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GASBUGGY

HYDROLOGY OF PROJECT
GASBUGGY SITE,
RIO ARRIBA COUNTY,
NEW MEXICO

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGY OF PROJECT GASBUGGY SITE,
RIO ARRIBA COUNTY, NEW MEXICO

By

Jerry W. Mercer

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Authorizing Official

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September 1969

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ABSTRACT

The Project Gasbuggy nuclear experiment of 26 kilotons design yield was detonated at 4,240 feet below ground surface at the Gasbuggy site in the SW $\frac{1}{4}$ sec. 36, T. 29 N., R. 4 W., Rio Arriba County, New Mexico, on Sunday, December 10, 1967, 1230 mountain standard time. The experiment was designed to increase the permeability of a low-yield natural gas formation.

The Ojo Alamo Sandstone reportedly was the only aquifer within probable range of fracturing at the site. Thus, hydrologic testing in the exploratory holes was in that sandstone between approximate depths of 3,475 and 3,650 feet.

Data from packer tests determined that the average transmissivity of the Ojo Alamo Sandstone is less than 3 gallons per day per foot and that relative specific capacities are less than 0.03 gallon per minute per foot of drawdown. Tests also showed that the hydraulic pressure in the Ojo Alamo Sandstone is greater than the gas pressure in the Pictured Cliffs Sandstone. These data indicated that if the nuclear detonation fractured the Ojo Alamo Sandstone, water from this sandstone would fill the chimney or detonation chamber at an estimated rate of less than half a foot per day. The low transmissivity of the sandstone aquifer would hinder the transport of radioactive contaminants in water in the aquifer, even if momentary overpressure in the explosion cavity caused contaminants to reach the Ojo Alamo Sandstone.

Observation of water levels in wells and measurements of yields of springs preshot, at shot time, and postshot indicate that the detonation did not significantly or permanently disturb nearby water wells or springs.

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INTRODUCTION

Historical Description of the Gasbuggy Event ^{1/}

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 4,240 feet below ground surface, 1,770 feet from the West line and 1,218 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 -- $36^{\circ}40'40.4''$ North; and longitude -- $107^{\circ}12'30.3''$ West. The elevation of surface ground zero was 7,204 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 gas-bearing Pictured Cliffs Sandstone.

Early indications are that the explosive performed satisfactorily.

^{1/} This statement is the official description provided by the U.S. Atomic Energy Commission after the event.

Objectives

Where underground nuclear devices are detonated, ground- and surface-water contamination is a possibility if radioactivity escapes through fractures radiating upward from the detonation chamber and intersecting water-bearing formations. In addition, water inflow through the fractures could fill the chimney.

To provide data useful in evaluating hydrologic problems at and near the Project Gasbuggy site, the U.S. Atomic Energy Commission asked the U.S. Geological Survey to (1) provide preshot hydrologic data from exploratory holes at Project Gasbuggy site; (2) inventory and examine wells and springs within a 10-mile radius of ground zero before the detonation; and (3) monitor fluctuations of water levels in wells and discharge of springs during and immediately following the detonation.

Background

Two exploratory holes, GB-1 and GB-2, were drilled to 4,308 and 4,247 feet, respectively, at the Gasbuggy site (fig. 1). Order of penetration into the various formations was: San Jose, Nacimiento, and Ojo Alamo Formations of Tertiary age (Baltz, Ash, and Anderson, 1966), and Kirtland Shale, Fruitland Formation, Pictured Cliffs Sandstone, and Lewis Shale of Late Cretaceous age. The Pictured Cliffs Sandstone was of primary importance because within this formation the chimney was formed by block-caving and (or) collapse activity after detonation of the nuclear device in the underlying Lewis Shale.

Figure 1.-- Location of exploratory holes GB-1 and GB-2, Project Gasbuggy site, Rio Arriba County, N. Mex.

Topography

Project Gasbuggy site (fig. 2) lies in the eastern part of the San Juan Basin, a structural feature in the eastern part of the Navajo physiographic section of the Colorado Plateau Province. Structural elements of the basin (fig. 2) were named and described by Kelley (1950, p. 101-104). The roughly circular basin is about 180 miles long and 135 miles wide. Except for badland surfaces in areas of sedimentary rocks of Tertiary age, young plateaus with moderate to strong relief characterize the central part of the basin. The Gasbuggy site is within the Central Basin structural element.

The central part of the San Juan Basin drains mostly northwest to the San Juan River. However, tributaries of the Little Colorado River drain most of the south and west sides of the basin; and the extreme southeastern part lies in the Rio Grande drainage basin.

Lithology

Rocks in and around the San Juan Basin range in age from Precambrian to Holocene. Nonmarine sedimentary rocks of early Tertiary age blanket the central part of the basin. Marine and nonmarine strata of Late Cretaceous age surround the Tertiary sedimentary rocks. Older Mesozoic and Paleozoic sedimentary rocks encircle the Cretaceous rocks and mark the outer limits of the depressed part of the basin. Facies changes and intertonguing of marine and nonmarine strata are common throughout the area. The sedimentary rocks in the center of the basin range in thickness from 10,000 to 15,000 feet. Small intrusive plugs, dikes, and flows of basalt occur along the margins of the basin.

Figure 2.--Major structural elements of the San Juan Basin, New Mexico (from Kelley, 1950).

Nacimient and San Jose Formations.--The Nacimient and the San Jose Formations are continental flood plain deposits and are the predominant surface formations in the Project Gasbuggy area. At the test site, they compose a 3,500-foot sequence of fine- to medium-grained, locally conglomeratic sandstone, interbedded with claystone and sandy variegated shale. The thick beds of sandstone in these formations commonly contain water throughout the central part of the San Juan Basin.

Ojo Alamo Sandstone.--The Ojo Alamo Sandstone overlies the Kirtland Shale; it is about 180 feet thick at Project Gasbuggy test site. The formation consists primarily of a light-gray, fine- to medium-grained, clayey sandstone but also contains a few minor beds of shale. The Ojo Alamo Sandstone is water bearing and yields water to domestic wells along the San Juan River 50 miles west of the test site where the formation is 1,700 feet higher than it is at the Gasbuggy site. At the test site, the formation yields minor amounts of water.

Fruitland Formation and Kirtland Shale.--The Fruitland Formation and the Kirtland Shale overlie the Pictured Cliffs Sandstone in ascending stratigraphic order. These formations compose a 260-foot interval of gray to dark-green shale and siltstone interbedded with thin, very fine- to medium-grained sandstone. Abundant carbonaceous material and coal generally are associated with the beds of shale. Coal stringers in the Fruitland Formation yield small amounts of water in some parts of the basin. Exploratory hole GB-1 was drilled with gas as the circulating fluid through the lower part of the Kirtland Shale and through the Fruitland Formation. The cuttings recovered during this drilling were dry, and there were no other indications of water yield from these formations.

Pictured Cliffs Sandstone.--The Pictured Cliffs Sandstone is predominantly a marine sandstone, underlain by the Lewis Shale and overlain by the Fruitland Formation. At the Gasbuggy site, the Pictured Cliffs Sandstone is about 290 feet thick and is chiefly a light-gray, fine- to very fine-grained sandstone interbedded with dark, sandy shales. The sandstone beds bear natural gas and contain minor coal fragments, carbonaceous layers, and traces of oil. The formation yields only small amounts of water in the San Juan Basin. Exploratory hole GB-1 was drilled through the Pictured Cliffs Sandstone with gas as the circulating fluid without noticeable indications of water yield. After the hole was completed, water filled only the lower 10 feet of hole in 18 hours of observation.

Well- and spring-numbering system

All wells and springs discussed in this report are identified by a location number used by the Geological Survey and the New Mexico State Engineer's office for numbering water wells in New Mexico. The location numbers are based on townships, ranges, sections, and tracts within a section. The first three parts of the number, separated by decimal points, represent the township north, range west, and section number, respectively. For convenience, the quarters of a section are numbered 1, 2, 3, and 4. The first digit of the last part of the number gives the quarter section, the second digit gives the quarter of that quarter and the third digit designates the 10-acre tract. Letters a, b, c, and so on are added to the last part of the number to designate the second, third, fourth, and succeeding wells or springs listed in

Figure 3.--System of numbering wells and springs in New Mexico.

the same 10-acre tract. For example, the location of well 19.2.3.122 in Rio Arriba County is the NE¹/₄NE¹/₄NW¹/₄ of sec. 3, T. 19 N., R. 2 W. Springs are numbered in the same manner, except that the letter "S" precedes the number.

Theory

Underground nuclear explosions generally fracture the surrounding rocks. The volume of broken rock and the distance that fractures extend from the shot point depend on the yield of the device and the properties of the rock. The design yield of 26 kilotons was not expected to create continuous fractures from the point of explosion to water-bearing sandstones higher in the stratigraphic section (El Paso Natural Gas Company, and others, 1965). Should the fractures have extended upward to the Ojo Alamo Sandstone, or higher beds of water-bearing sandstone, the rubble chimney could be flooded with water and, conversely, radioactive contaminants could momentarily move into the beds of water-bearing sandstone, while the gas overpressure due to the explosion still existed.

PROCEDURE

Hydraulic Test and Sampling

Hydraulic testing was designed to determine how much water might enter the chimney if the Ojo Alamo Sandstone were ruptured by fractures extending upward from the chimney. Testing was not scheduled in the San Jose and Nacimiento Formations above the Ojo Alamo Sandstone, because these formations are well above the expected position of the

top of the chimney and zone of radial fractures and because previous drilling and testing in the area indicates that hydrostatic head decreases with depth.

Procedures for testing selected zones in the Ojo Alamo Sandstone in holes GB-1 and GB-2 were similar. With deepening of the holes, test intervals were isolated with a Lynes packer attached to the drill stem and were then tested. Tubing was then inserted into the drill stem to a depth of about 3,000 feet and a swab was run in the tubing to remove fluid from the hole. All measurements during testing are referenced to lsd (land-surface datum). Land surface altitude at GB-1 is 7,198 feet and at GB-2 is 7,198.6 feet above mean sea level.

Hole GB-1

The upper test zone (3,463-3,563 feet) in the Ojo Alamo Sandstone was swabbed twice (fig. 4). On February 23, 1967, fluid was swabbed from a depth of 3,000 feet for 146 minutes at an estimated rate of 5.3 gpm (gallons per minute) (fig. 5). After swabbing, the fluid level was approximately 2,700 feet below lsd. The specific conductance of the fluid removed from the test zone during the latter part of the swabbing period was 9,000 micromhos per cm at 25°C. Water samples for chemical analysis were collected immediately before the end of swabbing. During 349 minutes of water-level recovery measurements after swabbing, the water level recovered to 1,685 feet.

During the second swab test in the upper test zone, on February 24, 1967 (fig. 6), fluid was swabbed from a depth of 3,300 feet for 217 minutes at an estimated rate of 5.3 gpm. After swabbing, the

DEPTH
IN
FEET
BELOW
lsd

REMARKS

	San Jose and Nacimiento Formation:		
3463		} Water test zones	Transmissivity 0.4 gallon per day per foot. Static water level about 1,000 feet below lsd.
3563	Ojo Alamo Sandstone		
3642			Transmissivity 2.6 gallons per day per foot.
3684	Kirtland Shale		
3747		-	
3767		-	The Fruitland Formation was cored using gas as the circulating fluid. Exhaust gas and cuttings showed no indication of water. When the hole was 3,806 feet deep, the electric probe was lowered to depth of 3,738 feet (length of line) but showed no indication of water.
3806	Fruitland Formation		
3902			Dry cuttings obtained from gas carrier. Some cores recovered from lower part of Pictured Cliffs Sandstone and from Lewis Shale were wet. Ten feet of water in hole about 18 hours after test hole was cleaned out to total depth.
	Pictured Cliffs Sandstone		
4191	Lewis Shale		Total depth 4,308 feet.

ion

Figure 5 --Recovery of water level in hole GB-1 after first swabbing test of upper zone of Ojo Alamo Sandstone, February 23, 1967.

Figure 6.--Recovery of water level in hole GB-1 after second swabbing test of upper zone of Ojo Alamo Sandstone, February 24, 1967.

fluid level was approximately 3,000 feet below lsd. Specific conductance of the fluid removed from the test zone was 9,000 micromhos per cm at 25°C. During 436 minutes of water-level recovery measurements after swabbing, the water level recovered to 1,434 feet. To expedite recovery of the fluid to static level, water was injected into the tubing for 1 hour at a rate of 2.5 gpm.

The lower test zone (3,563-3,642 feet) of hole GB-1 in the Ojo Alamo Sandstone was swabbed twice. On February 26, 1967, fluid was swabbed from a depth of 3,000 feet for 179 minutes at an estimated rate of 14 gpm (fig. 7). After swabbing, the fluid level was approximately 2,300 feet. Specific conductance of the fluid removed from the test zone during the latter part of the swabbing was 9,000 micromhos per cm at 25°C. Water samples for chemical analysis were collected immediately before the end of swabbing. During 470 minutes of water-level recovery measurements after swabbing, the water level recovered to 1,032 feet.

On February 27, 1967, fluid in hole GB-1 was swabbed from a depth of 3,000 feet for 213 minutes at an estimated rate of 13 gpm. After swabbing, the fluid level was approximately 2,350 feet. Water-level recovery measurements were not made after swabbing.

Hole GB-2

On April 17, 1967, the Ojo Alamo Sandstone in hole GB-2 was hydraulically tested in the depth interval 3,465 to 3,649 feet (fig. 8). Fluid was swabbed from a depth of 3,000 feet for 225 minutes at an estimated rate of 9.5 gpm (fig. 9). After swabbing, the fluid level

Figure 7.--Recovery of water level in hole GB-1 after first swabbing test of lower zone of Ojo Alamo Sandstone, February 26, 1967.

DEPTH
IN
FEET
BELOW
lsd

REMARKS

	San Jose and Nacimient Formation		
3465	Ojo Alamo Sandstone	Water test zones	Transmissivity 2.9 gallons per day per foot. Static water level about 1,000 feet below lsd.
3637	Kirtland Shale and Fruitland Formation		
3900	Pictured Cliffs Sandstone		Dry cuttings obtained from gas carrier.
4184	Lewis Shale		Total depth 4,247 feet

Figure 8 --Formations tested and remarks on hydrologic conditions
in hole GB-2, April 17, 1967.

Figure 9.--Recovery of water level in hole GB-2 after swabbing test of Ojo Alamo Sandstone, April 17, 1967.

was approximately 1,600 feet. Specific conductance of the fluid removed from the test zone during the latter part of the swabbing period was 9,000 micromhos per cm at 25°C. Water samples for chemical analysis were collected immediately before the end of swabbing. During 360 minutes of water-level recovery measurements, the water level recovered to 1,018 feet.

Water samples for determination of chemical constituents, physical properties, gross alpha, gross beta, and tritium were collected from the Ojo Alamo Sandstone during swabbing tests in holes GB-1 and GB-2.

Calculations

Analysis of recovery curves

Equation 1 was used for analyzing the recovery properties of the hydrologic tests.

$$T = \frac{264Q}{s} \log_{10} \frac{t}{t'} \quad (1)$$

T = Transmissivity in gallons per day per foot

s = Residual drawdown in feet

t = Time since swabbing began

t' = Time since swabbing stopped

Q = Swabbing rate in gallons per minute

Time may be in any unit, as the term t/t' becomes dimensionless by cancellation of units. However, time in minutes is recorded in the data tables. Over one log cycle, $\log_{10} t/t'$ becomes unity; s equals Δs or change in s: and then

$$T = \frac{264Q}{\Delta s} \quad (2)$$

The recovery data were also used to compute the relative specific capacity of the interval tested, a common practice for estimating water inflow to mined chambers at the Nevada Test Site. The equation used to compute specific capacity is as follows:

$$\text{Relative specific capacity} = \frac{Q}{(h' - h)} \quad (3)$$

where: Q = Gallons of water accepted by an interval isolated with straddle packers during 1-minute time span. The time span 3-4 minutes after the tool is opened is commonly used.

h = Static water level of the hole, or interval tested, in feet below land surface.

h' = Average water level in the tubing, in feet below land surface, in 1-minute time span used for determining Q. The water level at 3.5 minutes is used.

Estimated water flow into chimney

Equations 4 and 5 (Jacobs and Lohman, 1952) were used to estimate rates of water flow into the rubble chimney should the rubble chimney for some unpredictable reason extend upward to the Ojo Alamo Sandstone:

$$Q = \frac{T s G(\alpha)}{229} \quad (4)$$

$$C Y = \frac{0.134 T t}{r_e s} \quad (5)$$

where: Q = Discharge of well, in gallons per minute

T = Transmissivity, in gallons per day per foot

s = Constant drawdown in the discharging well, in feet

t = Time since pumping began, in days

r_e = Effective radius of the discharging well, in feet

S = Storage coefficient, a decimal

and values of $G(\alpha)$ have been tabulated by Jacobs and Lohman (1952). The calculation proceeds on the following assumptions which represent the worst conceivable situation: The chimney intercepts the entire aquifer; water is released to atmospheric pressure.^{2/} Values of α (equation 5) for a particular time are then calculated from assumed values of transmissivity, effective radius of the rubble chimney, and storage coefficient. $G(\alpha)$ can then be obtained from the reference and flow rate into the chimney for the time calculated. If the porosity and the radius of the chimney are known, one can compute the rate of rise of water level in the chimney as a function of time.

In computing potential flow of water into a rubble chimney extending through the Ojo Alamo Sandstone, the following values of variables were used in equations 4 and 5:

Transmissivity = 3.0 gallons per day per foot

Constant drawdown = 2,654 feet (bottom of aquifer, 3,654 feet,
minus static water level,
1,000 feet)

^{2/} Although the gas pressure in the Pictured Cliffs Sandstone is less than the hydrostatic pressure in the Ojo Alamo Sandstone, the pressure in the chimney would not approach atmospheric except during uncontrolled flow of gas from the chimney.

Storage coefficient = 1×10^{-4}

Radius of rubble chimney = 160 feet

Porosity = 20 percent.

In 5 days after detonation of the Project Gasbuggy nuclear explosive, the water level in the chimney would rise 2.3 feet; in 10 days after the detonation it would rise 4.0 feet. If the assumed values of the variables are correct and if equations 4 and 5 apply to the assumed conditions, the water-level rise in the chimney will be less than half a foot per day.

Preshot Investigation of Wells and Springs

All known wells and springs within a 5-mile radius of ground zero were investigated during June 1967 as were all accessible wells and springs between the 5- and 10-mile radius. Locations of these wells and springs are plotted on figure 10 and listed in tables 2 (wells) and 3 (springs). The 13 wells investigated range in depth from 54 to 229 feet and are completed in alluvium. Well yields in the range 1 to 3 gpm are considered good. Specific conductance of the water ranges from 700 to 2,600 micromhos per cm at 25°C.

Twenty-three springs of the contact type were investigated. The springs discharge from sandstones in the San Jose Formation of Eocene age. Some of the springs are seeps with little or no visible flow; others are characterized by yields generally ranging from 1 to 8 gpm. Specific conductance of spring water ranges from 370 to 2,300 micromhos per cm at 25°C.

Figure 10.--Location of wells and springs within a 10-mile radius of Project Gasbuggy site.

Table 1.--Record of wells inventoried within a 10-mile radius of Project Gasbuggy Site, Rio Arriba County, N. Mex.

Location number: See test for explanation of well-numbering system.

Depth: Depths listed are measured depths to the nearest foot.

Diameter: Diameter of the casing to the nearest inch.

Altitude: Altitude of land surface at well. Altitude interpolated from U.S.C.S. topographic maps, scale 1:24,000 and contour interval 20 feet.

Water level: Measured depths below land surface, to nearest tenths of a foot.

Stratigraphic unit: Q1 - Alluvium.

Type of pump: P - plunger or cylinder; N - none.

Type of power: W - wind; I - internal combustion.

Use of water: D - domestic; S - stock.

Note: Unless specified, all wells are drilled and cased to total depth.

Location no.	Owner or name	Year completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water level		Stratigraphic unit	Pump	Power	Use of water	Distance from ground-zero (miles)	Specific conductance (micro-mhos per cm at 25°C)	Remarks
						Depth below land surface (feet)	Date							
28.2.15.14	Jicarilla Apache Reservation	-	152	6	7,236	110.2	6-29-67	Qal	P	W	S	10.2	2,100	Upper Burro Canyon well.
28.2.18.33	do	-	229	6	7,089	72.2	6-29-67	Qal	P	W	S	7.1	3,000	Lower Burro Canyon well.
28.3.33.23	do	-	81	6	6,920	51.8	6-29-67	Qal	P	I	S	6.3	-	--
28.5.16.21	U.S. Bur. Land Management	-	95	6	6,580	57.5	6-30-67	Qal	P	I	S	8.6	-	--
28.5.22.22	do	-	-	-	6,698	-	-	-	P	W	S	7.5	700	Yield 1 gpm; temp 50°F.
28.5.35.14	Russell Arnold	1950	-	6	6,630	-	-	Qal	P	I	D,S	7.9	-	Reported yield 11 gpm; reported depth 54 ft.
29.2.22.44	Jicarilla Apache Reservation	1962	198	6	7,150	174.1	6-29-67	Qal	P	W	S	10.2	1,500	Yield 1 gpm; temp 44°F.
29.3.20.23	do	-	75	7	6,875	22.2	6-29-67	Qal	P	W	S	3.1	2,600	Yield 3 gpm; temp 43°F.
29.4. 1.223	J.S. Forest Service	1953	115	7	6,680	29.9	6-30-67	Qal	N	N	N	5.6	-	Vaqueros well old ranger station.
29.5.28.422	J.S. Bur. Land Management	-	130(?)	7	6,650	122.4	6-30-67	Qal	P	W	S	8.2	-	--
30.3.29.132	Jicarilla Apache Reservation	-	-	7	7,235	-	-	-	P	W	S	7.5	850	Yield 2 gpm; temp 47°F.
30.3.32.343	do	-	200	7	7,038	64.1	6-29-67	Qal	P	W	S	5.9	-	--
30.4.35.22	Red Bixler	-	175	6	7,140	52.7	6-29-67	Qal	P	W	D	6.6	-	Reported yield 3 gpm.

Table 2.--Records of springs inventoried within a 10-mile radius of Project Gasbuggy Site, Rio Arriba County, N. Mex.

Location number: Number preceded by S designates spring location (see text for explanation of well-numbering system).

Altitude: Altitude of land surface at spring, altitude interpolated from U.S.G.S. topographic map, scale 1:24,000 and contour interval 20 feet.

Stratigraphic unit: Qal - Alluvium; Tsj - San Jose Formation.

Yield: Measured unless specified.

Use: N - none; S - stock.

Location no. Location	Owner	Name	Topographic situation	Altitude (feet)	Stratigraphic unit	Yield (gpm)	Date	Use of water	Temperature (°F)	Distance from ground-zero (miles)	Specific conductance (micro-mhos per cm at 25°)	Remarks
S27. 4. 1.222	S. Forest Service	Piedra Blanca	stream channel	6,960	Tsj	0.2	6-29-67	S		4.9		Temp 55°F at discharge point, developed spring.
S27. 4. 2.232	do	Chosa	do	7,095	Tsj	.1	6-27-67	N	46	5.0	1,400	Discharge from SS above SH.
S27. 4. 2.234	do	Willow	do	7,050	Tsj	.1	6-27-67	N	43	5.2	2,200	--
S27. 4. 9.414	do	Agua Bonita	Hillside	6,730	Tsj	8.6	6-26-67	S	49	7.1	1,500	Good spring, developed.
S27. 5. 1.224	do	Tecolota	stream channel	7,190	Tsj		6-10-67	9	48	7.0	850	Damaged; yield not measured.
S28. 4. 9.342	do	Cedar	Hillside	7,150	Tsj	0.1	6-21-67	3	47	2.6	470	Partially developed.
S28. 4.14.113	do	Arnold	do	7,200	Tsj	0.1	6-23-67	N	47	1.1	950	--
S28. 4.17.311	do	Cave	do	7,410	Tsj	.1	6-21-67	S	48	1.2	370	Partially developed, stock tank.
S28. 4.21.444	do	Gettem	stream channel	7,200	Tsj	.2	6-28-67	3	44	3.4	1,400	--
S28. 4.21.444	do	-	do	7,200	Tsj	0.1	6-28-67	N	43	1.4		--
S28. 4.22.134	do	Mud	do	7,210	Tsj		6-27-67	S	52	2.9		Series of seeps. Called Hungry by U.S. Forest Service.
S28. 4.22.241	do	Horse	do	7,260	Tsj		6-23-67	N	41	2.4		Seep.
S28. 4.23.234	do	Caesar	do	7,130	Qal	0.6	6-23-67	S		2.1	1,950	Developed, stock tank seepage in excess of measured flow.
S28. 4.26.312	do	Horn	do	7,180	Tsj	.1	6-27-67	N	48	3.4	2,300	Called Aspen by U.S. Forest Service
S28. 4.27.444	do	Aspen	do	7,135	Tsj	.1	6-27-67	N	34	3.8		Seep, called Horn by U.S. Forest Service.
S28. 4.29.221	do	Munoz	Hillside	7,080	Tsj	.5	6-21-67	S	43	4.1		--
S28. 5.25.142	Arnold Ranch	-	valley flat	6,780	Tsj(?)		6-30-67	S	48	6.4		Seep.
S28. 5.25.142	do	-	do	6,790	Tsj(?)		6-30-67	S	47	6.4		Seep.
S29. 4.19.412	do	Bubbling	do	6,555	Tsj	4.3	6-23-67	3	45	5.1	1,290	Developed.
S29. 4.19.421	do	-	do	6,570	Tsj	40	6-23-67	N	45	4.9	900	--
S29. 4.25.241	do	Campo	stream channel	6,920	Tsj		6-22-67	N	45	1.5		Seep.
S29. 5.24.413	do	Amarante	Hillside	6,570	Tsj	.6	6-23-67	N	44	5.8	815	--
S29. 5.25.132	do	Burro	do	6,580	Tsj	0.3	6-23-67	S	50	6.0	140	Developed, stock tank.

Measurements of Wells and Springs

Water levels in five wells and discharges in five springs were measured on December 8, 1967. On December 10, a few hours after the nuclear shot, repeat measurements were made in these same wells and springs. During the shot, recording instruments were in operation in one well and in two springs. The well (29.3.20.234), 3.1 miles from ground zero, was monitored by an electro-mechanical recorder with a , chart time drive of 2 inches per minute and a water-level magnified response ratio of about 2:1. The pressure-sensing unit (strain-gage transducer) was installed 65 feet below the water level in the well. Mechanical recorders were installed on springs 5.1 miles northwest (S29.4.19.412) and 7.1 miles southwest (S27.4.9.414) of ground zero. Table 3 lists the wells and springs observed at, or near shot time, and the observations made in them.

Table 3.--Wells and springs observed at, or near, shot time, Project Gasbuggy, Rio Arriba County, N. Mex.

Location no.: See text for explanation of numbering system.

Location no.	Owner	Name	Water level, depth below land surface (feet)		Yield (gpm)		Remarks
			Date		Date		
			12-8-67	12-10-67	12-8-67	12-10-67	
28.5.16.213	U.S. Bur. Land Management	--	58.80	58.84	--	--	--
29.3.20.234	Jicarilla Apache Reservation	--	21.30	20.41	--	--	Instrumented.
29.4.1.223	U.S. Forest Service	Old Vaquero well	37.37	37.84	--	--	
30.3.32.343	Jicarilla Apache Reservation	--	61.76	62.42	--	--	--
30.4.35.22	Fred Bixler	--	56.31	57.93	--	--	Well had been pumped shortly before measurement of 12-10-67.
27.4.9.414	U.S. Forest Service	Agua Bonita	--	--	8.75	8.87	Instrumented.
28.4.17.311	do	Cave	--	--	.08	.12	--
29.4.19.412	Arnold Ranch	Bubbling	--	--	4.23	4.35	Instrumented.
29.4.19.421	do	--	--	--	9.30	10.00	--
29.5.24.413	do	Amarante	--	--	.50	.35	--

RESULTS

In hole GB-1, the transmissivity of the Ojo Alamo Sandstone is about 0.4 gpd per ft in the upper 100 feet and 2.6 gpd per ft in the lower 70 feet. In hole GB-2, the transmissivity of the sandstone is 2.9 gpd per ft. Calculated relative specific capacities are 0.003 gpm per ft in the upper zone and 0.016 gpm per ft in the lower zone of hole GB-1 and 0.026 gpm per ft in hole GB-2.

Temperature of the formation fluid at the well head (GB-1) during swabbing was 112°F.

The hydraulic conductivity of the Ojo Alamo Sandstone is about 0.017 gpd per sq ft. This value was derived by using a transmissivity of 3 gpd per ft and an effective aquifer thickness of 180 feet. The average porosity, determined by Core Laboratories, Inc., is 13 percent. Calculations based on this average value and a hydraulic gradient of 30 feet per mile (the average gradient from the Gasbuggy site to the nearest discharge points at outcrops along the San Juan River) indicate that the rate of movement of ground water in the Ojo Alamo Sandstone is about 0.0001 foot per day or 0.04 foot per year.

Seismic effects of the Project Gasbuggy nuclear shot caused a hydrostatic pressure pulse in the monitored well (fig. 11). An initial water-level rise of 0.75 foot was followed by a decline of water level to within 0.1 foot of the original static level after 1 second and an oscillation due to seismic arrivals of 0.2 foot magnitude that continued for 3 seconds. About 6 seconds after the first pulse, the water level returned to the preshot static level.

Figure 11.--Hydrograph of well 29.3.20.234 during time of Project Gasbuggy nuclear shot, December 10, 1967.

Twelve seconds after the first pressure pulse, the water level rose steadily for 35 seconds to 0.5 foot above static level. It then continued to rise at a lesser rate for 80 seconds to 1.05 feet above static level where it held steady for 24 seconds before starting a steady decline that continued for 13 minutes after the first pulse. About 40 minutes after the first pulse, the fluid level was 0.1 foot above static level. The ink in the recorder pen ceased to flow 40 minutes after the first pulse; several hours later when the recorder station was attended, the pen position indicated the water level in the well was near static level.

In response to the Project Gasbuggy nuclear shot, the pen of the recorder on a spring 5.1 miles northwest of ground zero moved slightly upward (fig. 12). This rise suggests an increased rate of flow of only a small fraction of a gallon per minute. The increase continued for 4 days after the shot. The recorder on a spring 7.1 miles southwest of ground zero did not respond to the shot. Preshot and postshot measurements in 5 wells and 5 springs showed only slight differences of water level and yield. These differences are attributed to normal daily variations and are probably unrelated to the nuclear shot.

Examination of table 4 reveals the quality of ground water at Project Gasbuggy site. Table 4 shows that water in both holes GB-1 and GB-2 is sodium sulfate type, hard (hardness as calcium carbonate exceeds 600 ppm), and moderately saline (dissolved solids range from 6,060 to 7,370 ppm). This salinity indicates poor circulation of ground water in the Ojo Alamo Sandstone in the vicinity of the Project Gasbuggy site.

Figure 12.--Stage height of water level at weir on spring S29.4.19.412 (Bubbling Spring) during time of Project Gasbuggy nuclear shot, December 10, 1967.

Table 4.--Analyses of water samples from holes GB-1 and GB-2,
Project Gasbuggy. Rio Arriba County. N. Mex.

Water samples analyzed by G. F. Scarbro and R. K. Glanzman (chemical);
P. K. Roscio and R. S. Dewar (gross beta and gross alpha);
and W. A. Tarrant (tritium).

(Chemical components are in parts per million)

Hole no.	GB-1	GB-1	GB-2
Zone sampled (ft below land-surface datum)	(3.463- 3.563)	(3.563- 3.642)	(3.465- 3.649)
Date of collection	2-23-67	2-26-67	4-17-67
Silica (SiO ₂).....	8.0	16	10
Iron (Fe).....	.49	.69	1.4
Aluminum (Al).....	.02	.02	.4
Manganese (Mn).....	1.5	.08	.33
Arsenic (As).....	<.01	<.01	--
Strontium (Sr).....	4.6	5.3	4.7
Calcium (Ca).....	218	242	251
Magnesium (Mg).....	14	14	12
Lithium (Li).....	.28	.28	.28
Sodium (Na).....	2,160	1,880	2,220
Potassium (K).....	14	12	1.6
Copper (Cu).....	.01	.01	--
Zinc (Zn).....	.01	.01	.03
Bicarbonate (HCO ₃).....	223	86	306
Carbonate (CO ₃).....	0	0	0
Boron (B).....	.40	.25	.86
Sulfate (SO ₄).....	4,060	3,630	4,440
Phosphate (PO ₄).....	.00	.00	.00
Selenium (Se).....	<.01	<.01	.02
Chloride (Cl).....	272	221	282
Fluoride (F).....	1.4	1.4	2.3
Nitrate (NO ₃).....	.0	.0	.0
Dissolved solids, calculated.....	5,860	6,060	7,370
Hardness as CaCO ₃			
Total.....	607	668	682
Non-carbonate.....	424	598	430
Specific conductance (micromhos per cm at 25°C).....	3,210	7.450	9,350
pH.....	7.7	6.9	7.2
Percent sodium.....	88	86	88
SAR.....	38	32	37
Tritium (T. U.).....	<400 ^{1/}	<400 ^{1/}	<400 ^{2/}
Gross beta as Sr ⁹⁰ -Y ⁹⁰ (pc per l)...	14 ^{34/}	13 ^{34/}	--
Gross alpha as U equivalent (μg per l)	3.1 ^{3/}	1.5 ^{3/}	--

^{1/} Determined on 4-24-67.

^{2/} Determined on 5-10-67.

^{3/} Determined on 5-18-67.

^{4/} Includes activity due to K⁴⁰

CONCLUSIONS

The alluvium, the San Jose and Nacimiento Formations, and the Ojo Alamo Sandstone are the aquifers in the Project Gasbuggy area. The San Jose and Nacimiento Formations at the Gasbuggy site were considered to be far above the expected position of the top of the chimney and fracture zone. The Ojo Alamo Sandstone was considered to be within the unlikely but remotely possible range of fracturing. Thus, hydrologic testing in the exploratory holes was limited to the Ojo Alamo Sandstone..

The low transmissivities and the specific capacities determined for the Ojo Alamo Sandstone indicate that should fracturing reach the formation the entry of water into the chimney would cause filling of the chimney at an estimated rate of about half a foot per day. The low transmissivity of the aquifer and the decreasing hydrostatic head with depth would prevent extensive radioactive contamination of water in the aquifer.

The major discharge point for water moving in the Ojo Alamo Sandstone is probably the **San** Juan River, 50 miles northwest of the Project Gasbuggy site. The computed average rate of ground-water movement is about 0.0001 foot per day or *0.04* foot per year.

Thirteen wells and 23 springs within a 10-mile radius of thh Project Gasbuggy site were investigated before the nuclear shot. These wells and springs tap either alluvium or the San Jose Formation; no wells in the area are known to tap deeper aquifers.

The effects of the nuclear shot were minimal to those springs and wells observed within a 5- to 6-mile radius of ground zero. These temporary effects could be detected only by delicate recording instruments; flow of the springs and change in water levels in wells affected by the shot were discernible for about 5 days. These disturbances to the ground-water regime caused by the shock of the detonation were only of short duration and possibly were due to mechanical adjustments of the aquifer material. Water levels in wells and the flow of springs over a period of a few months are more significantly affected by natural hydrologic influences than they were by the nuclear shot.

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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
USEM	Bureau of Mines, U. S. Department of the Interior
USC&GS	U. S. Coast & Geodetic Survey, Las Vegas, Nev.
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