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CESIUM-137 FALLOUT IN RED DESERT BASIN OF
WYOMING, USA

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Product and Health Physics Research
HEALTH PHYSICS RESEARCH GROUP

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CESIUM-137 FALLOUT IN RED DESERT BASIN OF WYOMING, USA

Donald E. Michels

Abstract. High variability characterizes fallout cesium-137 in the Red Desert Basin of Wyoming in the U. S. Correlations between fallout levels and factors of climate, topography, and vegetation suggest that bare soil more readily captures fallout from wind than does sagebrush; that *wet* fallout processes are of little significance in this arid place; that association between cesium-137 and snow is weak, hence drifting of snow is not a significant factor in the distribution of fallout; and that impingement of fallout particles directly on soils by wind action may be the dominant mechanism of fallout deposition in the Basin.

Analysis was not conclusive when the data were sorted according to a single parameter; either mean annual precipitation or topography or vegetation. However, significant differences between average values and smaller values for standard deviations result when sorting is done according to two parameters, topography and vegetation. Highest levels of cesium-137 were found on barren ridges which, in the Basin, are exposed to persistent synoptic winds.

INTRODUCTION

Soil samples taken from south-central Wyoming in 1972 suggested a high degree of variability in the levels of fallout. Subsequently, a series of samples was taken to check the degree of variability and to find the cause. One suggested cause of variability related to the drifting of winter snows.¹ Alternatively, variations in effectiveness of direct scavenging of airborne debris could result from the large variety and small extent of microclimates within

Wyoming. The Red Desert was selected because its topography is of a low order, mean annual precipitation varies by a factor of two across the Basin, vegetation ranges from abundant to nonexistent, and moderate to strong westerly winds dominate the climate. Thus, within the Red Desert a range of combinations are available for topography, vegetation, and moisture. The objectives of this study are firstly to correlate the levels of fallout with factors of vegetation, topography, and precipitation; and secondly, to infer which deposition mechanisms are operating and which are not.

DISCUSSION

Description of Study Area:

The Red Desert Basin in south central Wyoming comprises a closed drainage basin of about 4700 square kilometres (1800 square miles) in an area 120 kilometres long (75 miles), having low to moderate topographic relief (Figure 1). Elevations range from 2000 to 2300 metres (6600 to 7500 feet) with a few isolated points to 2600 metres (8700 feet). The Basin is indented into the continental divide such that drainage north and east lies in the Missouri River (North Platte River) watershed, while drainage south and west lies in the Colorado River (Green River) watershed. Because the area is low compared to the adjacent parts of the continental divide, winds are almost wholly synoptic, often exceeding 40 kilometres per hour (25 miles per hour) in steady blows.

Precipitation within the Basin ranges from 0.15 to 0.3 metres per year (6 to 12 inches). About half comes as snow from October through March. Severe and persistent drifting of snow occurs on

¹L. T. Alexander, E. P. Hardy, and H. L. Hollister. *Radioisotopes in Soils. Symposium on Radioisotopes in the Biosphere.* Editors R. S. Caldecott and I. A. Snyder. University of Minnesota, Minneapolis, Minnesota. October 19-23, 1959.

NOTE: The author is currently with Environmental Services, Aerojet Nuclear Company, Idaho Falls, Idaho.

FIGURE 1. Location of Red Desert Basin and Two Study Areas.

the lee of ridges and other obstructions due to prevailing southwest winds.²

Dominant vegetation is sagebrush with short prairie grasses, other woody shrubs, and succulents being locally abundant. Many areas are barren of vegetation or nearly so. Winter winds scour snow cleanly from areas without vegetation, whereas sagebrush areas collect snow nearly to the point of being covered.

Drainage within the basin is poorly integrated. Many closed basins from 0.5 to 5 kilometres across exist, particularly around the perimeter of the Basin. Often these closed basins contain standing water in early spring.

Soils are mostly sandy. Clay accumulations occur as alluvium in mud flats. Usually mud flats are sparsely vegetated to barren and are more abundant toward the central part of the Basin. The sandy hills surrounding the Basin on the east and south have some appearances of dunes which have become stabilized. Despite the sandy loose dry soil and the prominent winds, wind erosion is of minor effect today. No active dunes or blow-outs were observed in the southeastern and central parts of the basin, where soil samples were taken for this study.

Sampling and Analysis:

Seventeen soil samples (Creston group) were taken from the vicinity of a two-kilometre broad depression located on the southeast perimeter of the Basin (Figures 1, 2).

In plan, the samples are in two crossed traverses with two auxiliary samples, spacings were 60 to 800 metres. An additional eight samples (Desert group) were taken from the central part of the Basin about 40 kilometres northwest (Figure 1). These were

taken alternately from ridges and adjacent lowlands where a 5-kilometre traverse followed a dirt road.

At each site, soil was taken from two levels; 0 to 5 centimetres and 5 to 10 centimetres. A jig 10 centimetres square was used to cut the perimeters of the sample and prevent sloughing of the sides during extraction. A flat-bottomed scoop was used to cut the bottom of the sample and to transfer soil into a plastic bag. Each element of the profile thus obtained was 0.5 litres of soil measured *in situ*.

In the laboratory, soils were dried in air at 200 °C, weighed, homogenized in a blender, and aliquotted. Dry weights ranged from 500 to 770 grams. Aliquots were taken which exactly filled a 177-cubic centimetre cylindrical cup, so as to maintain a constant counting geometry. Aliquots ranged from 250 to 320 grams, except for Sample R6, taken from a mud flat, which weighed 190 grams.

Analysis was by direct gamma-ray counting, using a lithium-drifted detector. Homogenized soil was loaded into a constant-geometry sample holder for counting the 661.6-kiloelectron volt (keV) gamma. Calibration was made with a soil spiked with a known amount of cesium-137 (Cs-137). An interference due to radium-226 and its daughters occurs at 665 keV and cannot be resolved from the 662-keV Cs gamma with this counting system.

Allowance for this interference was done by using a radium source alone to find the relative sizes of the 665-keV (weak) transition and a stronger transition at 609 keV. The counting ratio of these two transitions was found to be 32. During sample analysis, the 609-keV transition (Ra and daughters) was monitored along with the 662-keV Cs in order to estimate the correction needed for the 665-keV interference.

Precision of analysis was approximately 7 percent. Twelve replicate analyses were made by recombining the counted aliquot with the remainder of the sample, remixing, and taking a new aliquot. Coefficients of variation for these replicate pairs was 7.4 percent.

² U. S. Department of Commerce, Washington, D. C. *Climatic Atlas of the United States*. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 1968.

Legend

- ▲ — Creston Sample Sites,
(See Table I).

FIGURE 2. Creston Soil Sites, Wyoming (T20N R92W).

RESULTS

Values of Cs-137 reported in Table I (Column 2) are the total amounts found at a site. Remaining columns in Table I show different ways of categorizing the 25 samples. For each categorization, averages and standard deviations are calculated for the Cs-137 contents. Comparisons of these average values indicate whether the categorizing parameter is related to actual deposition.

Within the soil profile, Cs-137 was highly confined to the top 5 centimetres. Only 12 of the 25 profiles contained Cs in the interval 5 to 10 centimetres, and in only one of these [F4, 13.1 millicuries per square kilometre (mCi/km^2), 26% of total] did the amount exceed $5 \text{ mCi}/\text{km}^2$. Site F4 lay near the axis of the study basin. There, melt-water percolates on its way to the site of accumulation, about 0.7 kilometres northward. The soil was saturated at the time of collection (April) and presumably becomes saturated every spring and possibly during occasional rainstorms. Such saturation does not occur in other sites, hence, the greater Cs-137 content at depth likely results from a systematic effect.

Comparing Cs deposition with mean annual precipitation (MAP), Columns 3 and 4, shows no effect, in contrast to several other studies which have indicated a linear relationship between fallout and rainfall.^{3, 4, 5} Explanations for this null result involve the sporadic character of rainfall within the Basin. Rainfall data are sparse in and around the Basin. The estimates here are based on the 30-year averages (1931-1960) published in the *Climatic Atlas of the United States*.⁶ Whether the average MAP corresponds well with precipitation during the years of most active fallout, 1954 to 1960, is not established.

However, differences in vegetation between the two sampled areas indicate a substantial difference in MAP, qualitatively verifying the published data. The question remains open about how the sampling of two areas may have spuriously matched an anomalous pattern of fallout deposition. Rainstorms are fairly infrequent and many are local thundershowers which are narrow and leave a sinuous trail.

Vegetation heights listed in Column 5, Table I, refer to the sagebrush only. Grass is sparse, often occurring as single blades separated by a few to several centimetres. Scattered fescues appear near some sites, but these were avoided during sampling. The percent vegetative cover (Column 6) also refers only to sagebrush. For ease in categorizing, sites where sagebrush was less than 10 centimetres tall were considered as barren. The comparison between vegetated and barren areas is shown in Columns 7 and 8 of Table I. Numerically, the barren sites had more Cs-137, showing that Cs-137 is weakly associated with snow, if at all, since sagebrush effectively captures wind-driven snow. Thus, the effective mean annual precipitation is greater on sagebrush-covered ground than on adjacent sagebrush-free areas. If Cs-137 were brought by snow, one would expect the barren areas to have less Cs-137 rather than more. This outcome also is compatible with the lack of correlation between MAP and Cs-137 shown in Columns 3 and 4.

Additionally, this noncorrelation between sagebrush and Cs-137 suggests that direct scavenging from air by vegetation is not significant. Dead and decaying sagebrush parts collect in sagebrush patches and would be expected to contribute Cs-137 to the soil if any had been scavenged during their life of exposure to winds. This observation contrasts with studies in Nevada which showed a positive correlation between vegetation and fallout levels.⁷ However, an inverse relationship between vegetated and unvegetated sites was noted by Alexander and

³ L. T. Alexander and E. P. Hardy. "Rainfall and Deposition of Strontium-90 in Clallam County, Washington." *Science* 136:881, n.3519. 1962.

⁴ H. L. Volchok and M. T. Kleinman. *Global Strontium-90 Fallout and Precipitation*. USAEC HASL-245. Health and Safety Laboratory, Long Island, New York. 1971. Page 1.

⁵ L. D. Y. Ong. *A Simple Correlation Analysis between Strontium-90 from Fallout and Precipitation Rates*. USAEC ASL-115. Health and Safety Laboratory, Long Island, New York. 1961. Page 271.

⁶ *Loc. cit.*

⁷ K. H. Larson and J. H. Olafson. *Strontium-90 and Total Beta Contamination in Eleven Areas in Nevada and Utah as of August 1958*. Department and Laboratories of Nuclear Medicine and Radiation Biology, University of California. Los Angeles, California. 1958.

TABLE I. Correlations of Cesium-137 Fallout with Vegetation, Topography, and Mean Annual Precipitation.

Site	Cesium-137 (millicuries per square kilometre)	Mean Annual Precipitation		Sagebrush		Vegetation		Topography		Lowland		Ridges	
		0.15 metres	0.3 metres	Height (centimetres)	Percent Cover	<10 (centimetres)	>10 (centimetres)	Ridge	Lowland	Barren	Vegetated	Barren	Vegetated
A1	26		x	20	25	x		x					x
A2	44		x	75	20	x		x					x
A3	67		x	20	20	x		x					x
A4	24		x	10	40	x		x					x
A5	79		x	15	50	x		x					x
F1	124		x	60	60	x			x		x		
F2	106		x	20	30	x			x		x		
F3	89		x	25	30	x			x		x		
F4	50		x	25	60	x			x		x		
F5	97		x	30	50	x			x		x		
F6	48		x	—	0	x			x	x			
F7	128		x	—	0	x		x				x	
F8	80		x	—	0	x		x				x	
F9	71		x	35	40		x		x		x		
F10	87		x	20	30		x		x		x		
M1	120		x	—	0	x		x				x	
M2	119		x	—	0	x		x				x	
M3	105	x		—	0	x		x				x	
M4	68	x		5	50	x			x	x			
R1	60	x		20	15		x	x					x
R2	65	x		25	50		x		x		x		
R3	86	x		—	0	x		x				x	
R4	69	x		20	20		x		x		x		
R5	125	x		20	20		x	x					x
R6	46	x		—	0	x			x	x			
Average	79.3	78	79.9			88.9	73.9	81.8	76.7	54.0	84.2	106.3	60.7
Standard Deviation	31.3	26	33.5			31.0	30.2	36.5	24.4	12.1	22.9	19.6	35.0
Number of Samples	25	8	17			9	16	13	12	3	9	6	7
Coefficient of Variation	39	33	42			35	41	45	32	22	27	18	58

Hardy (see Footnote 3) in comparing tundra-covered Point Barrow, Alaska with barren Ellesmere and Cornwallis Islands. Topographic categorizing was fairly simple because ridges tend to be narrow. The lowland category includes basins, drainage areas, and slopes. This categorization, Columns 9 and 10, also yields a null result for average Cs-137 content. However, the variability on ridges significantly exceeds the variability in the lowland samples, ($p > 0.96$), suggesting that the simple category *ridge* should be subdivided according to an additional parameter (p = probability).

Accordingly, a dual classification shown by Columns 11 through 14 separates barren lowlands (BL), vegetated lowlands (VL), barren ridges (BR), and vegetated ridges (VR). The averages for all four categories are significantly different ($p > 0.9$) from the whole group average, indicating that the dual classification is useful. Additionally, the standard deviations for BL, VL, and BR are significantly less than the standard deviation for the whole group, ($p > 0.9$), further indicating that the dual classification makes a good basis for sorting analytical results.

Furthermore, the averages for BL and VL are significantly different from one another, ($p > 0.99$). Vegetation in lowlands appears positively correlated with Cs-137 in accordance with expectations about collection of snow and scavenging of airborne debris by exposed parts of plants.

The greater deposition of Cs-137 on barren ridges, compared to vegetated lowlands also is significant ($p > 0.98$). Paradoxically, the barren ridges are richest in Cs-137 fallout despite their smaller effective MAP and their dearth of vegetative air scrubbers. A greater effectiveness of soil, compared to vegetation, in the scavenging of airborne weapons debris also is indicated by the significant difference ($p > 0.99$) between vegetated ridges (VR) and barren ridges (BR).

CONCLUSIONS

The environment of Wyoming's Red Desert provides for a high effectiveness of *dry* fallout processes. The

most effective dry process is postulated as the interaction between bare soil and airborne fallout particles. The presence of vegetation insulates soil from winds so that in vegetated areas the fallout in soil results mainly from *wet* processes that tend to be proportional to MAP. The high variability of fallout levels in the Red Desert Basin, and presumably throughout the larger Wyoming Basin, reflects the presence or absence of insulating vegetation. Implicit within this explanation are the relative affinities between soil and airborne fallout particles on one hand and vegetation and airborne fallout particles on the other hand. Apparently, the soil-fallout affinity is much greater in the sense that a coefficient of capture (number of airborne particles captured on a unit area of collector divided by the number impinging) favors capture by soil. In vegetated sites the amount of wind impinging on vegetation may exceed the amount impinging on soil, yet this extra impingement may not overcome the effect due to relative affinities. That is, the insulation that vegetation provides for soil reduces the soil capture of fallout to a greater degree than the increased scavenging capability of the vegetation increases deposition. The result is smaller net fallout levels where vegetation interferes with the soil-wind interaction.

Since the MAP is small in and around the Red Desert, wet processes are relatively nonsignificant. If scavenging by snow is considered as a *wet* process, different from raindrop scavenging plus rainout, then snow appears to be weakly associated with fallout in the Red Desert as indicated by the weak relationship between Cs-137 levels and the presence of snow-holding vegetation. Possibly this apparent outcome results more from the timing of fallout injections to the troposphere than to relative affinities between fallout and raindrops versus snowflakes. Higher levels of weapons debris exist in the spring months March through May, a time when the Red Desert experiences rains more than snows. The period of snowfall coincides with the cleaner parts of air-concentration cycles.

Accumulation of Cs-137 on barren ridges relates also to the general lack of wind erosion in the Basin. By contrast, part of the strontium-90 found associated with vegetation in Nevada (see Footnote 7) resulted when windborne soils were deposited near vegetation.