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Historical Information
H.5 Radioactivity

Book 1

Proposed Radiological Experiments for the Project Rulison Flaring Operation

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PROPOSED RADIOECOLOGICAL EXPERIMENTS FOR THE PROJECT RULISON FLARING OPERATION

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Bio-Medical Division, Lawrence Radiation Laboratory,
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18 May 1970

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PROPOSED RADIOECOLOGICAL EXPERIMENTS FOR THE PROJECT RULISON FLARING OPERATION

Bio-Medical Division

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Livermore, California 94550

The Rulison flaring operation offers a unique opportunity for research on the movement of tritium through a natural open ecosystem. Several of the proposed field measurements cannot be duplicated by laboratory investigations. In addition, field verification of parameters that are amenable to laboratory study or of derived parameters is always highly desirable whenever such studies are feasible. The Rulison site is particularly appropriate for study at this time since its source and ecology are much more representative of proposed new sites of gas stimulation experiments than any other available study site.

The ecological experiments proposed here and the ecology program which the U.S. Public Health Service will carry out are supplementary to each other and not duplicative. Our program has very specific objectives, including the measurement of parameters related to model building. It would be accomplished by intensive sampling over a short period of time. The PHS program is more concerned with the fate of the released tritium over long, integrated time periods without the measurement of the same specific parameters. The experiments outlined below represent a continuation of studies on the movement of tritium through the biosphere that Division Scientists have been conducting over the past six years.

Objectives

The general objectives of this program would be to determine the movement of tritium through an exposed, open ecosystem, and to acquire sufficient quantitative data to adequately evaluate the combined predictive efforts made by many organizations for the Rulison flaring operation. Within the context of these objectives, the following parameters will be evaluated under actual field conditions wherever the tritium levels are sufficient to permit measurement.

1. Deposition velocity of tritium.
2. Fraction of tritium deposited upon vegetation.
3. Half-residence time of tritium deposited upon vegetation.
4. Half-residence time of tritium in soil.
5. Transfer of tritium ingested by dairy cows (via forage) per liter of milk.
6. Rate of incorporation of tritium into organic matter by exposed organisms.
7. Transfer of tritium between trophic levels.

A particular interest in the study would be the evaluation of possible isotopic fractionation mechanisms between organic matter and free water. The field studies are designed to test current models of tritium movement through the environment, and to provide data to improve these models if necessary.

Experimental Procedures

The experimental plan is divided into two parts: the rapid location of exposed areas and further detailed studies of exposed areas. If no areas can be found that are exposed at levels significantly above background, the second phase would not be pursued. Most of the measurements will have to be completed within a few days following any one of the three high-rate flaring periods, so that re-exposure is not a factor. An exception would be the determination of the half-residence time in soil. This measurement could not be started until a large fraction of the total activity had been released, and would necessarily extend over a lengthy period. Suitable background samples will be collected before flaring begins.

1. Location of Exposed Areas. Areas of possible exposure will be located by fielding 45 atmospheric moisture condensers at locations within the Grand Valley-Morrisania Mesa-Holms Mesa area (see map) that might be expected to be exposed under nighttime wind conditions. These samplers will be operated during the high-rate flaring operations, and water collected at two hour intervals during favorable wind conditions. The analysis of these samples will be done in the field, and results should be available within several hours after collection. It will not be possible to field samplers in areas of expected exposure during daytime wind conditions due to the rough terrain.

2. Detailed Studies of Exposed Areas. If such areas are located, the following samples would be collected simultaneously at daily intervals: air moisture, soil at several depths down to a few centimeters, vegetation, available small mammals, surface water, and milk if dairy cows are within the exposed area. The collection of soil samples at several depths down to six feet would be started later and at much longer sampling intervals. Sample collection trips into areas of possible daytime exposure may also be attempted at this time.

Analytical Methods

A liquid scintillation counting facility will be established in the vicinity of Rifle which will be used to analyze the atmospheric samples. The sensitivity of this analysis will be at least as good as 7 pCi/ml (about 20 pCi/m^3 of air) for a ten minute count. Aliquots of these samples will be saved if necessary for more sensitive analysis by direct gas counting or more sensitive liquid scintillation counting (sensitivities of 0.1 and 0.4, respectively, for a 100 minute count). Measurements of relative humidity temperature, and pressure will be made so that tritium concentration values in atmospheric water may be converted to concentration per unit volume of air. Two wind velocity recorders will also be placed in the area to aid in the interpretation of data.

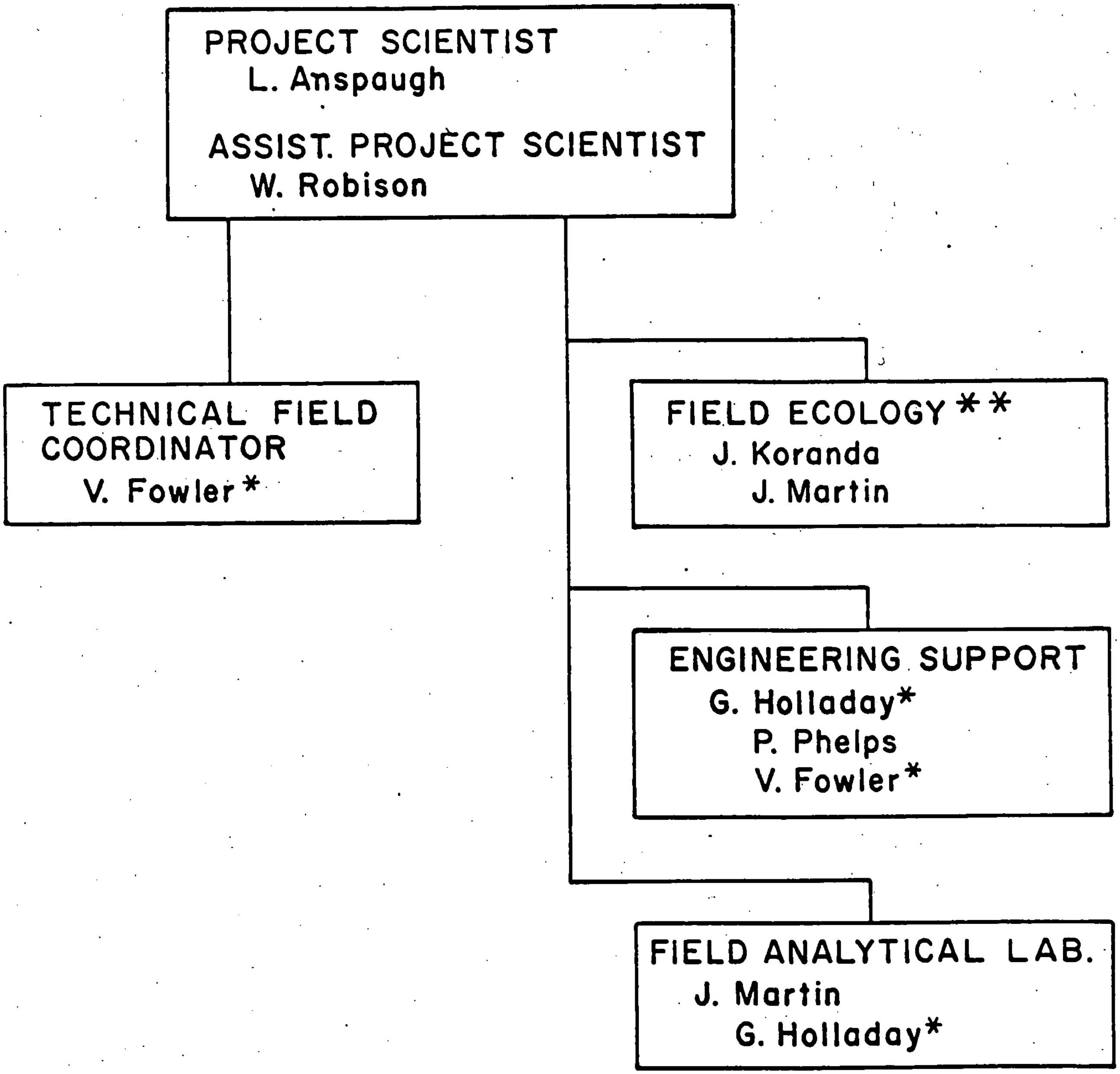
Samples other than atmospheric moisture will be returned to Livermore for preparation and analysis. Biological and soil samples will be lyophilized and the free water analyzed. Organic residues will be combusted and analyzed for tritium content.

Needed Cooperation with Other Agencies

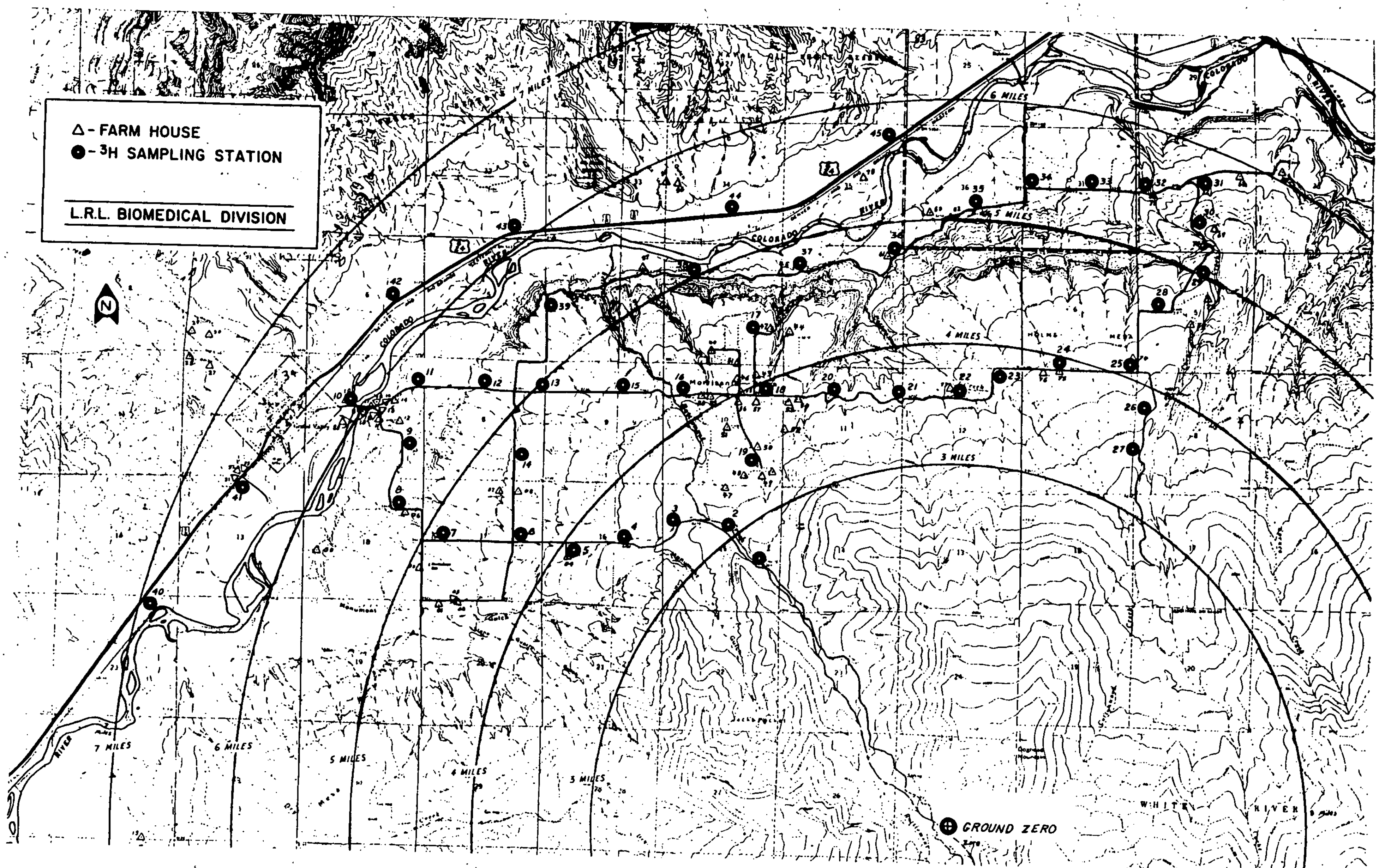
We are fully aware of the sensitivity of the residents within the area to indiscriminate sample collection. Coordination of all field activities with members of the U.S. Public Health Service and other pertinent agencies is therefore highly desirable. It may be useful to extend such coordination to cooperative sampling programs in areas where tritium levels would be high enough for extended study, particularly where pasture grass and milk samples are required. This would have the additional benefit of providing a cross calibration between the two laboratories. Collaberation with AEC-NVOO and ESSA will be sought to provide information on the general meteorological conditions affecting the plume movement.

Funding

This would be an add-on, non-interference experiment. All funds would be provided through the Division of Biology and Medicine of the AEC.



**–All available personnel will participate in Field Ecology as need arises.



△ - FARM HOUSE
● - ³H SAMPLING STATION
L.R.L. BIOMEDICAL DIVISION
COLORADO RIVER
3 MILES
4 MILES
5 MILES
6 MILES
7 MILES
GROUND ZERO
WHITE RIVER

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Radioactivity of Ground Water

~~2 RADIOACTIVITY IN GROUND WATER~~

Isotopes, Inc., an AEC safety contractor, predicted concentrations and movement of radionuclides in water for the Rulison detonation and concluded that the occurrence of levels of radioactivity exceeding the applicable concentration guides was not likely at any use point.(15) The nearest use point for ground water is the community of Morrisania Mesa, approximately three miles from the detonation point, where water for domestic use is taken from relatively shallow wells penetrating alluvium. (11) Morrisania Mesa lies approximately 6,000 feet above the detonation point; almost the entire thicknesses of the Mesaverde and Wasatch Formations separate the water-bearing alluvium from the Rulison chimney, and movement of radionuclides from the chimney to the alluvium is very improbable. Movement of radionuclides to the Colorado River, which lies about 5,000 feet above the chimney and at least five miles distant, is also unlikely.

Little information is available concerning occurrence and movement of ground water or magnitudes of hydraulic gradients existing in the Mesaverde Formation near the Rulison chimney. The USGS indicates that usable ground water in the Rulison area is primarily limited to alluvium and terrace deposits, and that the underlying bedrock formations (Green River, Wasatch, Ohio Creek Conglomerate, and Mesaverde Formations) are generally impermeable and yield little water. From observations made during the drilling of the exploratory hole R-EX, the USGS concluded that little mobile water occurs in the formations penetrated by the hole. (11)

cking sufficient data to predict accurately the fate of radionuclides from the detonation, ~~Isotopes, Inc. evaluated~~ the effect on the hydrologic environment may be evaluated by assuming that radioactivity from the detonation ~~was~~ is uniformly mixed with a quantity of water equivalent to the void volume of the chimney. Since significant proportions of the refractory radionuclides such as strontium are known to be immobilized in the melted zone at the bottom of the chimney, this is a conservative assumption. ~~Using~~ From this assumption and the estimated tritium production from Table 1, the resulting tritium concentration would be 0.17 μCi/ml. The corresponding concentrations of Cs-137 and Sr-90 would be 0.12 μCi/ml and 9.8×10^{-2} μCi/ml, respectively. These concentrations are approximately 170, 1.8×10^{4}, and 1×10^{6} times the concentration guides for tritium, Cs-137, and Sr-90, respectively. The concentration guides are taken from the AEC Manual, Chapter 0524, Annex A, Table II, Column 2 and are reduced by a factor of three to be consistent with standards for population groups and individuals in uncontrolled areas. (Note to reviewer: these guides will be changed to reference the appropriate FRC recommendations in a later draft.)

The Green River, Wasatch, Ohio Creek Conglomerate, and Mesaverde Formations dip to the north at about two degrees. (11) In the absence of disturbances, the hydraulic gradient could reasonably be assumed to follow the dip of the beds; flow of ground water would also follow the dip of the beds. Assuming the beds were saturated and the porosities and permeabilities correspond to the values given as average reservoir characteristics for the Rulison Field (10), the expected average (tracer) velocity of the ground water would be less than one foot/year. (See Appendix D).

Assuming that the Rulison detonation initially increased ground water velocities in the vicinity of the chimney by a factor of 200(see Appendix D), initial post-shot velocities as high as 150 feet/year might occur. If these velocities were sustained indefinitely, tritium would migrate less than three miles before radioactive decay would reduce the concentration to 1×10^{-3} uCi/ml, the appropriate guide recommended by AEC Manual 0524. This estimated reduction ignores dilution by diffusion and mixing.

Tritium can be assumed to move with the velocity of ground water, but Cs-137 and Sr-90 will be retarded by ion exchange with the medium, depending on a property of the combination of medium and ground water called the distribution coefficient, K_d. Values of K_d for rocks in the Rulison area were not measured, but Isotopes, Inc. has reported values for sandstones and ground water in the Gasbuggy area which will be assumed to be representative of the Rulison area(15). Using these values, effective velocities of movement for Cs-137 and Sr-90 are calculated in Appendix D. Assuming the initial increase in ground water velocities caused by the detonation is prolonged indefinitely, Cs-137 would move only a few dozen feet before decaying below the concentration guide of 0.67×10^{-5} uCi/ml. Under the same conditions, Sr-90 would move less than one-half mile before decaying below its concentration guide of 1×10^{-7} uCi/ml.

These estimated velocities of movement are conservative because the initial increase in ground water velocities will not persist indefinitely, because entrapment of radionuclides in the melted zone is ignored, and because dilution of radionuclide concentrations by mixing and diffusion is ignored.

Since the Mesaverde sandstones are not saturated with water, a ground ter anomaly of the type discussed in Appendix D might not have been eated, and in this case the assumed initial increase in ground water elocities would not have occurred. The estimate of groundwater movement is based on the assumption that the entire Mesaverde Formation has the ermeabilities and porosities reported for the sandstone lenses; however the Mesaverde consists of sandstone lenses interbedded with shales of much lower permeabilities (10,11). Permeabilities of the shales could reasonably be expected to be two orders of magnitude smaller than the permeabilities of the paying sandstone lenses (16), and ground water velocities in the shale would then be much smaller (see Equation D-1). Values of K_d for shale would be larger than for sandstone, resulting in much lower effective velocities for radionuclides which are retarded by ion exchange. [redacted]

During the period when gas is released from the well, hydraulic gradients in the portion of the gas-producing rock contacted by the chimney will drive water toward the well because chimney pressure will be lower than the pore pressure of the formation. Until gas production from the well ceases, no migration of radioactivity away from the chimney can occur.

For the above reasons ~~the possibility of~~ significant concentrations of radionuclides in water at any use point ~~is~~ are considered ~~to be very small~~ very unlikely.

Table 1 Radionuclide Activity at T_o + 180 days Resulting from Detonation of 40 Fission Kilotons.

Nuclide	Half-life	Curies
Kr^{85}	10.76 y	0.96×10^3
Sr^{89}	50.6 d	0.91×10^5
Sr^{90}	28.8 y	0.59×10^4
Y^{91}	59 d	1.01×10^5
Zr^{95}	65 d	1.82×10^5
Nb^{95}	35 d	0.32×10^8
Ru^{103}	40 d	0.41×10^5
Rh^{103}	57 min	0.41×10^5
Ru^{106}	1.0 y	1.52×10^5
Rh^{106}	30 sec	1.52×10^5
I^{131}	8.05 d	1.13
Xe^{133}	5.27 d	0.86×10^{-3}
Cs^{137}	30 y	0.75×10^4
Ba^{137}	2.6 min	0.69×10^4
Ba^{140}	12.8 d	0.34×10^3
La^{140}	40 h	0.40×10^3
Ce^{141}	32.5 d	0.52×10^5
Pr^{143}	13.7 d	0.63×10^3
Ce^{144}	285 d	1.47×10^5
Pr^{144}	17.3 min	1.47×10^5
Pm^{147}	2.6 y	0.28×10^5
H^3	12.27 y	1.[illegible] $\times 10^4$

NOTE: This table was taken from reference 15.

APPENDIX D

ESTIMATION OF GROUND WATER VELOCITIES

An expression for the average velocity (tracer velocity) of ground water flow ~~(tracer velocity)~~ under Darcian conditions is (23, 24):

$$v = \frac{k\ s}{u\ n} \frac{dp}{dx} \qquad \text{Equation D-1}$$

WHERE:

v = Tracer velocity, feet/second

s = Specific weight of water, lbs/ft^3 = 59.8 lb/ft^3 at 215°F

u = Viscosity of water at formation temperature
= 0.59×10^{-5} $lb\text{-}sec/ft^2$ (approximate)

n = Formation porosity

$\frac{dP}{dx}$ = Pressure gradient or hydraulic gradient, feet of water per foot of distance

k = Permeability of the saturated medium, ft^2

The reported average permeability and porosity of the sandstone lenses of the Mesaverde Formation are 0.5 millidarcys and 8-10%, respectively. Using these values in Equation D-1 and assuming the hydraulic gradient is approximately equal to the dip of the beds, the estimated pre-detonation ground water velocity is approximately 0.7 ft/year. This development assumes that the medium is saturated.

A well-known study of the Aardvark event by Knox, et. al., indicated that a nuclear detonation in nearly saturated rock may create a ground-water mound* by compaction of the rock. Their calculations indicated that after Aardvark ground water initially flowed inward toward the chimney for a period of days and then flowed radially outward with early velocities approximately 200 times pre-shot velocities. After about 400 days, ground water velocities had declined to less than their pre-shot values(14).

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* A ground water mound is a mound-shaped irregularity in the water table (or ground water free surface) and in the sense used here would occur only in saturated media.

If the detonation is assumed to create a ground water mound that produces ground water velocities 200 times greater than normal, the initial and peak velocity of flow would be about 150 feet/year. Assuming that this increased velocity persists indefinitely and that the distribution coefficients for the Mesaverde sandstones and ground waters are equal to those reported by Isotopes, Inc. for Gasbuggy sandstones (15), the distance which Cs-137 and Sr-90 would move before radioactive decay reduces their concentrations to the concentration guides can be predicted.

The relationship between the average ground water velocity, v, and the effective velocity v' of a given radionuclide in ground water is (24)

$$\frac{v'}{v} = \frac{1}{1 + K_d(m/n)} \qquad \text{Equation D-2}$$

WHERE:

K_d = Distribution coefficient for the particular radionuclide for a given combination of rock and ground water, in ml/g

m = Bulk density of the rock or aquifer, g/cc

Isotopes, Inc. reported values of K_d for Gasbuggy sandstone and ground water of approximately 100 for Cs-137 and 1.4 for Sr-90 (15). CER Geonuclear reported an average overburden density of 2.35 g/cc and a core grain density of 2.67 g/cc for the Rulison site (10); as assumed bulk density of 2.4 g/cc seems reasonable. Using these values the ratio (v/v') is

$$v/v' = 4.2 \times 10^{-3} \text{ for Cs-137 and}$$

$$v/v' = 0.029 \text{ for Sr-90}$$

The distance travelled by Cs-137 before its concentration decays to the concentration guide of 0.67×10^{-5} µCi/ml would be less than 30 feet, and Sr-90 would move about 0.47 miles before decaying to the concentration guide of 1×10^{-7} µCi/ml.

REFERENCES

1. Technical Discussions of Off-Site Safety Programs for Underground Nuclear Detonations, NVO-40, Revision No. 2, May 1969, U.S. AEC/NVOO.

2. Safety Involving Detonation of Nuclear Devices, NVO-28, May 1966 (presently being updated), U.S. AEC/NVOO.

3. Rapp, E. G., "Containment of Buried Nuclear Explosions," UCRL-50604, October 1968.

4. Ward, Don C., and Lemon, R. F., "Status of Reservoir Evaluation Project Gasbuggy, (Presented at Annual Fall Meeting; the Society of Petroleum Engineers, Houston, Texas, Sept. 29, 1968) PNE-G-13.

5. Holzer, Fred, "Gasbuggy Preliminary Postshot Summary Report," PNE-1003, Jan. 1968.

6. Preliminary Site Climatology Western Colorado, ESSA/ARL, Feb. 1969.

7. Addendum to Preliminary Site Climatology Western Colorado, ESSA/ARL, June 1969.

References 6 and 7 were obtained directly from ESSA/ARL on Oct. 10, 1969 (from Joe Morrell).

8. Briggs, Gary A., "Prediction of Plume Rise Heights," to be published in the proceedings of the 8th Annual Environmental and Water Resources Engineering Conference, Vanderbilt University School of Engineering, Nashville, Tenn., June 1969.

9. Turner, D. Bruce, "Workbook of Atmospheric Dispersion Estimates," Environmental Health Series, Air Pollution, PHS

Pub. No. 999-AP-26, Revised 1969.

10. CER Geonuclear Corporation, "Project Rulison Definition Plan," 26 March 1969.

11. Voegeli, Paul T. Sr., "Geology and Hydrology of the Project Rulison Exploratory Hole, Garfield County, Colorado," 4 April 1969, U. S. Geological Survey, Denver, Report No. USGS-474-16 or PNE-R-2.

12. Smith, C. F., and F. F. Momyer, "Studies of Chemical and Radiochemical Composition of Natural Gas from the Cavity Produced by the Project Gasbuggy Nuclear Shot," *Radiological Health Data and Reports*, V. 10, No. 7, July 1969.

13. Rawson, D. E., J. A. Korver, R. L. Pritchard, and W. Martin, "Gasbuggy Postshot Geologic Investigations," November 1968, AEC Report PNE-G-11.

14. Knox, J. B., D. E. Rawson, and J. A. Korver, "Analysis of a Groundwater Anomaly Created by an Underground Nuclear Explosion," Journal of Geophysical Research, 70:823-835, 15 February 1965.

15. Nork, William E., "Final Pre-Event Prediction of Radioactivity in the Hydrologic Environment--Project Rulison," 13 August 1969, AEC Report No. NVO-1229-108 (soon will be available to public in AEC Plowshare Open File).

16. Davis, S. N., and R. J. M. DeWeist, *Hydrogeology*, John Wiley and Sons, New York (May 1967).

17. Higgins, G. H., D. D. Rabb, and H. C. Rodean, "Theoretical and Experimental Studies Relating to the Purging of Radioactivity from a Gas Well Stimulated by a Nuclear Explosion," 24 December 1968, AEC Report No. UCRL-50519.

18. Eakin, J. L., R. V. Smith, and J. S. Miller, "Estimation of Well Capacities and Gas Reserves," Gas Engineers Handbook, pp. 4/28 - 4/47, The Industrial Press, New York (1966).

19. El Paso Natural Gas Company, USAEC, US Bureau of Mines, and LRL, "Project Gasbuggy," El Paso, 14 May 1965, AEC Report PNE-1000.

20. Coffer, H. F., B. G. Bray, and C. F. Knutson, "Applications of Nuclear Explosives to Increase Effective Well Diameters," Engineering with Nuclear Explosives, pp. 269 - 287, 21-23 April 1964, AEC Report TID-7695.

21. Austral Oil Company, Inc. and CER Geonuclear Corporation, "Summary Project Rulison Feasibility Study," July 1966.

22. Brundage, Robert, CER Geonuclear Corporation, personal communication, September 1969.

23. Todd, D. K., Ground Water Hydrology, John Wiley and Sons, August 1963.

24. Davis, S. N., "Hazards Evaluation--Groundwater," Nuclear Civil Engineering, ed. Paul Kruger, Technical Report No. 70, Department of Civil Engineering, Stanford University, September 1966.

25. Effects Evaluation Division, NVOO, AEC, "Effects Evaluation for Project Rulison," AEC Report NVO-43, June 1969.

26. Environmental Research Corporation, "Prediction of Seismic Motion and Close-In Effects," NVO-1163-180, PNE-R-5.

27. Southwestern Radiological Health Laboratory, USPHS, "Off-Site Safety and Environmental Surveillance Operation Plan for Project Rulison," April 1969.