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A profile of external dose rates, cosmic and terrestrial, has been obtained with ionization chambers.

Leonard R. Solon, Wayne M. Lowder, Arthur Shambon, Hanson Blatz

We have reported previously the results of external environmental measurements made during the summer of 1957 by members of the United States Atomic Energy Commission's Health and Safety Laboratory (*1*). The purpose of these measurements was to establish the approximate range of population exposures to penetrating cosmic and terrestrial gamma radiation; exposure to terrestrial beta radiation was excluded.

In the present article are summarized further measurements made in the eastern United States and in New England, and a series of measurements made in Western Europe. In addition, cosmic radiation ionization intensities as a function of altitude have been obtained by several series of measurements experimentally, and all observations, including those presented in the earlier reports, have been corrected correspondingly.

Also reported are measurements made in single-family and multiple-family dwellings in the metropolitan New York area, including three boroughs of New York City, nearby Long Island, and Westchester County.

The ionization chamber used in the measurements has been described in detail elsewhere (*2*). This chamber has a gas volume of 20 liters and is filled with air at atmospheric pressure. Ionization current is measured with a vibrating-reed electrometer, connected

Mr. Solon, Mr. Lowder, and Mr. Shambon are affiliated with the Health and Safety Laboratory, New York Operations Office, U.S. Atomic Energy Commission. Mr. Blatz is director of the Office of Radiation Control of the Department of Health, New York City.

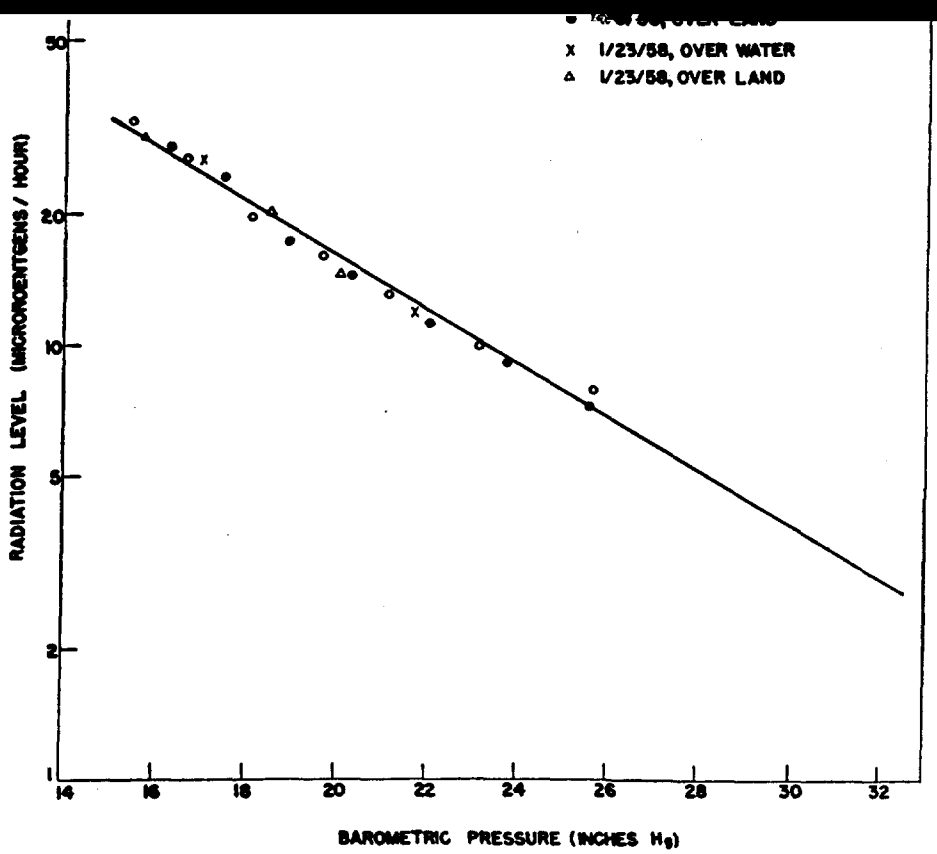


Fig. 1. Measurements of cosmic radiation ionization intensity made inside a C-47.

deviation) of the outdoor intensity.

The first series of measurements made in an automobile—made during August 1957 (*1*)—are summarized here, corrected for attenuation of the terrestrial radiation component by the automobile. Measurements made in the New England states in May 1958 and in the southeastern states in August 1958 have been corrected similarly.

A portable scintillation detector with a sodium iodide phosphor was used for scanning purposes at locations inaccessible to the automobile. This detector was also turned on and observed continuously in the automobile between points of measurement. The detector, though not capable of reading absolute dose rate, can measure a change in radiation level of about 0.4 $\mu$r/hr.

In all the measurements throughout the United States, an effort was made to obtain results which would be representative of the unperturbed natural background, affected as little as possible by the occasional substantial variation in the observed natural radiation levels produced by localized sources (for example, by granite buildings, brick paving, and fallout).

In Table 2 are summarized the measurements for major cities in the United States, including the range of total radiation levels encountered and an estimate of the mean annual dose (*8*).

Most of the readings taken in the eastern United States are between 10 and 15 μr/hr. Low radiation levels were found in New Haven, Connecticut; in the state of Vermont; and in the region north of Charleston, South Carolina. Relatively elevated levels were observed with the scintillation detector along U.S. highway 401 northeast of Raleigh, North Carolina, to the Virginia line. The highest reading found with the ionization chamber in the 1958 measurements, 19.7 μr/hr, was made on a dirt road off the aforementioned highway, 2 miles south of Louisburg, North Carolina.

Measurements in 1957 were made during part of the period of Operation Plumbbob, that year's series of United States continental weapon tests at the National Test Station in Nevada, and, as reported earlier, these tests influenced certain of the measured values in an important way, particularly in eastern Arkansas and in the Black Hills of South Dakota.

The measurements made during August 1958 were undertaken during part of the period of Operation Hardtack, the series of United States weapon tests at the Pacific proving ground. By comparing scintillation detector readings taken over patches of bare ground and grassy spots, it was inferred that nuclear debris had some influence on almost all of these observations. Where test fallout is present, the larger surface presented by patches of grass or weeds results in elevated readings as compared to readings for bare ground.

In April 1959, 84 of the measurements were repeated as close to the original positions as possible in order to estimate the effects of fallout on the initial readings as well as to check the reproducibility of the data. Reductions in the readings were observed at almost all these locations and in some instances were considerable. In six locations the reductions were greater than 10 μr/hr, ranging up to 54 μr/hr in one Arkansas town. If these locations are excluded, the average reduction was about 2 μr/hr. These changes probably are due in large part to the radioactive decay and dispersion of fallout debris which affected the original measurements.

Table 2. Environmental radiation levels measured in principal United States cities. The number of observations for each range is shown in parentheses. Elevated radiation levels produced by localized sources are shown in the last column.

| City | Range of radiation levels (μr/hr) | Mean annual dose (mrad) | Cosmic radiation (μr/hr) | Atypical radiation levels (μr/hr) |
|---|---|---|---|---|
| New York, N.Y. | 8.2–15.6 (19) | 91 | 3.8 | |
| Harrisburg, Pa. | 11.3–14.3 (2) | 104 | 4.0 | |
| Pittsburgh, Pa. | 11.5–16.8 (3) | 114 | 4.3 | |
| Cleveland, Ohio | 12.4–14.1 (2) | 108 | 4.2 | |
| Toledo, Ohio | 10.1–11.8 (2) | 89 | 4.1 | 18.1 (over granite paving stone) |
| Chicago, Ill. | 12.2–13.9 (4) | 105 | 4.1 | 20.9 (adjacent to granite U.S. post office building) |
| Madison, Wis. | 11.8–12.2 (3) | 98 | 4.3 | |
| Minneapolis–St. Paul, Minn. | 10.6–15.0 (4) | 109 | 4.2 | |
| Sioux Falls, S.D. | 13.6–14.0 (2) | 112 | 4.5 | |
| Cheyenne, Wyo. | 19.8–20.4 (2) | 164 | 8.5 | |
| Denver, Colo. | 19.2–22.9 (9) | 172 | 7.9 | 26.8 (between U.S. mint and city and county buildings) |
| Colorado Springs, Colo. | 22.5–26.4 (4) | 197 | 8.7 | |
| Grand Junction, Colo. | 18.2–20.8 (3) | 159 | 7.2 | |
| Albuquerque, N.M. | 15.7–16.5 (4) | 132 | 7.5 | |
| Amarillo, Tex. | 14.9–15.8 (4) | 126 | 6.4 | |
| Oklahoma City, Okla. | 11.5–12.3 (4) | 99 | 4.6 | |
| Tulsa, Okla. | 12.8–13.9 (4) | 109 | 4.2 | |
| Little Rock, Ark. | 15.5–16.1 (2) | 129 | 3.9 | |
| Memphis, Tenn. | 11.0–13.2 (2) | 99 | 3.9 | 16.2 (near brick apartment house) |
| Chattanooga, Tenn. | 13.2–14.8 (2) | 114 | 4.0 | 18.0 (near brick-faced motel units)<br>19.7 (on narrow business street) |
| Bridgeport, Conn. | 10.8–13.8 (2) | 100 | 3.8 | |
| New Haven, Conn. | 8.7– 9.1 (2) | 73 | 3.8 | |
| Hartford, Conn. | 11.9 (2) | 97 | 3.8 | |
| Springfield, Mass. | 12.9–13.9 (2) | 109 | 3.8 | |
| Worcester, Mass. | 14.0–16.4 (2) | 124 | 4.0 | |
| Providence, R.I. | 11.1–13.8 (2) | 101 | 3.8 | |
| Boston, Mass. | 11.0–14.3 (4) | 103 | 3.8 | |
| Portland, Me. | 12.5–13.5 (3) | 106 | 3.8 | |
| Philadelphia, Pa. | 11.7–12.5 (3) | 99 | 3.8 | |
| Baltimore, Md. | 9.0–12.1 (3) | 86 | 3.9 | |
| Washington, D.C. | 11.1–13.3 (3) | 99 | 3.9 | |
| Lynchburg, Va. | 12.4–15.4 (2) | 113 | 4.2 | |
| Winston-Salem, N.C. | 12.9–14.7 (2) | 112 | 4.3 | |
| Charlotte, N.C. | 10.6 (2) | 86 | 4.1 | |
| Columbia, S.C. | 15.0–15.2 (2) | 123 | 3.9 | |
| Charleston, S.C. | 13.5–14.5 (3) | 114 | 3.7 | |
| Raleigh, N.C. | 12.1–13.5 (2) | 108 | 4.0 | |
| Richmond, Va. | 9.8–11.1 (3) | 85 | 3.9 | |

Table 3. Radiation levels in dwellings in the metropolitan New York area. The number of observations for each range is shown in parentheses.

| Construction and location | Radiation levels (μr/hr) | |
|---|---|---|
| | Indoors | Outdoors |
| *Apartments* | | |
| Second floor, brick private dwelling, Bronx | 10.2–12.3 (6) | 12.4 |
| Third floor, brick apartment house, Manhattan | 9.9–12.0 (6) | 10.9 |
| Fourth floor, brick apartment house, Bronx | 10.4–10.8 (2) | |
| First floor, brick apartment house, Manhattan | 9.6–11.0 (2) | 10.7 |
| Third floor, brick apartment house, Manhattan | 11.9–13.5 (2) | |
| Fourth floor, brick apartment house, Manhattan | 9.0– 9.3 (2) | 9.5 |
| *One-family dwellings, Long Island* | | |
| Ranch type, cedar shingle, concrete basement; Roslyn | 7.4– 9.2 (13) | 8.4 (concrete patio) |
| Split level, cedar siding, concrete basement; East Norwich | 8.0– 9.1 (12) | 11.8 (4 ft from brick wall) |
| Two-story contemporary, brick veneer, glass, cypress siding; Sea Cliff | 8.5– 9.4 (4) | 10.9 |
| Two-story, stone; Freeport | 9.6–11.2 (5) | 11.0 (50 ft in front of house)<br>13.8 (9 ft in front of house) |
| *One-family dwellings, Staten Island* | | |
| Native serpentine stone, Radcliff Road | 7.3– 8.7 (4) | 10.6 |
| Stone, Bard and Forest Aves. | 6.5– 7.5 (4) | 11.4 |
| Westchester granite veneer, Beacon Ave. | 6.7– 9.8 (4) | 9.8 |
| *One-family dwellings, Westchester County* | | |
| Three-story dolomite and sandstone, New Rochelle | 12.0–13.8 (5) | 13.6 |
| Wood frame, Pelham | 7.3–12.9 (5) | 12.1 |
| Wood frame, Pelham | 8.7–11.3 (3) | |
| Wood frame, New Rochelle | 10.1– | |

## Environmental Radiation Measurements in Houses

Seventeen single-family and multiple-family dwellings in the metropolitan New York area, including three boroughs of New York City, nearby Long Island, and Westchester County, also have been investigated. The apparatus used was essentially the same as that used for the outdoor measurements, except that the ionization current was measured with a Cambridge Lindemann-Ryerson quadrant electrometer rather than with a vibrating-reed electrometer.

A summary of these measurements is shown in Table 3. The general conclusion that may be reached is that the radiation level inside houses in this area, essentially irrespective of construction materials, is generally somewhat lower than, but not very different from, the outdoor level in the same location.

## Measurements in Western Europe

A 20-liter ionization apparatus which had been exhibited at the second International Conference on the Peaceful Uses of Atomic Energy was taken to Radiofysika Institut in Stockholm, Sweden, by one of us (H. B.) for comparison with the environmental radiation equipment of Rolf Sievert's laboratory (*9*). En route between Geneva and Stockholm, a number of measurements were made. Some of these observations were made over granite paving blocks or near granite buildings, which presumably produced somewhat higher readings than would have been obtained over unpaved or more open areas.

A tabulation of these measurements is given in Table 4. In general, the radiation levels observed are similar to measurements made at corresponding altitudes in the United States. The four measurements made in Sweden are consistent with the published work of Sievert (*10*).

Table 4. Radiation measurements in Western Europe, September 1958.

| Location | Radiation ($\mu$r/hr) | | | Notes |
|---|---|---|---|---|
| | Cosmic | Terrestrial | Total | |
| Geneva, Switzerland | 4.6 | 6.9 | 11.5 | Airport |
| Geneva, Switzerland | 4.6 | 9.0 | 13.6 | Near Cathedral of St. Pierre |
| Geneva, Switzerland | 4.6 | 8.1 | 12.7 | Residential area |
| Montreux, Switzerland | 4.6 | 9.0 | 13.6 | Center of town |
| Offenburg, Germany | 4.1 | 11.6 | 15.7 | Center of town; block pavement |
| Heidelberg, Germany | 4.0 | 11.8 | 15.8 | Business district |
| Cologne, Germany | 4.0 | 8.3 | 12.3 | Near cathedral |
| Wesel, Germany | 3.9 | 10.4 | 14.3 | Center of town |
| Delft, Netherlands | 3.9 | 10.0 | 13.9 | Center of town; brick pavement |
| Leeuwarden, Netherlands | 3.8 | 9.2 | 13.0 | Center of town; brick roadway |
| Hamburg, Germany | 3.8 | 9.9 | 13.7 | Business district |
| Schleswig, Germany | 3.7 | 12.4 | 16.1 | Center of town; Belgian block pavement |
| Nyborg, Denmark | 3.7 | 9.9 | 13.6 | Off highway |
| Granna, Sweden | 4.4 | 12.1 | 16.5 | Off highway |
| Nykoping, Sweden | 3.9 | 19.1 | 23.0 | Center of town |
| Stockholm, Sweden | 3.9 | 13.4 | 17.3 | Business district |
| Stockholm, Sweden | 3.9 | 19.5 | 23.4 | Residential area; stone paving blocks |

### References and Notes


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9. The agreement in the same locations between measurements made with our air-filled, relatively thin-walled chamber and Sievert's pressurized, nitrogen-filled, steel-walled chamber was very close (within 2 percent). Since both chambers were calibrated with radium, there is some support for our belief that the spectral composition of terrestrial radiation is not very different in quality from the radium spectrum. Analytical work relevant to this point may be found in K. O'Brien, W. M. Lowder, L. R. Solon, *Radiation Research* **9**, 216 (1958).
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# SPECTROMETRIC DETERMINATION OF DOSE RATES FROM NATURAL AND FALL-OUT GAMMA-RADIATION IN THE UNITED STATES, 1962–63

By WAYNE M. LOWDER, HAROLD L. BECK and WILLIAM J. CONDON

Health and Safety Laboratory, U.S. Atomic Energy Commission, New York

THE Health and Safety Laboratory of the U.S. Atomic Energy Commission has been examining for nearly a decade the dosimetric properties of environmental radiation, particularly the natural components. Instrumentation and analytical techniques have been developed which are directed toward securing precise interpretations of *in situ* radiation measurements in terms of air dose rate[1–3], from which quantities of biological interest may be derived. Because of the importance of total body and genetic exposure in considerations of the long-term interaction between ionizing radiation and man, our interest has been focused on the more penetrating radiations. These include the γ-radiation from potassium-40 and the daughters of radium-226 and thorium-232 in the Earth and the ionizing component of the cosmic radiation, consisting primarily of the high-energy muons and electrons. We have also had to take account of the presence of fall-out in the environment, and have developed techniques for determining the individual dose-rate contributions to the total environmental γ-field of the various significant natural and fall-out γ-emitters. These techniques are described in this article and a summary of the field data obtained during 1962 and 1963 is given.

During the late 1950's, the importance of the γ-radiation from locally deposited fission products from weapons tests was first noted. Gamma dose rates considerably in excess of the ambient natural levels were recorded by a number of investigators either by direct monitoring[4–6] or by inference from soil and/or air sample analyses[7–10]. Similar increases were noted during the testing period that began in September 1961 (refs. 11–14). Under such conditions, ionization chambers have proved valuable as monitors of changes in total environmental radiation-levels at individual locations, particularly when the mean natural radiation-levels are known from readings taken during periods of little or no fall-out[4–6,14]. Other techniques are needed if such readings are not available or if it is desired to survey new locations.

ns for separating the fall-out
ural is by means of energy dis-
he more prominent γ-energies
ural emitters lie between 1·1
st all important energies from
1·1 MeV. The properties of the
n products are given in Table 1.
lanthanum-140 is important in
ut this is prominent only within
on because of its short half-life.
mple spectrometric techniques
providing detailed information
utions to the total dose rate of
d fall-out γ-emitters.

field measurements were made
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ll wooden tripod at a height of
A 50-ft. cable connected this
ector to a Nuclear Data 256-
yser mounted in the rear com-
k and operated directly from the
through a 300-W a.c.–d.c.
s provided adequate statistics,
given in Fig. 1. The prominent
0·5, 0·75, 1·46 and 2·62 MeV
spectra obtained during 1962
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76 MeV, are generally not con-
f the 0·61- and 1·76-MeV peaks,
e prominent neighbours.

t the field spectra obtained in
howed considerable detail, it
of inferring dose rates from the
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chniques. In the first method[15],
absorption peaks were simply
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he continua on either side of
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that peak. These results were
al to the true peak areas and
primary flux at the detector in
assumption was tested satis-
for several γ-energies and the
y between the measured areas
fluxes determined. Assuming
s in the ground half-space and
potassium-40 and the uranium
and angular distribution of the
ergies of interest and the total
at 3 ft. above the ground were
sponse of the detector in terms
ux as a function of angle was



Table 1. IMPORTANT FALL-OUT γ-EMITTERS

| Isotope | Half-life | γ-Energy (MeV) | γ/d* |
|---|---|---|---|
| $^{95}$Zr | 65·0 d. | 0·724 | 0·5 |
| | | 0·757 | 0·5 |
| $^{95}$Nb | 35·4 d. | 0·768 | 1·00 |
| $^{106}$Ru | 39·7 d. | 0·498 | 0·9 |
| | | 0·610 | 0·06 |
| $^{106}$Rh | 30 s.† | 0·513 | 0·205 |
| | | 0·624 | 0·105 |
| $^{124}$Sb‡ | 60·1 d. | 0·603 | 0·98 |
| | | 0·645 | 0·072 |
| | | 0·722 | 0·105 |
| | | 1·69 | 0·48 |
| | | 2·09 | 0·063 |
| $^{137}$Cs | 30 yr. | 0·662 | 0·94 |
| $^{140}$Ba | 12·8 d. | 0·030 | 0·16 |
| | | 0·537 | 0·25 |
| $^{140}$La | 40·2 h | 0·325 | 0·2 |
| | | 0·488 | 0·4 |
| | | 0·815 | 0·2 |
| | | 0·923 | 0·10 |
| | | 1·60 | 1·00 |
| $^{141}$Ce | 32·5 d. | 0·145 | 0·70 |
| $^{144}$Ce | 284·5 d. | 0·134 | 0·105 |

* γ-lines with γ/d < 0·05 are omitted; data from *NAS–NRC Nuclear Data Tables* (to date).

† Effective half-life is that for $^{106}$Ru, or approximately 1 year.

‡ Not a fission product.

obtained from laboratory measurements with standard radioactive sources, a simple calculation yielded the calibration constants of the measured peak areas in terms of dose rate. These results are given in Table 2.

A second method for determining natural radiation dose rates utilizes a well-known energy band technique (for example, refs. 16–18), where the total counts in the spectrum between energy values that bracket significant peaks are related to the dose-rate contribution from the radiation that contributes to these peaks. Three bands were therefore chosen to include the three total absorption peaks already calibrated, that is, from 1·32 to 1·60 MeV to include the 1·46-MeV $^{40}$K peak, from 1·62 to 1·90 MeV to include the 1·76-MeV $^{214}$Bi peak, and from 2·48 to 2·75 MeV to include the 2·62-MeV $^{208}$Tl peak. The band and peak methods have given essentially identical values for the inferred natural radiation dose rates. The band method has the advantage of providing greater precision for individual measurements and being more easily amenable to routine data analysis, although it is sensitive to the instrument gain drift and to our determinations of the zero energy channel and energy per channel for the field spectrum.

The energy-band approach has also been extended to provide a measure of the total γ-dose rate. The total energy in the spectrum between 0·15 and 3·4 MeV has been found to correlate very well with total γ-dose rate as measured by a high-pressure ionization chamber[3]. Further, the calibration factor determined in the laboratory using a standard radium-226 source is consistent with that inferred from the ionization chamber readings[15].

The fall-out γ-dose rate can be estimated by taking the

Table 2. DOSE-RATE CALIBRATION OF SPECTROMETER

| Peak energy (MeV) | Isotope | Source | Peak counts/$\mu$r./h |
|---|---|---|---|
| 0·5 | $^{140}$Ba–$^{140}$La | Exponential | 6,000 |
| | $^{103}$Ru–$^{103}$Rh | ,, | 35,000 |
| | $^{106}$Ru–$^{106}$Rh | ,, | 18,000 |
| 0·75 | $^{95}$Zr–$^{95}$Nb | ,, | 21,000 |
| 1·46 | $^{40}$K | Uniform | 5,550 |
| 1·76 | $^{214}$Bi (U series) | ,, | 700 |
| 2·62 | $^{208}$Tl (Th series) | ,, | 700 |

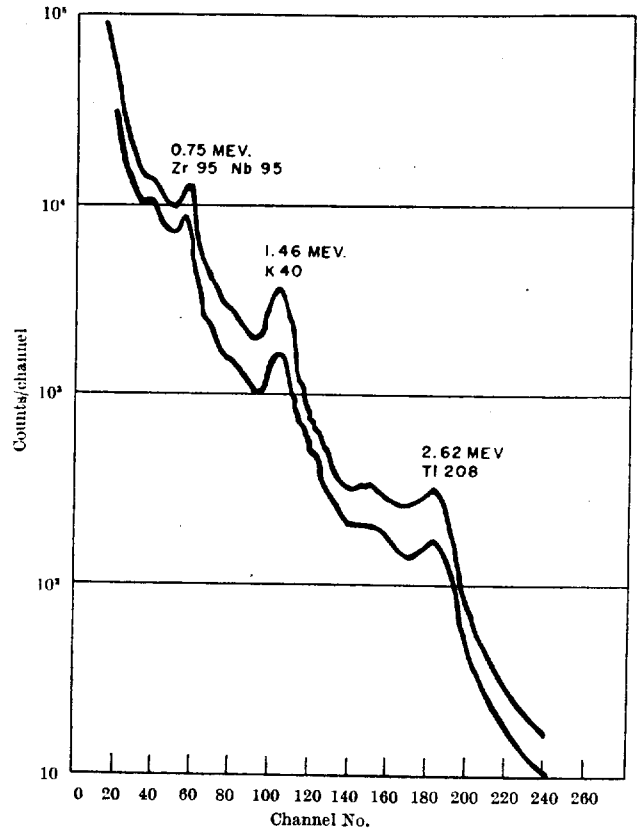
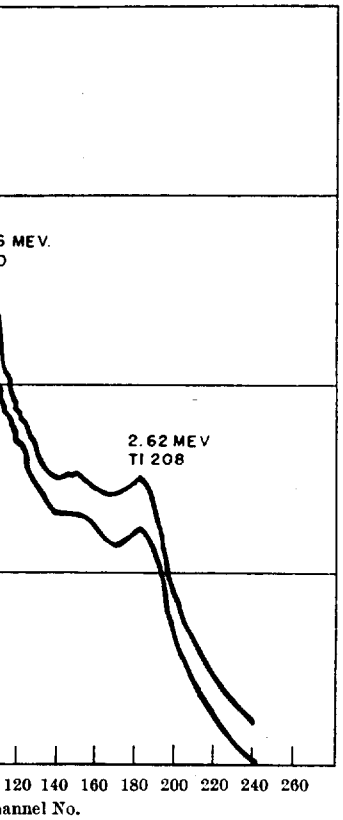



Fig. 1. Two typical field spectra obtained during late 1962. Top curve: Colorado Springs, Colo., October 11, 1962; bottom curve: Argonne, Ill., October 15, 1962. The cosmic ray, natural and fall-out levels are all somewhat higher at the Colorado Springs location

difference between the total $\gamma$-dose rate, as measured by the spectrometer and ionization chamber, and the natural $\gamma$-dose rate, as determined by the peak or energy-band analysis. A second method involves the determination of the areas of the 0·5- and 0·75-MeV total absorption peaks

E CALIBRATION OF SPECTROMETER

| oe | Source | Peak counts/μr./h |
|---|---|---|
| | Exponential | 6,000 |
| | ,, | 35,000 |
| | ,, | 18,000 |
| | ,, | 21,000 |
| | Uniform | 5,550 |
| ies) | ,, | 700 |
| ries) | ,, | 700 |




obtained during late 1962. Top curve: r 11, 1962; bottom curve: Argonne, mic ray, natural and fall-out levels are the Colorado Springs location

tal γ-dose rate, as measured by zation chamber, and the natural d by the peak or energy-band nod involves the determination 0·75-MeV total absorption peaks



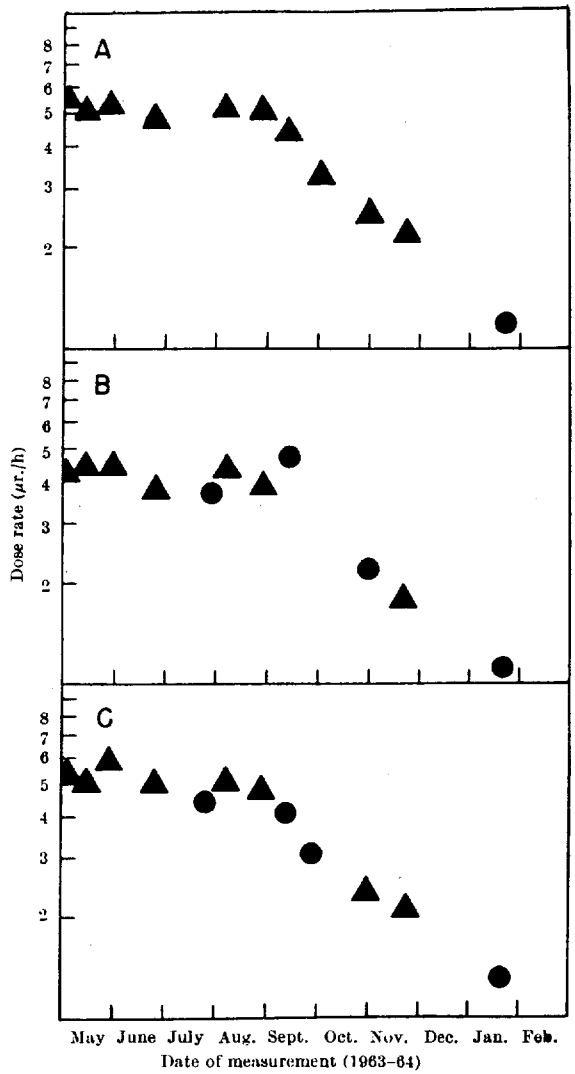



Fig. 2. Fall-out γ-dose rates at three locations in Westchester Co., N.Y. (*A*, Mamaroneck; *B*, West Harrison; *C*, Pelham.) The triangles refer to spectrometer readings and the circles to readings with the ionization chamber only

in a manner analogous to that for the higher energy peaks characteristic of the natural emitters. These areas can also be related to the incoming primary flux in the field situation and thus to the total dose rate from the contributing isotopes.

However, two problems arise with the peak method as applied to fall-out that are not encountered in the case of the natural emitters. First, the source distribution in the ground is less well defined than for the natural emitters, where the assumption of uniform concentration in the ground half-space is a reasonable one on the scale of our measurements. Fission products are, of course, not necessarily distributed uniformly in the upper layers of the ground, nor is the assumption of a uniform plane source distribution adequate for any but the most recently deposited fall-out. Measured soil-depth distributions of the significant γ-emitters[19-22] indicate that an exponential source distribution as a function of depth with a 'relaxation length' of 3 cm may be a reasonable model. Of course, significant deviations from this average situation would not be unexpected at some locations, particularly where there has been substantial recent deposition.

Secondly, several radionuclides contribute to the 0·5-MeV peak (Table 1). Since the total γ-dose rate per unit 0·5-MeV flux depends on the decay scheme of the nuclide or series of nuclides under consideration, the dose-rate calibration of the 0·5-MeV peak area depends on the relative population of these nuclides, which in turn is a function of the mean age of the fall-out. Since rhodium-106 dominates the 0·5-MeV activity for fall-out more than several months old and has an intermediate value for its peak calibration factor, the use of the rhodium-106 peak calibration and the exponential source distribution provides a reasonable estimate for the dose contribution of the 0·5-MeV emitters in most circumstances.

The peak calibration factors for the main fall-out γ-emitters are given in Table 2, along with those for the natural emitters. Part of the dose rate contribution of cæsium-137 (0·66 MeV) would be included with that of zirconium-95 (0·75 MeV), since the two peaks overlap in our spectra, the 0·66-MeV peak generally being completely hidden by the larger 0·75 MeV peak. Other fall-out γ-emitters generally give only a very small proportion of the dose rate.

The overall consistency of the two methods for determining the fall-out dose rates, obtained over a wide range of natural γ-fields, and the apparently high degree of precision of individual total γ-dose-rate measurements suggest that a standard deviation of about ± 0·5 μr./h would be appropriate for individual fall-out dose-rate estimates. The individual natural dose-rate components have standard deviations conservatively estimated at ± 10 per cent; the total dose-rate values have somewhat smaller deviations.

Since July 1962, a number of survey trips have been undertaken to various parts of the United States. These surveys have generally been motivated by an interest in natural radiation-levels in certain areas (for example,

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tes, obtained over a wide range
the apparently high degree of
total γ-dose-rate measurements
deviation of about ± 0·5 μr./h
or individual fall-out dose-rate
al natural dose-rate components
as conservatively estimated at
dose-rate values have somewhat

mber of survey trips have been
arts of the United States. These
een motivated by an interest in
in certain areas (for example,



least 50 ft. from other surfaces. In every case, a survey of the immediate area was conducted with portable scintillation detectors to ascertain that the measured total dose rate was representative for the area. The requirement for flatness is an important one, for ground depressions have often shown elevated γ-ray-levels. Several spectrometer readings have been taken over depressions of large area where such elevated readings were observed. As expected, the resulting spectra exhibited large fall-out peaks (0·5 and 0·75 MeV). The observed dose rate increases above the values for adjacent flat areas generally were consistent with those predicted from the differences in peak areas.

It should be noted that open-field fall-out determinations may be representative of areas of bare or grass-covered ground, but not necessarily of all areas which are of significance with respect to the radiation exposure of the human population in their daily rounds. Thus, any consideration of the influence of fall-out on general population exposure-levels must take into account a number of factors not discussed here, such as the distribution of fall-out on roadways, sidewalks and buildings, the degree to which the activity is distributed to other locations, and the shielding effect of man-made structures. For example, Franke *et al.*[24] have reported finding very little artificial radioactivity in homes, and then only

Table 3. SUMMARY OF 1962–63 SURVEY RESULTS

| Survey area | Date | No. Loc. | Dose-rate range ($\mu$r./h) (natural $\gamma$) | (fall-out $\gamma$) |
|---|---|---|---|---|
| New York State | | | | |
| (1) South and west | 8/63 | 35 | 5–7 | 3–4 |
| (2) North | 8/63 | 19 | 4–8 | 3–5 |
| (3) New York City | 5–9/62 | 3 | 5–10 | 3–5 |
| | 5–9/63 | 3 | 7 | 4–5 |
| Vermont | 7/62 | 26 | 4–8 | 2–3 |
| | 8/63 | 6 | 4–8 | 4–5 |
| New Hampshire | 7/62 | 39 | 6–15 | 2–3 |
| | 5/63 | 5 | 6–8 | 3–5 |
| | 9/63 | 10 | 6–15 | 3–5 |
| South-eastern U.S.* | 4/63 | 8 | 3–7 | 4–7 |
| (1) South Carolina | 4/63 | 6 | 3–10 | 4–7 |
| (2) North Carolina | 4/63 | 2 | 15–19 | 2–4 |
| Western U.S. | | | | |
| (1) Black Hills, S.D. | 10/62 | 6 | 6–8 | 2–5 |
| | 10/63 | 4 | 6–8 | 3–4 |
| (2) Seattle, Wash. | 10/62 | 3 | 4 | 2 |
| (3) Olympic Peninsula, Wash. | 10/62 | 9 | 3–5 | 1–4 |
| (4) San Francisco, Cal. | 10/62 | 6 | 4–8 | 1–2 |
| | 10/63 | 6 | 5–8 | 1 |
| (5) Nevada–Utah | 10/62 | 6 | 5–9 | 1–4 |
| | 10/63 | 3 | 5–9 | 2–8 |
| (6) Denver–Colorado Springs, Col. | 10/62 | 9 | 9–14 | 2–3 |
| | 10/63 | 10 | 8–15 | 1–2 |
| Central U.S.† | 10/62 | 15 | 7–9 | 3–6 |
| | 10/63 | 11 | 7–9 | 2–4 |

* Includes locations in Texas (2), Louisiana (1), Arkansas (1), Alabama (2), Tennessee (1), and Georgia (1).

† Includes locations in Wisconsin (1), Minnesota (1), Eastern South Dakota (4), Illinois (4), Kansas (3) and Missouri (2).

near entrances from outside. Spiers[5] has observed dose rate increases inside various structures during periods of high fall-out deposition, although these were generally of lesser amplitude than the corresponding outdoor changes. It is evident that the effect of deposition of fission products in the environment on indoor $\gamma$-radiation levels must be strongly dependent on the type of building material, thickness of the walls, the number and size of apertures in the walls (that is, doors and windows), the location of rooms, the presence of other buildings nearby, as well as the degree to which the fall-out is tracked indoors. Spiers[5] has suggested applying a shielding factor of about two to outdoor measurements as a means of estimating an upper limit to the dose-rate contribution of fall-out to general population exposure, this figure being derived from ground-floor observations in houses. The removal of artificial radioactivity from hard surfaces by weathering processes plays a part in reducing the outdoor exposure-level of the population, particularly in urban areas where a large number of people see very little open ground. It is probable that open field measurements provide a substantial overestimate of the total exposure of the population to fall-out $\gamma$-radiation.

Table 3 presents a summary of the results obtained during the 1962 and 1963 survey trips with respect to both natural and fall-out $\gamma$-levels. The dose-rate ranges quoted generally include about 80–90 per cent of the individual measurements at various locations in the particular areas. The detailed data for individual loca-

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| | |
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* with n

For example, the measurements in the San Francisco Bay area were carried out after periods of very little rainfall. The highest fall-out readings were observed during the spring and summer of 1963, when levels of 4–6 μr./h were found at a number of locations scattered throughout the eastern states.

Beginning in May 1963, an effort was made to monitor the changes in fall-out γ-levels in the New York City area by repeated measurements at several locations. Three flat grassy areas in Westchester County, New York, were chosen, separated by about 5 miles from one another. The spectrometer readings indicated that the natural γ-dose rates at the three locations were all approximately 7 μr./h. The measured total γ-dose rates were generally slightly more than 12 μr./h until September. Our best estimates for the fall-out γ-levels at these sites are shown in Fig. 2. These data provide strong evidence that open field fall-out γ-levels in the New York area remained roughly constant at a high level ($\sim$ 5 μr./h) from at least May until September 1963 and then decreased, roughly exponentially with an apparent 'half-life' slightly longer than that of $^{95}Zr$–$^{95}Nb$. This is consistent with the evidence provided by the field spectra that $^{95}Zr$–$^{95}Nb$ has been contributing 60–80 per cent of the fall-out dose rates during the periods of measurement.

During the 1962 survey trip to the Pacific coast, a specific effort was undertaken to obtain measurements on the northern part of the Olympic peninsula (Clallam Co.), Washington. Over a distance of approximately 50 miles, the mean annual rainfall varies by a factor of nearly ten from east (Sequim) to west (Forks); under such conditions one might expect a substantial variation in the fall-out

mpic peninsula (Clallam Co.),
ce of approximately 50 miles,
ries by a factor of nearly ten
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determining the fall-out γ-dose rate indicates that the assumptions involved in carrying out the peak method of analysis are reasonable. Thus, practically all the fall-out γ-radiation during late 1962 and 1963 derived from $^{95}Zr$–$^{95}Nb$, $^{106}Ru$–$^{106}Rh$, $^{103}Ru$–$^{103}Rh$, and $^{137}Cs$, with the

$^{95}Zr$–$^{95}Nb$ contributing 60–80 per cent of the fall-out dose-rate. This is consistent with Gustafson's results[27] during a comparable period in 1959, when more than 90 per cent of the inferred fall-out γ-dose rate at a location at Argonne National Laboratory was found to be derived from these isotopes. Peirson and Salmon[9] obtained similar results at several locations in Great Britain at about the same time.

The Health and Safety Laboratory has therefore developed techniques for the accurate determination of environmental γ-dose rates and the partial dose-rate contributions of the significant natural and fall-out emitters utilizing high-pressure ionization chamber and γ-spectrometric measurements directly in the field. These techniques depend on reasonable assumptions as to the distributions in the environment of the various radioisotopes and on relatively unsophisticated procedures for interpreting the spectral data.

Measurements at more than 200 sites in the United States indicate that the open-field γ-dose rates from natural sources do not vary over a wide range from place to place in this country, generally falling between 5 and 9 μr./h. In those areas where high natural levels (up to 20 μr./h) have been observed, high thorium and potassium content of the soil is generally responsible. The relatively small magnitude and narrow range of the observed dose-rate contributions from the uranium series are interesting results deserving of further study, and are probably related to the leaching of uranium-238 and radium-226 from weathered material and the migration of free radon-222 from the upper layers of the soil[15].

During the second half of 1962 and 1963 it was observed that γ-emitting fall-out in the environment had elevated the γ-background by a measurable amount at every location and that increases of 50 per cent or more in the total γ-level appeared to be quite common over open ground. The highest fall-out levels were observed during the spring and summer of 1963; the autumn 1963 readings were lower, and generally comparable with those a year earlier in the western States and in northern New England. A decline in fall-out levels set in at the New York City area sites in September of 1963 after at least four months of quite large elevations above the normal background-levels. These results are consistent with those of Burch *et al.*[14] in England between August 1962 and April 1963, who recorded with an ionization chamber somewhat elevated readings at one location during August–November 1962 and then a jump to roughly 50 per cent above normal γ-background in November, which was maintained except for the effect of snow cover until at least April 1963. There is also rough agreement with Gustafson's data[28], which seem to indicate a rather steady increase in fission product dose rate at a site at Argonne National Laboratory from 2 μr./h to 7 μr./h between September 1962 and July 1963 and then a

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Laboratory from 2 μr./h to
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