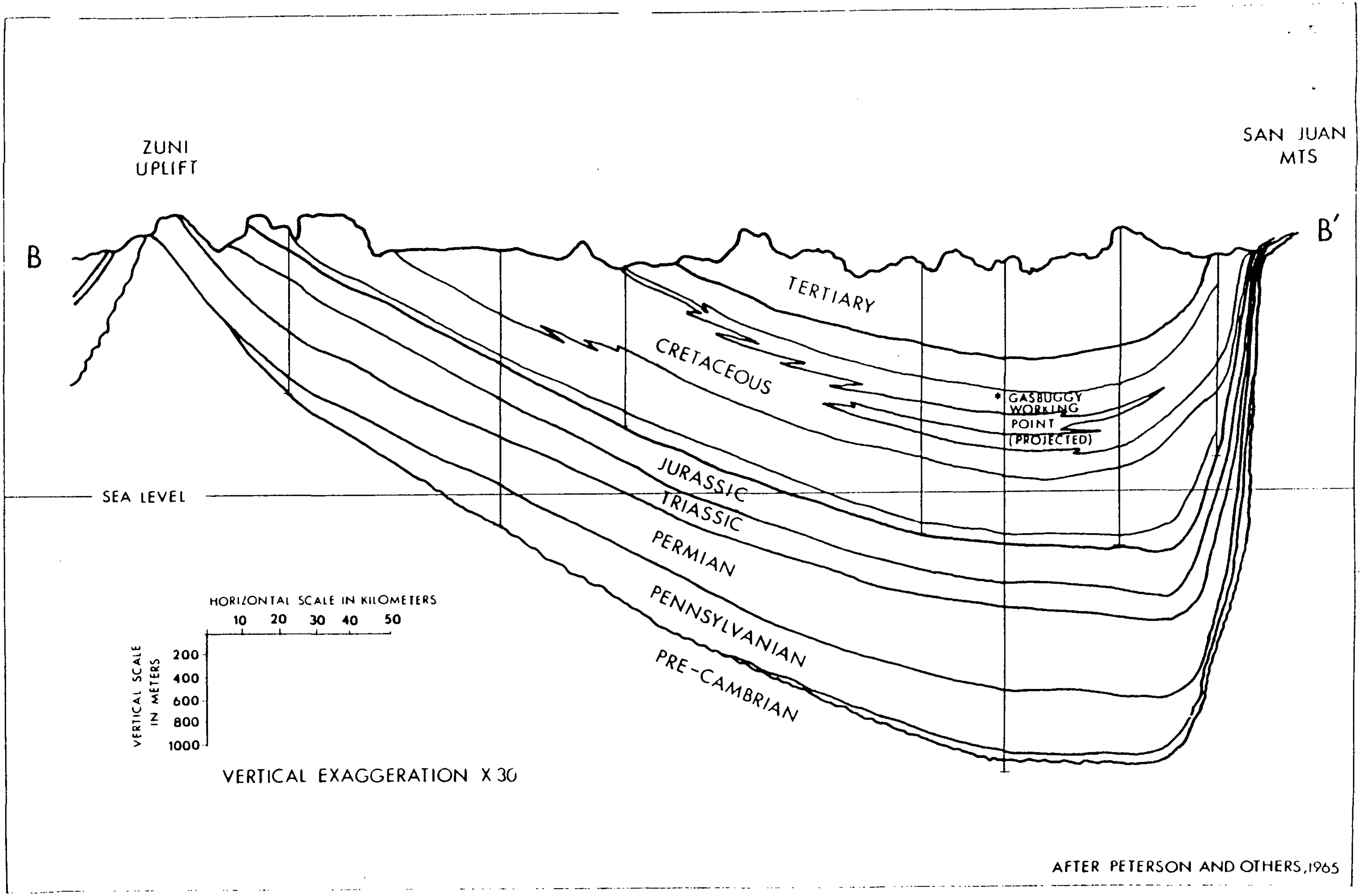



Figure 3: North-South Geologic Cross Section of the San Juan Basin

Site is about 4500 meters thick. A generalized lithologic section is shown in Table 1. A more detailed Cretaceous section is displayed in Table 2.

The depositional environment during Cretaceous time changed from an early dominantly shallow-marine stage to a late dominantly fluviolacustrine stage. The limestones and shales of the marine facies have low permeability. Shale and sandstone predominate in the fluviolacustrine facies. The sandstones are fine-grained and generally discontinuous. Hydraulic conductivity of even the most permeable rocks is low. Hydraulic connection between adjacent units is poor.

### 2.2 Hydrologic Setting

Rocks of Cretaceous age in the center of the San Juan Basin have not been developed as a water source. Thus, direct evidence of the character of the groundwater and its movement in these rocks is lacking. However, inferences can be drawn from measured hydraulic properties.[7] The low permeability of Tertiary rocks restrict hydrologic communication between land surface and the underlying Cretaceous rocks. If direct communication exists, the flow is downward from land surface to the Ojo Alamo Sandstone, whose potentiometric surface is about 300 meters below land surface.[7] Except toward the west, older rocks of extremely low permeability encircle the basin at higher elevations. These rocks appear to be groundwater barriers. The flow of groundwater from the Gasbuggy Site must therefore be westward. The San Juan River Valley includes all points within the

TABLE 1

STRATIGRAPHIC SEQUENCE AT THE GASBUGGY SITE

| Depth (meters) | System | Thickness (meters) | Description |
|---|---|---|---|
| | Tertiary | 1060 | Shale and sandstone, variegated; fluviolacustrine origin. |
| 1060 | | | |
| | Cretaceous | 1420 | (see Table 2) |
| 2580 | | | |
| | Jurassic | 520 | Interstratified sandstone, siltstone and shale, with some evaporites; fluviolacustrine origin. |
| 3100 | | | |
| | Triassic | 200 | Shale, siltstone, and sandstone, red; continental origin. |
| 3300 | | | |
| | Permian | 700 | Shale, siltstone, and sandstone, predominantly red, with evaporites; chiefly of continental origin with limestone of marine origin. |
| 4000 | | | |
| | Pennsylvanian | 500 | Limestone and shale of marine origin and red sandstone of continental origin. |
| 4500 | | | |

TABLE 2

STRATIGRAPHIC SEQUENCE OF ROCKS OF CRETACEOUS AGE

AT THE GASBUGGY SITE

| Depth (meters) | Formation | Thickness (meters) | Description |
|---|---|---|---|
| 1060 | | | |
| | Ojo Alamo Sandstone | 50 | Sandstone and conglomerate, yellow and gray; fluvial origin. May be partly Tertiary in age. |
| 1110 | | | |
| | Kirtland Shale | 40 | Shale and clay, with gray; fluviolacustrine origin. |
| 1150 | | | |
| | Fruitland Siltstone | 40 | Shale and fine-grained sandstone, gray; contains coal beds; lagoonal and marine origin. |
| 1190 | | | |
| | Pictured Cliffs Sandstone | 90 | Sandstone, grayish-white, fine- to medium-grained; contains bentonitic shale; marine origin. Gas-bearing. |
| 1280 | | | |
| | Lewis Shale | 480 | Shale, gray, with sandy streaks; marine origin. |
| 1760 | | | |
| | Mesaverde Group | 150 | Sandstone, brown, with gray shale; marine and lagoonal origin. |
| 1910 | | | |
| | Mancos Shale | 530 | Shale, gray to black shale, marl, limestone, and sandstone; marine origin. |
| 2440 | | | |
| | Dakota Sandstone and Burro Canyon Formation | 140 | Sandstone, brown, with black shale. |
| 2580 | | | |

San Juan Basin that are lower in elevation than the potentiometric surface for water in the Ojo Alamo Sandstone at the Gasbuggy Site. Therefore, any groundwater discharge from the Ojo Alamo Sandstone or underlying formations will be into the San Juan River or from springs in the San Juan River Valley.

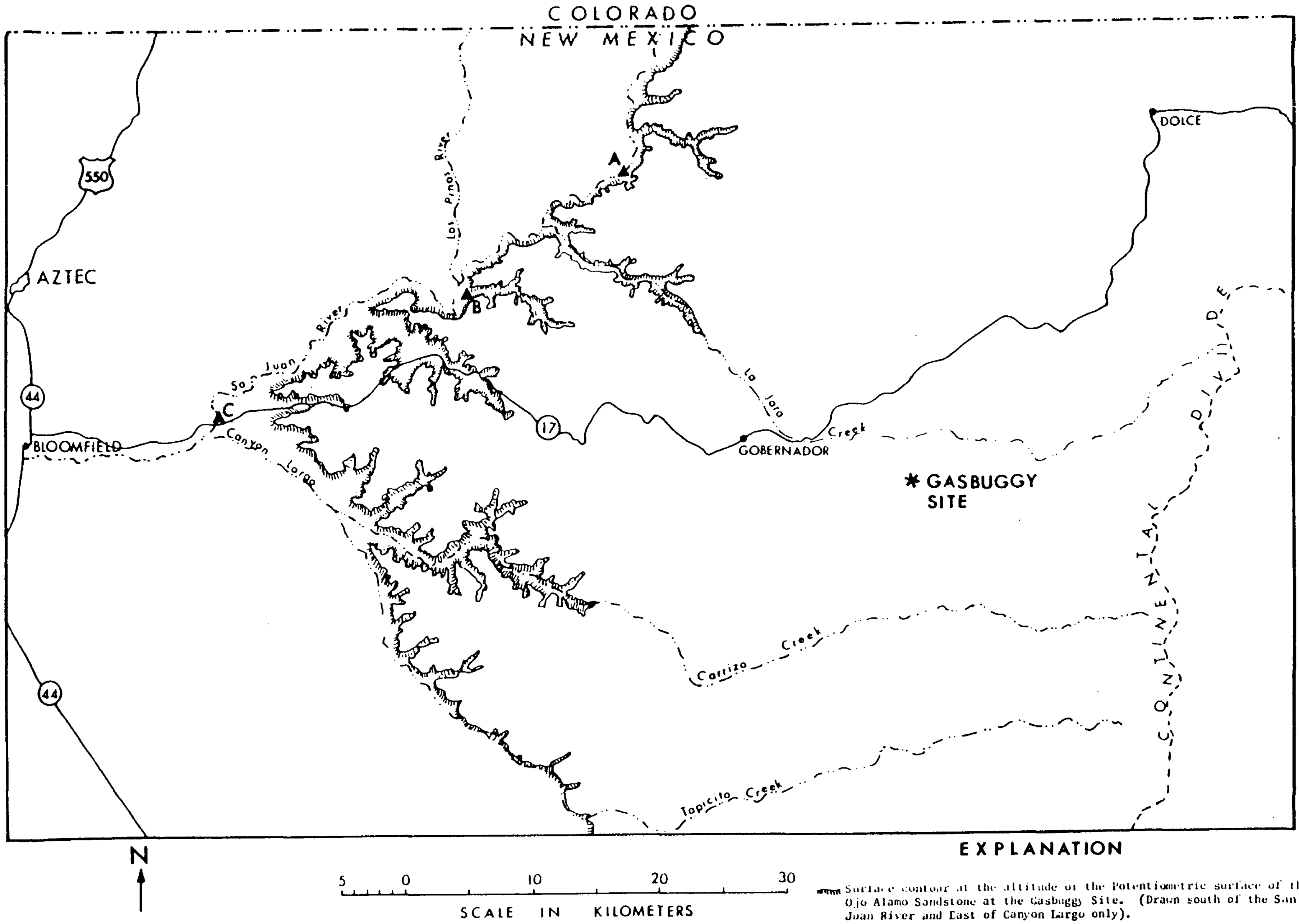
## III. CONTAMINATION PREDICTIONS

### 3.1 Hydrologic Contamination On-Site and Near-Site

The potentiometric surface of the Ojo Alamo Sandstone is 300 meters below the land surface[7] and is 1000 meters above the Gasbuggy shot-point. The water level in shallow wells penetrating near-surface aquifers within several kilometers of the site is within 100 meters of the land surface. If these near-surface aquifers are hydraulically connected with the Ojo Alamo Sandstone, the vertical component of groundwater flow between the surface to the Ojo Alamo Sandstone will be downward.

The potentiometric surface of groundwater in the Ojo Alamo Sandstone at the Gasbuggy Site is approximately 300 meters below land surface at the Gasbuggy Site, or approximately 1900 meters above sea-level. Therefore, no radionuclides resulting from the Gasbuggy Event can be expected to travel in groundwater to points higher than this elevation. No wells, streams, or springs with static water levels or discharge points higher than 1900 meters above sea-level can produce water containing radionuclides released by the Gasbuggy Event. The closest discharge point to the Gasbuggy Site below the elevation of 1900 meters where surface water contamination becomes possible is along La Jara Creek, 20 kilometers northwest of the site (Figure 4).

Development of the Ojo Alamo or the underlying formations as a water source is unlikely, because of low yield and poor water quality. The average permeability of Ojo Alamo Sandstone cores measured in the laboratory is 7.2 millidarcys . Permeability, calculated by Koopmen and




EXPLANATION

Surface contour at the altitude of the Potentiometric surface of the Ojo Alamo Sandstone at the Gasbuggy Site. (Drawn south of the San Juan River and East of Canyon Largo only).

▲ Points on the San Juan River to which time of travel from Gasbuggy Site has been calculated.

A - At Laguna Seco Draw
B - 2 km below mouth of Los Pinos River
C - 2 km below mouth of Canyon Largo

Figure 4: Sketch Map of North Central New Mexico Showing Features Pertinent to Hydrologic Contamination From Project Gasbuggy

Ballance[7,8] from field measurements of transmissivity of the Ojo Alamo Sandstone is 0.9 millidarcys.

Water from the Ojo Alamo Sandstone (Table 3) is not suitable for domestic use or for irrigation because of excessive calcium, sodium, sulfate, and total dissolved solids. Sodium and sulfate concentrations are more than 10 times the recommended maximum for drinking and general household use according to the U. S. Public Health Service standards[9] ; total solids are about 5 times greater than the acceptable maximum. The total solids and sodium-percentage factor cause the water to be classed by Wilcox[10] as water with a very high sodium hazard for irrigation.

3.2 Regional Hydrologic Contamination

Streams, springs, or shallow wells which might be contaminated by the Gasbuggy Event lie to the west of the Gasbuggy Site and all lie below an altitude of 1900 meters. The path along which transport of radionuclides would be the most rapid is the Ojo Alamo Sandstone. Discharge points to which these radionuclides would migrate first are adjacent to the San Juan River. Three points on the San Juan River appear most critical because maximum slope in the potentiometric surface occurs near them and because of their proximity to the Gasbuggy Site. The maximum groundwater flow velocity through the Ojo Alamo Sandstone and the minimum time of travel from the Gasbuggy Site were calculated (Table 4) for these points. Flow through formations below the Ojo Alamo Sandstone would be slower because

TABLE 3

CHEMICAL AND RADIOLOGIC ANALYSES OF WATER FROM THE OJO ALAMO SANDSTONE, RIO ARRIBA COUNTY, NEW MEXICO

(Water Collected and Analyzed by U.S. Geol. Survey: Letter West/Edwards, 11/2/67)

| Constituent or Property | HOLE GB - 1 UPPER ZONE Depth Interval 1059-1090 Meters | | HOLE GB - 1 LOWER ZONE Depth Interval 1090-1114 Meters | | HOLE GB - 2 TOTAL FORMATION Depth Interval 1058-1114 Meters | |
|---|---|---|---|---|---|---|
| pH | 7.7 | | 6.9 | | 7.2 | |
| Specific Conductance | 8210. | | 7450. | | 9350. | |
| Temperature ($^{o}C$) | 38. | | 38. | | 21. | |
| Gross $\beta$ (as $Sr^{90}$-$Y^{90}$) | 3.1 | | 4.0 | | - | |
| Gross $\alpha$ as U-equiv.($\mu g/l$) | 3.1 | | 1.5 | | - | |
| | ppm | epm | ppm | epm | ppm | epm |
| Silica ($SiO_2$) | 8.0 | - | 16 | - | 10 | - |
| Aluminum (Al) | 0.02 | - | 0.02 | - | 0.4 | - |
| Iron (Fe) | 0.49 | 0.03 | 0.69 | 0.04 | 1.4 | - |
| Manganese (Mn) | 1.5 | 0.11 | 0.08 | - | 0.33 | - |
| Calcium (Ca) | 218. | 10.88 | 242. | 12.08 | 251. | 12.52 |
| Magnesium (Mg) | 14. | 1.15 | 14. | 1.15 | 12. | 0.99 |
| Strontium (Sr) | 4.6 | 0.10 | 5.3 | 0.12 | 4.7 | 0.11 |
| Sodium (Na) | 2160. | 93.96 | 1880. | 81.78 | 2220. | 96.57 |
| Potassium (K) | 14. | 0.36 | 12. | 0.31 | 1.6 | 0.04 |
| Lithium (Li) | 0.28 | 0.04 | 0.28 | 0.04 | 0.28 | 0.04 |
| Selenium (Se) | <0.01 | - | <0.01 | - | 0.02 | - |
| Zinc (Zn) | 0.01 | - | 0.01 | - | 0.03 | - |
| Copper (Cu) | 0.01 | - | 0.01 | - | - | - |
| Arsenic (As) | <0.01 | - | <0.01 | - | - | - |
| Total Cations | - | 106.63 | - | 95.52 | - | 110.27 |
| Bicarbonate ($HCO_3$) | 223. | 3.65 | 86. | 1.41 | 306. | 5.02 |
| Carbonate ($CO_3$) | 0. | 0.00 | 0. | 0.00 | 0. | 0.00 |
| Sulfate ($SO_4$) | 4060. | 84.53 | 3630. | 75.58 | 4440. | 92.44 |
| Chloride (Cl) | 272. | 7.67 | 221. | 6.23 | 282. | 7.96 |
| Fluoride (F) | 1.4 | 0.07 | 1.4 | 0.07 | 2.3 | 0.12 |
| Nitrate ($NO_3$) | 0.0 | 0.00 | 0. | 0.00 | 0.0 | 0.00 |
| Phosphate ($PO_4$) | 0.00 | - | 0.00 | - | 0.00 | - |
| Boron (B) | 0.40 | - | 0.25 | - | 0.86 | - |
| Total Anions | - | 95.92 | - | 83.29 | - | 105.54 |
| Dissolved Solids | | | | | | |
| Calculated | 6860. | - | 6880. | - | 7370. | - |
| By evap. at 180° C | 7770. | - | 6060. | - | 7960. | - |

TABLE 4

MAXIMUM GROUNDWATER VELOCITY AND MINIMUM TIME OF TRAVEL

THROUGH THE OJO ALAMO SANDSTONE FROM THE GASBUGGY SITE TO THE SAN JUAN RIVER

| Possible Points for Discharge of Radionuclide-Bearing Groundwater at the San Juan River a/ | Distance from Gasbuggy Site (KM) | Elevation Difference from Potentiometric Surface in Ojo Sandstone (M) | Average Slope | Velocity b/ CM/DAY | Time of Travel (YEARS) |
|---|---|---|---|---|---|
| At Laguna Seca Draw | 33.2 | 1200 | 0.036 | 1.36 | 6,700 |
| 2 KM below mouth of Los Pinos R. | 38.2 | 1800 | 0.047 | 1.79 | 5,900 |
| 2 KM above mouth of Canyon Largo | 55 | 2400 | 0.044 | 1.67 | 9,000 |

a/ Locations of points shown of Figure 4.

b/ Calculation based on permeability = 59 millidarcys, porosity = 0.13.

of lower permeability[11] (Figure 5). The higher dissolved solids content of water in formations below the Ojo Alamo Sandstone[12] is also probably indicative of lower flow rates because water in prolonged contact with rock materials is often high in dissolved solids.

### 3.2.1 Computation of Groundwater Velocity and Travel Time

The velocity of groundwater can be computed from the following equation if the hydraulic conductivity and porosity of the aquifer and gradient of the potentiometric surface are known:

$$v = \frac{k}{\theta} \times \frac{dh}{dl} \qquad (1)$$

in which

$v$ = velocity of water,
$k$ = hydraulic conductivity,
$\theta$ = porosity,
$\frac{dh}{dl}$ = gradient of potentiometric surface.

The hydraulic conductivity used in the computations is $5.7 \times 10^{-5}$ cm/sec. This value is the hydraulic conductivity for water at 20°C in an aquifer with a permeability of 59 millidarcys, which was the highest permeability measured in cores from the Ojo Alamo Sandstone in Hole GB-1 .

This is a near-maximum value for hydraulic conductivity, compared to some of the following values which might have been used:

| | |
|---|---|
| $8.4 \times 10^{-5}$ cm/sec | aquifer with permeability of 59 millidarcys, water temperature 38°C (Table 3) |
| $1.5 \times 10^{-5}$ cm/sec | aquifer with permeability of 7.2 millidarcys (average value of 53 cores from 1060 - 1115 meters depth in GB-1), water temperature 20°C (Standard temperature) |

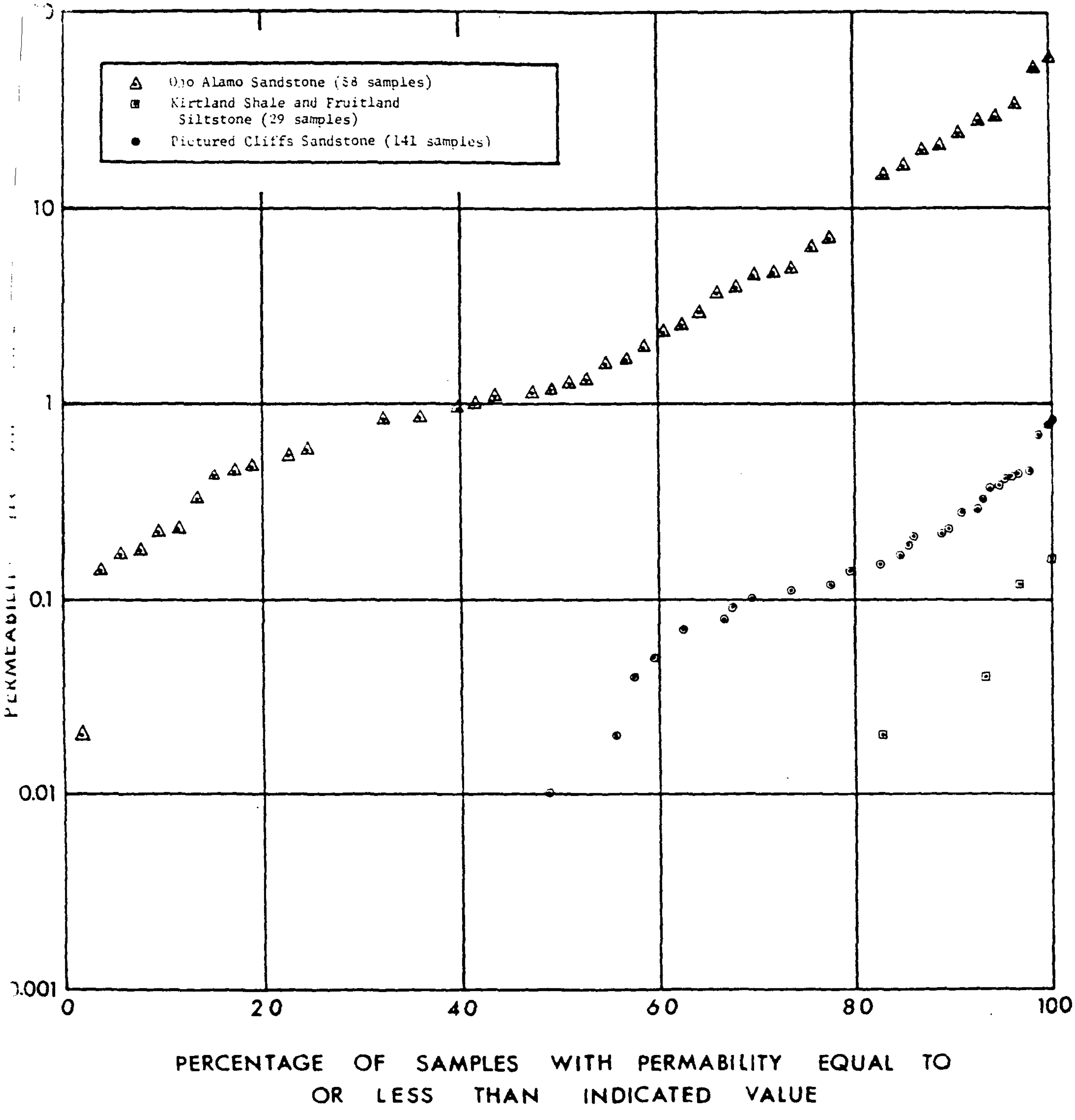



Figure 5: Distribution of Permeability Measurements in Cores from Hole GB-1, Rio Arriba County, New Mexico

| | |
|---|---|
| $1.0 \times 10^{-5}$ cm/sec | aquifer with permeability of 7.2 millidarcys, water temperature 38°C |
| $7.9 \times 10^{-7}$ cm/sec | aquifer with transmissivity of 3 gal/day/ft[7] = $4.3 \times 10^{-3}$ $cm^2$/sec, thickness of $5.5 \times 10^3$ cm. |

Although the porosity of the core sample with a permeability of 59 millidarcys is 0.17, the value used in the computations was 0.13, the average porosity of 53 measured core samples. Use of the 0.13 yields a higher velocity than would be computed if 0.17 were used.

Average velocities to three points on the San Juan River were computed using Equation (1). The results are shown on Table 4. Because of higher altitudes and much lower slope of the potentiometric surface, the travel time would be longer to points along the San Juan River or its tributaries other than those points chosen. Travel times to points lower in altitude would be longer because of the greater distances.

### 3.2.2 Computation of Concentration of Critical Radionuclides in Time and Space

The concentrations of tritium in time and space (Table 5) was computed from the following expression:

$$v_i = \frac{v}{K_f} \qquad (2)$$

in which

$v_i$ = the velocity of an ionic species in an aquifer,

$v$ = the average velocity of water in the aquifer,

$K_f$ = the retardation factor, $\left(\frac{1 - \theta}{\theta}\right) \rho K_d + 1$, in which $\theta$ is porosity; $\rho$ is the grain density; and $K_d$ is the distribution coefficient of the ionic species in the aquifer at equilibrium.

TABLE 5

CONCENTRATIONS OF, AND DISTANCES TRAVELED BY, SELECTED RADIONUCLIDES RESULTING FROM PROJECT GASBUGGY, AS A FUNCTION OF TIME AFTER DETONATION

| TIME | $H^3$ | | $Sr^{90}$ | $Cs^{137}$ |
|---|---|---|---|---|
| | DIST. | CONC. | DIST. | DIST. |
| (Yr) | M | $\mu$Ci/ml | M | M |
| 0 | 0 | $3.8 \times 10^4$ | 0 | 0 |
| 1 | 6.5 | $3.6 \times 10^4$ | 0.32 | 0.004 |
| 10 | 65 | $2.2 \times 10^4$ | 3.2 | 0.035 |
| 100 | 650 | $1.3 \times 10^2$ | 32 | 0.35 |
| 200 | 1300 | $4.7 \times 10^{-1}$ | 64 | 0.71 |
| 309 | 2000 | $1.0 \times 10^{-3}$* | - | - |
| 500 | 3300 | $2.0 \times 10^{-8}$ | 160 | 1.7 |
| 884 | - | - | - | 3.1 |
| 992 | - | - | 320 | - |
| 1000 | 6500 | $1.1 \times 10^{-20}$ | 320** | 3.5** |

* Value for the CG for tritium isotope. CG's are reference concentrations as given in November 8, 1968, revision of USAEC Manual, Chapter 0524, Standards for Radiation Protection, Annex A, Table II, Column 2, reduced by a factor of three to be consistent with standards applicable to a suitable sample of the exposed population in uncontrolled areas. These guides are applied in accordance with instructions in TN NV 0500-23, dated May 12, 1969. A CG is used in the same context as an MPC has previously been applied.

** Concentration of isotope will be less than the CG.

Computations in Table 5 were based on the following assumptions:

a. Yield = 26 kilotons (total fission plus fusion) — Announced pre-shot estimate.

b. Production of tritium is:

$H^3$ $3.8 \times 10^4$ Ci

The total amount of post-shot tritium wherever located expected to be present is about 4 grams.

c. All radioactivity will reach the Ojo Alamo Sandstone instantaneously through the annular space around the well casing and will be concentrated in 1 cubic meter of water. — This is the worst possible case. A more probable case is that contaminated water will migrate to the Ojo Alamo Sandstone through cracks in the Fruitland and Kirtland Formations as suggested by Rawson and Korver.

d. $K_d$ = 0 for $H^3$
= 1.13 $cm^3/g$, for $Sr^{90}$
= 102 $cm^3/g$, for $Cs^{137}$

It is assumed that tritium will move at the velocity of groundwater. Values selected for strontium and cesium are the lowest values of laboratory measurements made on cores of the Ojo Alamo Sandstone (Appendix A).

e. = 2.7 $g/cm^3$ — Average grain density of sediment-forming minerals.

f. $\Theta$ = 0.13 — Average of effective porosity (total pore space containing moveable fluids) for entire Ojo Alamo formation which was cored every 2 feet and analyzed by Core Laboratories, Inc., Dallas Texas. This value is less conservative for ratio of $v_i$ to v than the maximum value, but it is consistent with the value used for computing velocity. The value of 0.13 is more conservative for the estimate of $v_i$.

g. v = 1.79 cm/day — Maximum value for velocity computed (Table 4).

h. No lateral or longitudinal dispersion will occur. — This assumption will result in larger values for concentrations of contaminants than if dispersion were assumed.

The times required for tritium to decay to selected concentrations and the distances traveled within these times were computed using Equation 2 and the foregoing assumptions. Concentrations of the radionuclides and the distances traveled during a range of time up to 1000 years following the Gasbuggy Event are shown in Table 5. Among the concentrations selected is the CG (Concentration Guide) as defined by the U. S. Atomic Energy Commission in AECM 0524.[13]

Tritium will travel a maximum of 2100 meters in no more than 309 years before decaying to a concentration of $1 \times 10^{-3}$ $\mu$Ci/ml (the CG). Because of their high $K_d$ values, $Sr^{90}$ and $Cs^{137}$ will migrate no farther from the cavity than 320 meters and 3.5 meters respectively within 1000 years. By this time, both nuclides will have decayed to well below the appropriate CG.

## IV. MONITORING PROGRAM

### 4.1 Monitoring Network

A network of wells and springs in the area near the site of Project Gasbuggy was established in 1967 to provide data for pre-event and post-event comparison of radionuclide content of natural waters. The network, which included 20 springs (Appendix B) and 10 wells (Appendix C), was established during the period of June 26 - 30, 1967, by Mr. E. H. Essington of Teledyne Isotopes and Mr. Jerry Mercer of the U. S. Geological Survey. Of these, only 15 springs between 2 and 12 kilometers from ground zero, and seven wells between 7 and 17 kilometers from ground zero, were found to be suitable for radiochemical sampling.

### 4.2 Pre-Shot Monitoring

Water samples from the 15 springs and seven wells suitable for sampling were collected in June 1967. These were analyzed for radionuclide content in September 1967 by Mr. E. J. Forslow at Palo Alto Laboratories of Teledyne Isotopes. All samples contained less than 1400 TU (tritium units)*. Procedures and equipment used for these analyses had a lower detection limit of 1400 TU at the 99-percent confidence level.

Gross beta-gamma activity of dissolved solids ranged from 1.0 to 10.3 pCi/l (picocuries per liter) and gross alpha activity ranged from 1.4 to 6.2 pCi/l. Gross beta-gamma activity of suspended solids ranged from less than 0.5 to 4.5 pCi/l, and gross alpha activity ranged from less than 0.3 to 1.6 pCi/l.

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* One tritium unit (TU) is equivalent to 3.3 pCi of tritium per liter.

No significant difference was noted between well water and spring water. Radiochemical analyses are presented in Appendix D.

## 4.3 Post-Event Monitoring

Post-event monitoring of the radiochemical network was started in December 1969. Samples were collected to determine whether concentrations of radionuclides at stations near ground zero had increased a month after the event. Samples were collected by Mr. J. E. Leisek and Mr. Daniel Churchfield of Teledyne Isotopes in December 1967 and January 1968. Two springs and one well were sampled, with samples being taken from the springs on two different dates. Laguna Seca, a lake not included in the original network, was also sampled.

Radiochemical analyses of the 6 post-event samples were made by Mr. E. J. Forslow in March 1968. All samples were analyzed for tritium but no tritium was detected. The lower detection limit for tritium by the method used was 500 TU at the 99-percent confidence level.

No increase in concentration of radionuclides in the surface and subsurface waters was detected by comparing post-event samples with pre-event samples. The activities of the dissolved and suspended solids in post-event water samples from springs and wells in the vicinity of the Gasbuggy Site were slightly lower than those measured in pre-event samples. However, these differences can be attributed to normal statistical variations during counting.

## V. CONCLUSIONS

1. Groundwater flow from the Gasbuggy Site can be reasonably expected to be westward.

2. No radionuclides can be transported by groundwater flow to any point higher than the potentiometric surface of the Ojo Sandstone, which is 300 meters below the surface of the Gasbuggy Site, or 1900 meters above sea level.

3. The path along which radionuclides may travel most rapidly from the Gasbuggy Site is through the Ojo Alamo Sandstone.

4. The San Juan River is the closest place where radionuclides produced by Project Gasbuggy can be expected to discharge at land surface.

5. Based on potentiometric surface slope and distance, the most probable point for radionuclide discharge into the San Juan River from the Gasbuggy Site is near the mouth of Los Pinos River 38 kilometers from the site.

6. The most rapid, credible velocity for groundwater flow from the Gasbuggy Site to the mouth of Los Pinos River is 1.79 centimeters per day. At this rate, groundwater from the Gasbuggy Site can reach the San Juan River in 5900 years.

7. Based on conservative assumptions, all explosion-produced radionuclides migrating from the Gasbuggy Site in groundwater will decay to levels below the appropriate CG before reaching the San Juan River. Tritium will travel a maximum of 2100 meters in 309 years before decaying to a concentration of $1 \times 10^{-3} \mu Ci/ml$ (the CG). Because of their high $K_d$ values, $Sr^{90}$ and $Cs^{137}$ will migrate no farther from the cavity than 320 meters and 3.5 meters, respectively, within 1000 years. By this time, both nuclides will have decayed to well below the appropriate CG.

8. No detectable increase in radioactivity occurred in waters from use points near ground zero one month after the event, based on a comparison between samples collected before and after the event.

# APPENDIX A

## ANALYSES OF DISTRIBUTION COEFFICIENTS OF SELECTED RADIONUCLIDES WITH RESPECT TO CORES FROM HOLE GB-1, PROJECT GASBUGGY

Analyses performed under direction of E. H. Essington
Water from Hole GB-2, Depth 1064-1116 meters, used in analyses
Rock weight used = 5.00g
Water volume used = 20 ml
Suspension time = 72 hrs.
Temperature = 25° C Constant

| Core No. | Depth (meters) | Rock Description | Size (microns) | Distribution Coefficient (ml/g) | |
|---|---|---|---|---|---|
| | | | | $Sr^{85}$ | $Cs^{137}$ |
| 4 | 1097-1098 | Sandstone, fine, light gray | 4000<br>500<br><62 | 1.26<br>1.13<br>1.88 | 139<br>166<br>389 |
| 14 | 1183-1184 | Shaley siltstone, carbonaceous, black | 4000<br>500<br><62 | 8.32<br>9.41<br>9.56 | 309<br>472<br>541 |
| 20 | 1267-1268 | Sandstone, fine, light gray | 4000<br>500<br><62 | 1.37<br>1.36<br>2.08 | 102<br>141<br>298 |
| 318 | 1308-1309 | Sandstone, very fine, silty, dark gray | 4000<br>500<br><62 | 7.76<br>8.37<br>9.79 | 346<br>456<br>630 |

## APPENDIX B

### RECORD OF SPRINGS NEAR THE SITE OF PROJECT GASBUGGY

| SPRING NO.[1] | NAME | DATE | TIME | CONDUCTIVITY umhos | TEMP. °C | FLOW GPM | REMARKS |
|---|---|---|---|---|---|---|---|
| 27.4.1.222 | Peidra Blanca | 6-28-67 | 1030 | 1800 | 13 | - | Spring developed and closed off pipe to water tank. Sample taken at discharge pipe. |
| 27.4.2.232 | Chosa | 6-27-67 | 1540 | 1400 | 8 | - | Spring undeveloped but actively dripping from contact zone. |
| 27.4.9.413 | Agua Bonita | 6-26-67 | 1700 | 1506 | 9.5 | 8.6 | Contact spring. Spring source covered by land slip - pipe opening 15 ft from entrance into hillside. |
| 27.5.1.224 | Tecolote | 6-30-67 | 1230 | 850 | 9 | - | Undeveloped but fenced. |
| 28.4.9.342 | Cedar | 6-28-67 | 1345 | 470 | 13 | $<$ 0.03 | Spring developed as catch basin used for stock watering. |
| 28.4.14.113 | Arnold | 6-27-67 | 0830 | 950 | 8.5 | - | Contact spring. Water taken from spring box. Box positioned 1 - 4 ft from sandstone wall pipe drains box. |
| 28.4.17.311 | Cave | 6-28-67 | 1700 | 370 | 9 | $<$ 0.1 | Spring developed - sample taken from seep pond. |
| 28.4.17.311a | Cave #2 | - | - | - | 9 | - | Spring undeveloped. |
| 28.4.21.444 | Gettem | 6-28-67 | 1400 | 1400 | 6.5 | - | Spring complex - developed one, sampled one, qt. bottle broke; sample trans. to second bottle. |
| 28.4.22.134 | Mud | - | - | - | 11 | 0.1 | Seepage but no collected flow. |
| 28.4.22.241 | Horse | - | - | - | - | - | Min. seepage could not collect sample. Total spring about 75 ft along contact zone. |

APPENDIX B (Continued)

RECORD OF SPRINGS NEAR THE SITE OF PROJECT GASBUGGY

| SPRING NO. | NAME | DATE | TIME | CONDUCTIVITY µmhos | TEMP. °C | FLOW GPM | REMARKS |
|---|---|---|---|---|---|---|---|
| 28.4.23.234 | Ceasar | 6-27-67 | 1100 | 1950 | 13 | - | Spring in bottom of Valencia Canyon Wash. Sample taken from discharge pipe 300 ft down the wash. Spring developed (Cement box covered with silt, not found). |
| 28.4.26.312 | Horn | 6-27-67 | 1420 | 2300 | 9 | - | Spring seepage contact zone. Not flowing. Sampled pond below spring seep. Pond 3 inches deep. Shared water with cow. Must hike to spring from top and drop 100 ft off rock bluff. |
| 28.4.27.444 | Aspen | - | - | - | - | - | Seepage from creek bed outcrop. Undeveloped. |
| 28.4.29.221 | Munoz | 6-28-67 | 1445 | 2000 | 6 | ~ 0.5 | Visible water flow at spring contact zone but water could only be sampled at pipe discharge. Use - stock water. |
| 28.5.25.142 | Russell Arnold Ranch | 6-30-67 | 1200 | 3000 | 9 | - | Upper spring collected. Spring in stock yard fenced. |
| 29.4.19.412 | Bubbling | 6-29-67 | 1730 | 1290 | 7 | 4.3 | Spring on NW side of highway covered and inaccessible but discharge under SE side of highway into stock trough. |
| 29.4.19.421 | | 6-29-67 | 1745 | 900 | 7 | 3.8 | Spring on SE wall of LaJarra Canyon opposite Bubbling Spring. Contact fissure. |

## APPENDIX B (Continued)

### RECORD OF SPRINGS NEAR THE SITE OF PROJECT GASBUGGY

| SPRING NO. | NAME | DATE | TIME | CONDUCTIVITY µmhos | TEMP. °C | FLOW GPM | REMARKS |
|---|---|---|---|---|---|---|---|
| 29.5.24.413 | Amarante | 6-29-67 | 1830 | 815 | 6.5 | ~ 0.6 | Spring issuing from contact on side of hill over LaJarra Canyon. Undeveloped. |
| 29.5.25.114 | Burro | 6-29-67 | 1800 | 740 | 10 | ~ 0.3 | Spring not visible. Spring housing (drain) corrugated metal tank. Sample collected from tank. |

1/ Numbering system conforms to system used in New Mexico by U. S. Geological Survey.

# APPENDIX C

## RECORD OF WELLS NEAR THE SITE OF PROJECT GASBUGGY

| WELL NO.[1/] | NAME | DATE | TIME | CONDUCTIVITY µmhos | TEMP. °C. | REMARKS |
|---|---|---|---|---|---|---|
| 27.3.33.233 | - | - | - | - | - | Well with gasoline pump - out of gas. |
| 28.2.15.144 | Upper Burro Canyon | 6-29-67 | 1200 | 2100 | 10.5 | Well pumping on and off. |
| 28.2.18.331 | Lower Burro Canyon | 6-29-67 | 1400 | 3000 | - | Sample taken from tank storage, pump not working for lack of wind. |
| 28.5.22.221 | - | 6-30-67 | 1050 | 700 | 10 | Well periodically pumping. One gal. from storage tank. One quart from discharge pipe. |
| 29.2.22.441 | Jicarilla | 6-29-67 | 1100 | 1500 | 6.5 | Well off for water level measurement then started pump. Pump 10 minutes for sample. |
| 29.3.20.234 | Jicarilla Apache Indian Reservation | 6-28-67 | 1815 | 2600 | 6 | Well pumping (windmill) collected discharge from well head. |
| 29.4.1.223 | Vaqueros | - | - | - | - | No sample taken,but with bailer sample can be taken. Well is accessible 100 ft. S. of building. Depth to water 32 ft. |
| 29.5.28.244 | - | - | - | - | - | Well not pumping and water in stock trough not representative. |
| 30.3.29.132 | Jicarilla Apache Indian Reservation | 6-28-67 | 1840 | 850 | 8.5 | Well stopped pumping upon arrival but sample collected from trough at well head discharge. |
| 30.4.35.221 | Bixler Ranch | 6-30-67 | 0900 | 1240 | - | Sample taken from faucet in yard of Bixler Ranch farm site. Water from tank storage since well not pumping for lack of wind. Future samples can be taken from well discharge if wind blows. |

1/ Numbering system conforms to system used in New Mexico by U. S. Geological Survey.

## APPENDIX D

### PRE-EVENT RADIOCHEMICAL ANALYSES OF WATERS FROM WELLS AND SPRINGS NEAR THE SITE OF PROJECT GASBUGGY

Samples collected by E. H. Essington and Jerry Mercer, June 1967: analyzed by E. J. Forslow, September 1967.

| Well or Spring Number | Total Dissolved Solids | Potassium | GROSS RADIOACTIVITY[a] | | | |
|---|---|---|---|---|---|---|
| | | | As Dissolved Solids | | As Suspended Solids[b] | |
| | | | $\beta,\gamma$,[c,d] | $\alpha$ | $\beta,\gamma$[c] | $\alpha$[e] |
| | milligrams per liter | milligrams per liter | picocuries per liter | picocuries per liter | picocuries per liter | picocuries per liter |
| Wells: | | | | | | |
| 28.2.15.144 | 1341 | .8 | 3.1 ± 2.5 | < 3.3 | 0.58 ± 0.57 | < 0.3 |
| 28.2.18.331 | 1842 | 1.8 | 2.6 ± 3.1 | < 4.1 | 0.5 | < 0.3 |
| 28.5.22.21 | 156 | .3 | 2.7 ± 2.6 | < 1.6 | 2.4 ± 1.9 | < 0.9 |
| 29.2.22.441 | 915 | .6 | < 1.5 | < 4.0 | 0.77 ± 0.58 | < 0.3 |
| 29.3.20.234 | 1524 | 1.5 | 3.5 ± 2.7 | < 3.3 | 0.70 ± 0.53 | < 0.3 |
| 30.3.29.132 | 533 | .5 | 2.4 ± 2.8 | < 4.2 | 2.7 ± 2.2 | < 1.2 |
| 30.4.35.221 | 635 | 1.1 | 4.0 ± 2.2 | < 2.4 | 1.2 ± 0.6 | < 0.3 |
| Springs: | | | | | | |
| 27.4.1.222 | 1257 | 1.3 | 1.8 ± 2.6 | < 4.1 | < 0.6 | < 0.3 |
| 27.4.2.232 | 964 | 1.0 | 4.0 ± 2.1 | < 3.2 | 0.98 ± 0.56 | < 0.3 |
| 27.4.9.413 | 1054 | 1.1 | 2.3 ± 3.0 | 6.2 ± 6.2 | 4.2 ± 2.4 | < 0.3 |
| 27,5.1.224 | 453 | 1.5 | 10.3 ± 2.6 | 2.7 ± 3.4 | 1.5 ± 0.4 | < 1.2 |
| 28.4.14.113 | 616 | 1.1 | 3.1 ± 2.3 | 3.7 ± 4.6 | 0.73 ± 0.55 | < 0.3 |
| 28.4.17.311 | 167 | .5 | 2.6 ± 1.5 | < 1.4 | 0.82 ± 0.53 | < 0.3 |
| 28.4.21.444 | 864 | .9 | 1.2 ± 2.1 | < 3.9 | 0.91 ± 0.57 | < 0.3 |
| 28.4.23.234 | 1518 | .7 | 6.0 ± 2.9 | < 3.3 | 0.86 ± 0.56 | < 0.3 |

PRE-EVENT RADIOCHEMICAL ANALYSES OF WATERS FROM WELLS AND SPRINGS NEAR THE SITE OF PROJECT GASBUGGY

| Well or Spring Number | Total Dissolved Solids | Potassium | GROSS RADIOACTIVITY[a] As Dissolved Solids $\beta, \gamma$,[c,d] | As Dissolved Solids $\alpha$ | As Suspended Solids[b] $\beta, \gamma$[c] | As Suspended Solids[b] $\alpha$[e] |
|---|---|---|---|---|---|---|
| | milligrams per liter | milligrams per liter | picocuries per liter | picocuries per liter | picocuries per liter | picocuries per liter |
| 28.4.26.312 | 1608 | 1.4 | 1.8 $\pm$ 2.9 | < 3.9 | 1.3 $\pm$ 0.6 | < 0.3 |
| 28.4.29.221 | 1230 | .7 | 1.0 $\pm$ 2.5 | < 3.3 | 0.97 $\pm$ 0.66 | < 0.3 |
| 28.5.25.142 | 1970 | 1.0 | 4.3 $\pm$ 4.5 | < 6.3 | 4.5 $\pm$ 1.9 | < 0.3 |
| 29.4.19.412 | 766 | .8 | 2.0 $\pm$ 1.9 | < 3.2 | 0.83 $\pm$ 0.55 | 1.6 $\pm$ 1.1 |
| 29.4.19.421 | 499 | .4 | 2.2 $\pm$ 1.9 | < 3.2 | 0.86 $\pm$ 0.55 | < 0.3 |
| 29.5.24.413 | 522 | .5 | 1.6 $\pm$ 1.9 | < 2.6 | 0.86 $\pm$ 0.55 | < 0.3 |
| 29.5.25.114 | 447 | .2 | 4.2 $\pm$ 2.1 | < 3.1 | 0.97 $\pm$ 0.56 | < 0.3 |

a/ Detection Limits - Set at three standard deviations above the background count.

Counting Errors - The uncertainty values represent the statistical counting errors only calculated at the 95% confidence level.

b/ Suspended Solids - Separated by filtration through 0.45 micron filters.

c/ Gross beta, gamma activities are reported as $Cs^{137}$ equivalent.

d/ Corrected for $K^{40}$.

e/ Gross alpha activities are reported as $U^{233}$ equivalent.

# APPENDIX E

## POST-EVENT RADIOCHEMICAL ANALYSES OF WATERS FROM WELLS AND SPRINGS NEAR THE SITE OF PROJECT GASBUGGY

Samples collected by J. E. Leisek and Daniel Churchfield, December 1967 and January 1968
Analyzed by E. J. Forslow, March 1968

| Well or Spring Number | Date Sample Collected | GROSS RADIOACTIVITY[a] As Dissolved Solids (pCi/l) $\beta,\gamma$[c,d] | $\alpha$ | As Suspended Solids[b] (pCi/l) $\beta,\gamma$[c] | $\alpha$ |
|---|---|---|---|---|---|
| 28.4.14.113 | Dec. 16, 1967 | 2.6 ± 1.6 | 4.1 ± 5.3 | 1.3 ± 0.4 | 0.5 ± 0.3 |
| " | Jan. 7, 1968 | 1.1 ± 1.5 | <3 | 0.9 ± 0.4 | <0.1 |
| 29.3.20.234 | Jan. 11, 1968 | 0.0 ± 2.1 | <7 | 0.8 ± 0.4 | 0.3 ± 0.2 |
| 29.4.19.412 | Dec. 16, 1967 | 1.0 ± 1.5 | <7 | 0.4 ± 0.4 | <0.2 |
| " | Jan. 7, 1968 | 1.1 ± 1.5 | <4 | <0.3 | <0.1 |
| 29.4.35.34[f] | Jan. 7, 1968 | 8.4 ± 1.4 | 1.0 ± 1.2 | 1.1 ± 0.3 | 0.3 ± 0.2 |

(a) Detection Limits - Set at three deviations above the background count.

Counting Errors - The uncertainty values represent the statistical counting errors only calculated at the 95% confidence level.

(b) Suspended Solids - Separated by filtration through 0.45 micron filters.

(c) Gross beta, gamma activities are reported as $Cs^{137}$ equivalent.

(d) Not corrected for $K^{40}$.

(e) Gross alpha activities are reported as $U^{233}$ equivalent.

(f) Sample collected from Laguna Seca in Sec. 35, T. 29 N., R. 4 W. Laguna Seca was not sampled in June 1967 because of cattle in lake.

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PROJECT GASBUGGY

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| SL | PNE-1002 | Gasbuggy Seismic Source and Surface Motion |
| LRL | PNE-1003 | Preliminary Post-Shot Summary |
| EPNG | PNE-G-9 | Drilling & Testing Operations |
| LRL | PNE-G-10 | Gas Quality Investigation Program Status Rpt. |
| LRL | PNE-G-11 | Post-Shot Geologic Investigation |
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| JAB | PNE-1012 | Final Report on Structural Responce |
| USGS | PNE-1013 | Hydrology of Project Gasbuggy Site, Rio Arriba County, New Mexico |
| USC&GS | PNE-1014 | Seismic Measurements |
| NV | PNE-G-12 | Operational Safety Aspects |

D. SAFETY REPORTS - (to be prepared)

| | | |
|---|---|---|
| EIC | PNE-1006 | On-Site Radiological Safety |
| USPHS | PNE-1007 | Off-Site Radiological Surveillance |
| ESSA/ARFRO | PNE-1008 | Weather and Radiation Predictions |

## E. ABBREVIATIONS OF ORGANIZATIONS

| | |
|---|---|
| EIC | Eberline Instruments Corp., Santa Fe, N.M. |
| EPNG | El Paso Natural Gas Co., El Paso, Texas |
| ERC | Environmental Research Corp., Alexandria, Va. |
| ESSA/ARFRO | Environmental Science Services Administration/ Air Resources Field Research Office, Las Vegas, Nev. |
| II | Isotopes, Inc., Palo Alto, California |
| JAB | John A. Blume & Associates, San Francisco, Calif. |
| LRL | Lawrence Radiation Laboratory, Livermore, Calif. |
| NV | USAEC Nevada Operations Office, Las Vegas, Nevada |
| SL | Sandia Laboratory, Albuquerque, N.M. |
| USAEC | U. S. Atomic Energy Commission |
| USBM | Bureau of Mines, U. S. Department of the Interior |
| USC&GS | U. S. Coast & Geodedic Survey, Las Vegas, Nev. |
| USGS | U. S. Geological Survey, Denver, Colo. |
| USPHS | U. S. Public Health Service, Las Vegas, Nev. |

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