NVO-1229-131

MASTER

RADIOACTIVITY IN WATER -- PROJECT RULISON

by

William E. Nork
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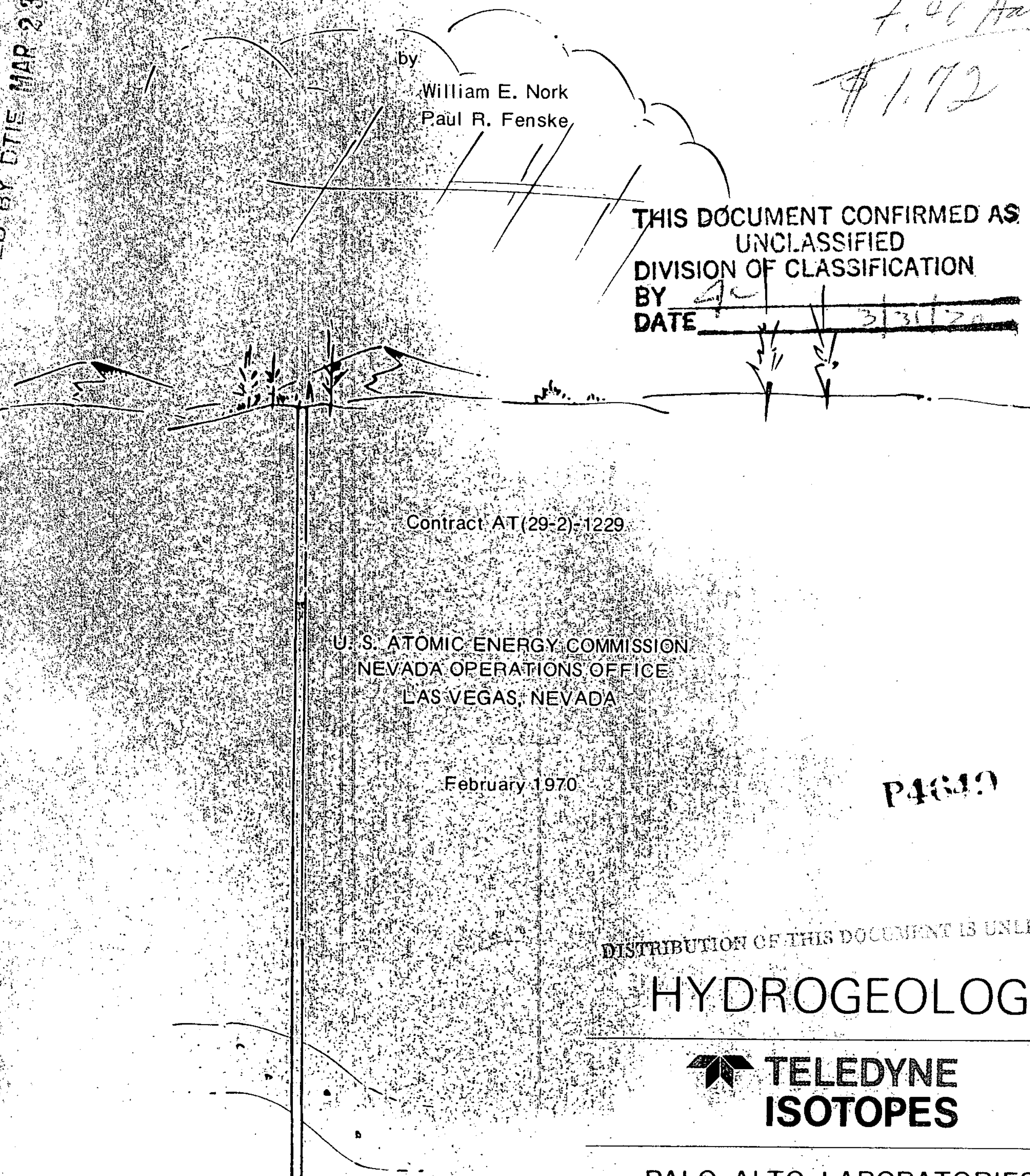

Contract AT(29-2)-1229

U. S. ATOMIC ENERGY COMMISSION
NEVADA OPERATIONS OFFICE
LAS VEGAS, NEVADA

February 1970

HYDROGEOLOGY

TELEDYNE
ISOTOPES

PALO ALTO LABORATORIES

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Palo Alto, California 94303

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CONTENTS

1.0 INTRODUCTION

Project RULISON is a joint experiment sponsored by Austral Oil Company, Inc., Houston, Texas, the U. S. Atomic Energy Commission, and the Department of the Interior, with the Program Management provided by CER Geonuclear Corporation of Las Vegas, Nevada, under contract to Austral. Its purpose is to study the economic and technical feasibility of using underground nuclear explosions to stimulate production of natural gas from the low productivity, gas-bearing Mesaverde Formation in the RULISON field.

The nuclear explosive for Project RULISON was detonated successfully at 3:00 p.m. plus 0.1 seconds Mountain Daylight Time, September 10, 1969, at a depth of 8431 feet below ground level and was completely contained. Preliminary results indicate that the RULISON device behaved about as expected; i.e., with a yield of 40^{+20}_{-4} KT. The wellhead of the emplacement well, Hayward 25-95A, is at an elevation of 8,154 feet above mean sea level (MSL) and is located 1,976.31 feet east of west line and 1,813.19 feet north of south line of section 25, Township 7 south, Range 95 west of 6th p.m., Garfield County, Colorado, which corresponds to geodetic coordinates of longitude 107°, 56', 53" west and latitude 39°, 24', 21" north.

2.0 SUMMARY AND CONCLUSIONS

The Project RULISON detonation was wholly contained, as planned, within the rocks of the Mesaverde Group. Explosion-produced radioactivity was initially distributed non-uniformly in the collapsed chimney and fractured rock surrounding the working point, WP. Redistribution of the explosion-radioactivity will occur as a result of transport of dissolved and/or particulate matter in any existing mobile ground water in Mesaverde Formation rocks or as a consequence of re-entry drilling and testing.

Quite possibly, ground water in the Mesaverde Formation is immobile. In this case all radioactivity will reside where it was initially emplaced unless it is artificially removed, and will decay eventually to concentrations below CG* levels.

Any mobile water in the Mesaverde Formation which becomes contaminated with explosion nuclides, and is located below about 7000 feet is expected to move downward or laterally but not upward. Above 7000 feet any contaminated mobile waters are expected to move laterally. Hydrologic data indicates that the rate of movement of contaminated water will be essentially negligible. Very likely the rate of movement will be low enough and chemical-exchange retardation high enough to prevent transport of nuclides in greater-than-CG concentrations for any significant distances.

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* An abbreviation for Concentration Guides. CG's are reference concentrations as given in November 8, 1968 revision of the 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 Individuals and Population Groups in Uncontrolled Areas. These guides are applied as per instructions in TN NV 0500-23, dated May 12, 1969. CG's are used in the same context as MPC's had previously been applied. These values are consistent with those given in USAEC Rules and Regulations, Title 10 - Atomic Energy, Part 20, Standards for Protection against Radiation, sometimes referred to as RPS's.

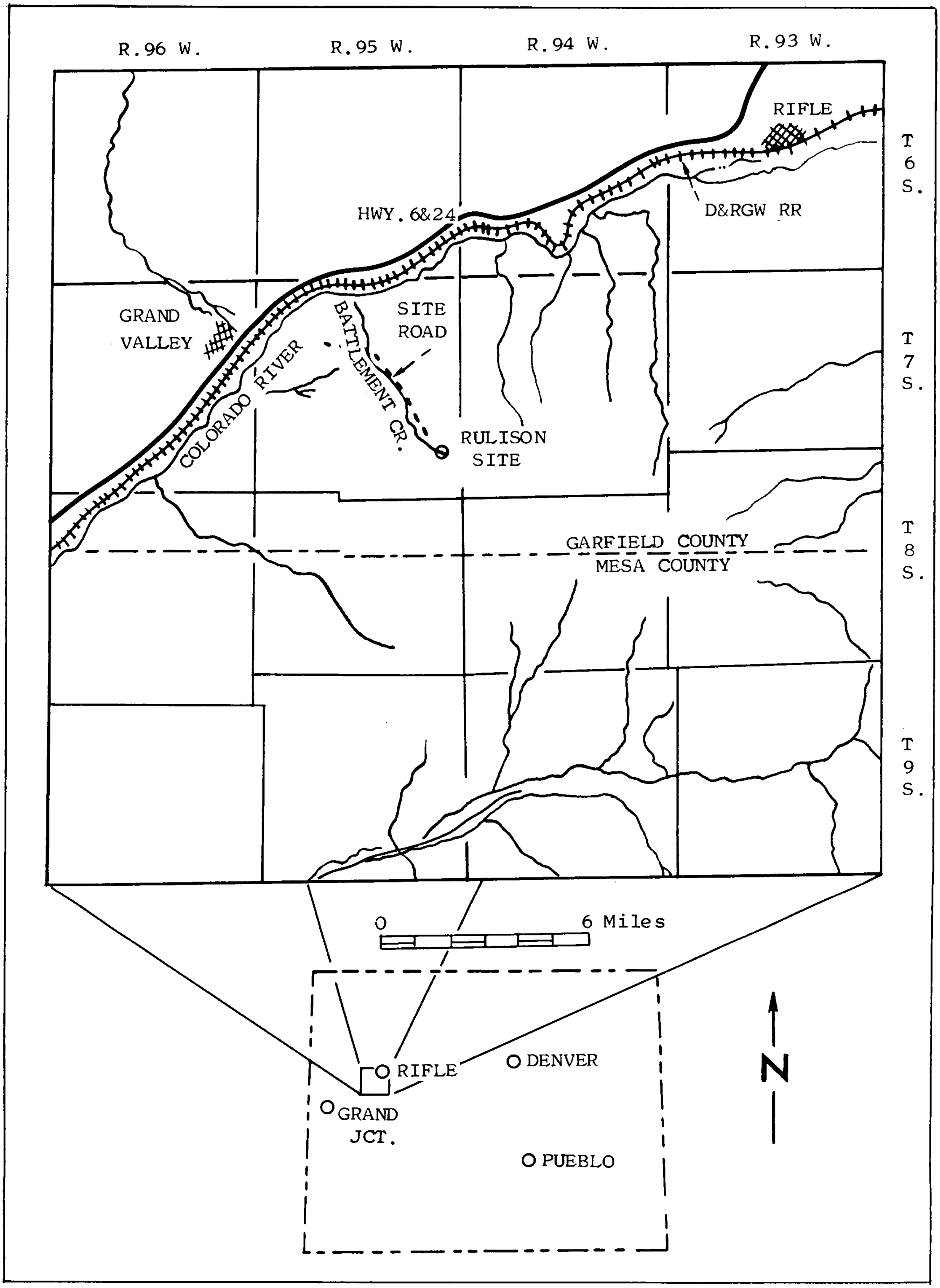

Figure 1. Index Map of Project RULISON Site (map from PL-4-5-69[1]).

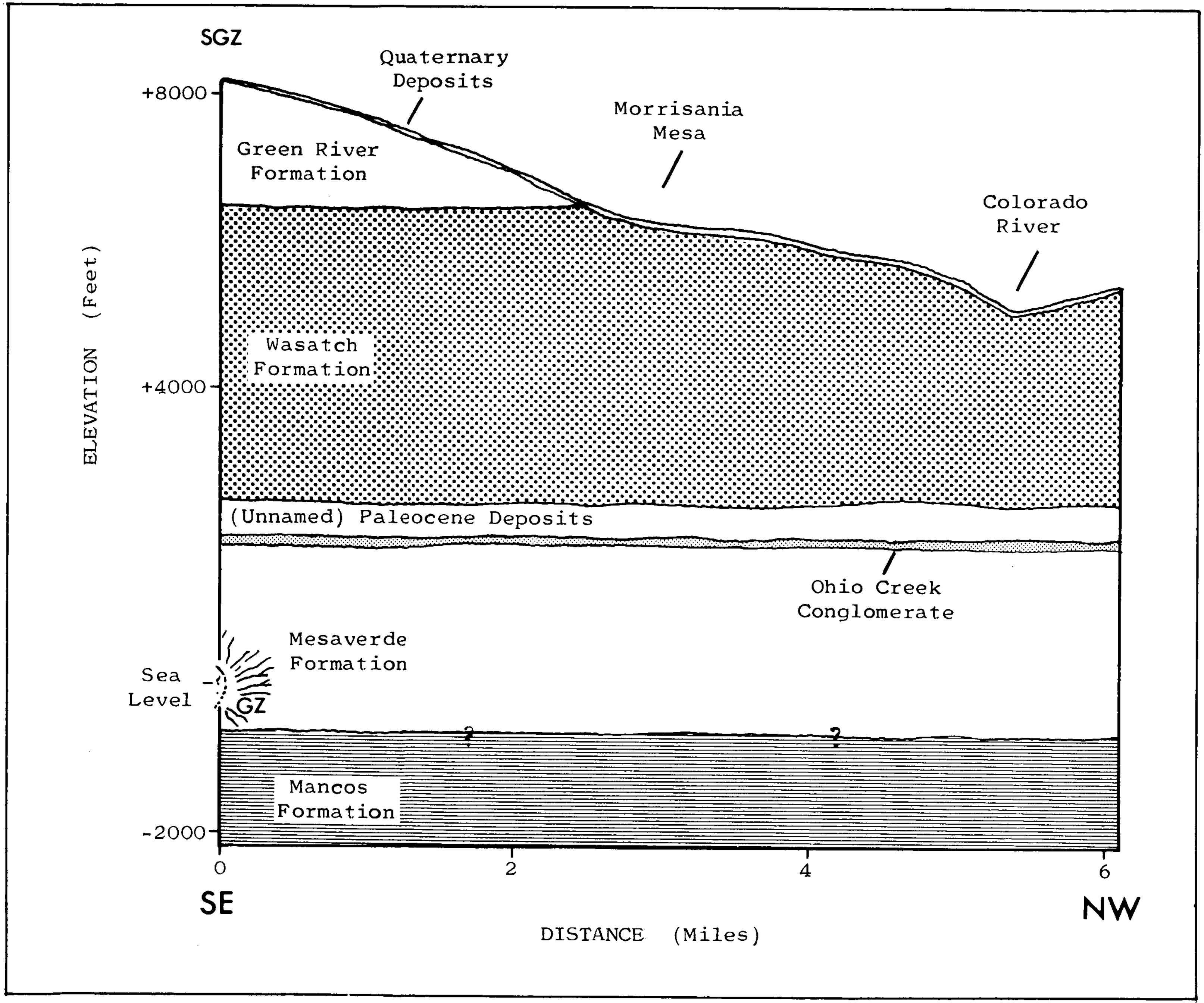

Figure 2. Diagrammatic Cross Section of RULISON Site along Trend of Battlement Creek.

3.0 HYDROGEOLOGY

The Mesaverde Formation rocks at the RULISON Site consist of about a 2,500-feet thick sequence of interbedded sandstone and shale. The Mesaverde Formation overlays the Mancos Shale Formation and is overlain in ascending order by the Ohio Creek Conglomerate, about 37 feet thick, an unnamed unit of Paleocene Age (possibly Fort Union or lower Wasatch), about 500 feet thick, the Wasatch Formation, about 3,900 feet thick, the Green River Formation, about 1,700 feet thick, and Quaternary alluvium as terrace and streambed deposits (Figure 2).

All rocks in the Project RULISON region contain ground water. At Morrisania Mesa, about 3 miles northwest of surface ground zero (SGZ), ground water is withdrawn from saturated alluvium and other near surface rocks for domestic use[2,3]. Surface water from Battlement Creek is used for irrigation[2,3].

Hydrologic tests were performed only on Ohio Creek and Mesaverde Formation rocks encountered in exploration drill hole R-EX. Little information was obtained about the hydraulic properties of rocks above 6,000 feet of depth.

Six drill stem tests were run in the vicinity of the shot point. The USGS interpreted the chemical character of fluids collected from tubing after each drill stem test in exploration hole R-EX as indicating that "little mobile water occurs in the zones tested"[2]. Three of these tests, 7,066-7,080, 7,196-7,198, and 7,312-7,320 feet below land surface resulted in pressure build-up curves that could be extrapolated to infinite time by the Van Everdingen method to estimate the virgin aquifer pressures. Table I shows the extrapolated shut-in pressures along with the post shot reservoir pressure compared to estimated hydrostatic pressures for the same depths.

TABLE I

Formation Pressures

Depth (feet)	Estimated Shut-in Pressure	Estimated Hydrostatic Pressure
7066 - 7080	3050 psi	3050 psi
7196 - 7198	2900 "	3096 "
7312 - 7320	2250 "	3150 "
About 8442	2950 "	3640 "

The actual distribution of pressures above 7,066 feet are not well known. However, there can be no general upward or downward movement of water in this interval, and lateral flow must predominate. Below 7,066 feet pressures drop off rapidly and downward movement of water is expected to a point within or below the 7,312 - 7,320 foot interval. Since the pressure increases below this interval, a drain exists between 7,312 and about 8,442 feet where lateral flow is possible.

The three drill stem tests analyzed indicate relatively steep pressure build-up curves as a function of time but low fluid recoveries. A possible explanation of this phenomenon is that the predominant permeability belongs to a fracture system. The presence of many linears on the geologic map at the RULISON Area tends to substantiate this hypothesis. If this is the case, lateral flow of water could occur at significant velocities in terms of usual ground water flow rates. However, since the interfracture blocks in the sandstone beds must also have some permeability, all water would also have to flow through these low permeability blocks. The average water velocity is therefore expected to be extremely low.

The direction of ground water flow in the alluvium is expected to be northward, consistent with topographic slope. Rocks below the alluvium dip two degrees or less to the north and ground water flow in these rocks is expected to be northward also.

4.0 EXPLOSION EFFECTS

Diagnostic data obtained at the time of detonation, as well as preliminary reports on measurement of ground motion by U. S. Coast & Geodetic Survey and Sandia Corporation, indicate that the RULISON device behaved about as expected, i.e., a nominal yield of 40 kilotons.

Environmental Research Corporation predictions of cavity dimensions for nominal yield, together with the chimney volume and the void space in the chimney (cavity volume) calculated from their predictions are given in Table II.

TABLE II

Physical Explosion Effects

	Maximum	Mean	Minimum	Units
Cavity Radius	108	90	72	feet
Cracking Radius	580	485	390	feet
Chimney Height	451	376	301	feet
Cavity Volume (or Chimney Void Space)	5.28×10^6	3.05×10^6	1.56×10^6	ft^3
Chimney Volume	16.5×10^6	9.57×10^6	4.90×10^6	ft^3

Quantities of radionuclides computed to be present at zero time (T_o) plus 180 days are given in Table III. Of the nuclides listed several will exist as gases (Kr, Xe, H, CH_4) and as volatiles (I, Cs, H_2O); others will be refractory (Sr, Y, Ru, Ba). Only those radionuclides having half-lives greater than one-half year (Kr^{85}, Sr^{90}, Ru^{106} - Rh^{106}, Cs^{137} Pm^{147}, and H^3) are considered significant in evaluation of hazard to the hydrologic environment.

TABLE III

Fission-Product and Neutron Induced Activity in Cavity, 180 Days After Detonation.

Nuclide	Half Life	Curies
^{85}Kr	10.76 y	0.96×10^{3}
^{89}Sr	50.6 d	0.91×10^{5}
^{90}Sr	28.8 y	0.59×10^{4}
^{91}Y	59 d	1.01×10^{5}
^{95}Zr	65 d	1.82×10^{5}
^{95}Nb	35 d	0.32×10^{6}
^{103}Ru	40 d	0.41×10^{5}
^{103}Rh	57 min	0.41×10^{5}
^{106}Ru	1.0 y	1.52×10^{5}
^{106}Rh	30 sec	1.52×10^{5}
^{131}I	8.05 d	1.13
^{133}Xe	5.27 d	0.86×10^{-3}
^{137}Cs	30 y	0.75×10^{4}
^{137}Ba	2.6 min	0.69×10^{4}
^{140}Ba	12.8 d	0.34×10^{3}
^{140}La	40 h	0.40×10^{3}

TABLE III

(continued)

Nuclide	Half Life	Curies
^{141}Ce	32.5 d	0.52×10^5
^{143}Pr	13.7 d	0.63×10^3
^{144}Ce	285 d	1.47×10^5
^{144}Pr	17.3 min	1.47×10^5
^{147}Pm	2.6 y	0.28×10^5
^{3}H	12.26 y	10^3 to 10^4 *
^{37}A	34.3 d	10 to 10^2 *
^{39}A	260 y	2 to 2×10^1 *
^{14}C	5770 y	10^{-2} to 10^{-1} *

* Produced by neutron activation.

Source term concentrations were calculated by assuming that the explosion-related nuclides as shown in Table III are completely and uniformly mixed with a quantity of water equivalent to the volume of the cavity void space (Table II) anticipated to be formed by the detonation. This assumption is conservative, leading to high values for radionuclide concentrations, because it is known that significant fractions of refractory nuclides will be incorporated in the melt. On the other hand, significant fractions of volatile or refractory nuclides having gaseous precursors (such as Sr^{90} and Cs^{137}) will be distributed in the rubble chimney. The cavity volume is calculated to be about 2×10^6 to 5×10^6 cubic feet (0.5×10^{11} to 1.5×10^{11} milliliters). In this water volume, tritium concentration would be about 6 to 200 CG, namely $1. \times 10^3$ curies per 1.5×10^{11} milliliters to $1. \times 10^4$ curies per 0.5×10^{11} milliliters or about 6×10^{-3} microcuries (μCi) per milliliter (ml), to 2×10^{-1} μCi/ml.

In the same water volume, strontium-90 concentration would be about 4×10^5 to 1×10^6 CG, namely 0.59×10^4 curies per 1.5×10^{11} to 0.5×10^{11} milliliters or 4×10^{-2} to 1×10^{-1} μCi/ml.

5.0 RADIOACTIVITY IN THE HYDROLOGIC ENVIRONMENT

The exaggerated overburial of the RULISON device was predicted to assure containment and retention of all of the explosion nuclides within the Mesaverde Formation.

Rock materials such as those at the RULISON Site retard the movement of radioactivity in varying degrees. The rate of movement of a particular isotope, relative to ground-water velocity, is dependent upon the nature of the rock constituents, porosity, and competition of the isotope with other dissolved constituents in the transporting fluid. Values for retardation of dissolved constituents is calculable from a laboratory measurement of the distribution coefficient, K_d, for the specific dissolved constituent and rock type through which transport will occur.

Distribution coefficients, K_d's, were not determined for the rocks at the RULISON Site. However, experience and analyses made on rocks of varying types from other locations permitted a reasonable approximation for retardation of nuclides. Some average K_d values previously determined by Teledyne Isotopes are given in Table IV. Distribution coefficients for Sr^{90} and Cs^{137} in shaley siltstone and sandstone similar to rocks in the RULISON Area are greater than 1.00. Significant retardation and sorption are predicted for these radionuclides. All of the other nuclides produced from the RULISON device except Kr^{85}, Xe^{133}, and H^3, will also be retarded by chemical exchange.

Quite possibly, ground water in the Mesaverde Formation is immobile. In this case all radioactivity will reside essentially in place unless artificially removed, and will decay eventually to concentrations below one CG. For the source term concentrations given (Section 4.0), six to eight half-lives decay time or about 75 to 100 years are required to reach tritium CG, and about 16 to 20 half-lives decay time, or about 450 to 550 years, to reach strontium-90 CG.

TABLE IV

Distribution Coefficients of Strontium-85 and Cesium-137 for Various Materials. Material suspended in 4 parts saturating solution for 72 hours. Minimum particle diameter is 4000μ.

Material	Saturating Medium	K_d (ml/g)	
		Sr	Cs
Basalt (Amchitka)	Sea Water	1.07	6.50
Carbonate (Yucca Flat Nevada Test Site)	Prepared Water* (Well)	0.19	13.5
Salt (Tatum Salt Dome)	Salt Saturated Water	0.19	0.027
Shaley Siltstone** (Gasbuggy Site, Northern New Mexico)	GB-2 Well Water	8.32	309.
Sandstone** (Gasbuggy Site, Northern New Mexico)	GB-2 Well Water	1.37	102.
Granite (Shoal Site, Nevada)	Deep Formation Water	1.7	34.3
Tuff (Rainier Mesa, Nevada Test Site)	Prepared Water* (Rainier Spring)	260.	1020.
Desert Alluvium (Hot Creek Valley, Nevada)	Deep Formation Water	50-2450	70-2640

*Water prepared to have major chemical composition similar to that of referenced water source.

**Rocks similar to those of the RULISON Site.

Any mobile water in the Mesaverde Formation will probably move slow enough and chemical-exchange retardation will be high enough to prevent transport of nuclides in greater-than-CG concentrations for any significant distance. At a higher than likely rate of ground water movement of one foot per day, explosion-produced tritiated water could move only about seven miles before it would decay below one CG. Under the same conditions of movement but with consideration of retardation effects (assuming $K_d = 10$), strontium-90 would probably move less than a mile before decay to below one CG. The most probable zone for radionuclide transport is a low hydraulic potential zone below 7,312 feet and radioactive water is expected to remain in this zone until reduced to below CG.

REFERENCES

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(2) Voegeli, Paul T. Sr., April 4, 1969, Geology and Hydrology of the Project RULISON Exploration Hole, Garfield County, Colorado, RULISON-1, USGS-474-16 (PNE-R-2).

(3) CER Geonuclear, March 26, 1969, Project RULISON Definition Plan (PNE-R-11).

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