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EXPERIMENTAL MEASUREMENT
OF FALLOUT
PROTECTION PROVIDED
BY TRANSPORTATION VEHICLES

LAS VEGAS OPERATIONS

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EXPERIMENTAL MEASUREMENT OF FALLOUT PROTECTION PROVIDED BY TRANSPORTATION VEHICLES

By

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1. INTRODUCTION

The Civil Effects Test Operations (CETO) of the Division of Biology and Medicine (DBM) of the U. S. Atomic Energy Commission requested that experimental measurements be made of the fallout protection provided by transportation vehicles normally used to transport personnel.

The information will be useful for planning the possible evacuation of personnel from or through contaminated areas.

2. EXPERIMENTAL METHOD

2.1 GENERAL DESCRIPTION

Measurements were made using the Mobile Radiological Measuring Unit (MRMU), a system which hydraulically pumps a ^{60}Co source through a length of tubing placed over the ground to simulate a uniform distribution of radioactivity. The measurements were conducted on a dry-lake bed at the Nevada Test Site.

Instrumentation for this experiment consisted of Victoreen condenser ion chambers which were previously calibrated with an NBS-calibrated ^{60}Co source.

Two ^{60}Co sources were used from the MRMU system for simulating the fallout field. The activities of these sources were 418 millicuries and 113 curies, calibrated with NBS-calibrated Victoreen condenser R-chambers. Complete details of MRMU instrumentation and source calibrations are presented in Ref. 1.

2.2 EXPERIMENTAL TECHNIQUE

The experimental technique consisted of creating simulated smooth planes of uniform contamination around the vehicles and measuring radiation levels at selected locations within. Three separate configurations were simulated, the results of which were used to obtain radiation levels (and thus protection factors) from a smooth, infinite plane of ^{60}Co contamination. These three configurations were:

1. First close-in ground contribution (Ground 1)
2. Second close-in ground contribution (Ground 2)
3. Far-out ground contribution (Ground FO)

The tubing was laid as uniformly as possible with a 1-meter separation between tubes out to an effective radius of 7 meters for the Ground 1 contribution, shown in Fig. 1. For the Ground 2 contribution, the tubing was laid in an effective radius of from 7 to 21 meters, with a tubing separation of two meters (see Fig. 2). Figure 3 shows a photograph of a type 4107 vehicle in position on the tubing distribution. To provide experimental data as a basis for estimating the far-out ground contribution (contribution from contamination beyond close-in measurement areas), a ring source of a 100-meter radius was used.

Detector locations are described and physical locations are listed in Tables 1 and 2. Floor plans and detector locations are shown in Figs. 4 and 5.

Table 1. Detector locations for types 4106* and 4107* vehicles (buses).

Test Designation	Description
L1.1	Driver's seat (bottom)**
L1.2	Driver's seat (top)**
L2.1	1st seat on left behind driver (bottom)
L3.1	5th seat on left (bottom); also center seat of bus
L3.2	5th seat on left (top); also center seat of bus
L4.1	9th seat on left (bottom)
L5.1	Rear seat (bottom)
L5.2	Rear seat (top)
R1.1	1st seat on right (bottom)
R1.2	1st seat on right (top)
R2.1	2nd seat on right (bottom)
R3.1	5th seat on right (bottom); also center seat of bus
R3.2	5th seat on right (top); also center seat of bus
R4.1	7th seat on right (bottom)
R5.1	9th seat on right (bottom)
R5.2	9th seat on right (top)
C-1	0.3 meter above floor, geometric center of bus
C-2	1 meter above floor, geometric center of bus
C-3	2 meters above floor, geometric center of bus

*Type 4106 is the manufacturer's designation of the type of bus now in use at NTS. Type 4107 is the manufacturer's designation of the typical "Scenic Cruiser" bus, which will eventually replace the type 4106 bus at NTS.

**Bottom refers to lower abdomen. Top refers to chest area.

Table 2. Detector locations of typical school bus.

Test Designation	Description
L1	Driver's seat (top)*
L2	1st seat on left behind driver (top)
L3	3rd seat on left (top)
L4	4th seat on left (top)
L5	5th seat on left (top)
L6	7th seat on left (top); also rear seat
R1	1st seat on right (top)
R2	3rd seat on right (top)
R3	4th seat on right (top)
R4	5th seat on right (top)
R5	7th seat on right (top); also rear seat
C-1	0.3 meter above floor, geometric center of bus
C-2	1 meter above floor, geometric center of bus
C-3	2 meters above floor, geometric center of bus

*Top refers to chest area.

At each location two dosimeters were placed in paper cups and taped in position to the seats and/or the backs of the seats of each vehicle. The average reading of dosimeters placed at one location was taken as the exposure at that location. The time of exposure varied from 10 minutes to 1 hour.

For each ground contribution, the following general procedures were observed:

1. All detectors were charged and placed in position while a dummy source capsule was pumped through the tubing to assure that it had not been damaged and to make sure that there were no restrictions to prevent the actual source from maintaining constant speed throughout the experimental tubing layout.

2. After radiological safety clearance was given, the hydraulic system was energized and an experimental run was made. After the test exposure, the source was secured in its shield, detectors were read, and readings were recorded. Temperature, pressure, and source exposure time were also recorded.

The experiment consisted of four phases: (1) free-field measurement, (2) vehicle type 4106, (3) vehicle type 4107, and (4) a school bus.

Fig. 1. Ground 1 tubing layout.

Fig. 2. Ground 2 tubing layout.

Fig. 3. Type 4107 vehicle in position for the experiment.

Fig. 4. Typical seating arrangement and detector locations for types 4106 and 4107 vehicles.

Fig. 5. Typical seating arrangement and detector locations for the school bus.

3. PRESENTATION OF DATA

All normalized data appear in Tables 3, 4, 5, and 6; all input data for the normalized data appear in Table 7. Data plotted on floor plans are shown in Figures 6, 7, and 8. The raw input data were averaged and then corrected for calibration, temperature and pressure, and source-exposure time and then normalized to a standard source density according to the equation

$$E_n = \frac{E_c \times A}{T \times S} \quad (1)$$

where E_n = normalized exposure rate in mr/hr per mc/sq meter

E_c = average corrected detector response in mr

A = total area of contamination in sq meters

T = exposure time in hours

S = source activity in millicuries

These normalized data appear in the Ground 1 and Ground 2 data columns. The Ground far-out (FO) column refers to the contribution from contamination beyond the close-in measurement areas. This contribution was estimated by experimental data from a ring source at a 100-meter radius and free-field (no vehicle) exposure. The equation used to estimate the far-out contribution was

$$\text{Ground FO} = \frac{D_c \times E_m}{I_c} \quad (2)$$

where Ground FO = far-out ground contribution (mr/hr per mc/sq meter)
to a particular point in the vehicle

D_c = free-field exposure rate (mr/hr per mc/sq meter)
at 1 meter above ground from contamination beyond the
close-in measurement area

E_m = measured exposure rate (mr/hr per mc/meter of
circumference) at the point in question from a ring
source at a 100-meter radius

I_c = measured free-field exposure ring (mr/hr per mc/meter
of circumference) 1 meter above ground from a ring
source at a 100-meter radius

Equation 2 can apply if the energy and angular distribution of D_c are the same as I_c . Figure 9* shows that with the source geometries used in this experiment, errors are expected to be negligible. The value of D_c was taken to be 14.35 mr/hr per mc/sq meter. D_∞ was taken as 44.8 mr/hr per mc/sq m (derived from a series of both theoretical and experimental determinations of the free-field infinite plane exposure rate). See for instance Ref. 2. I_c was measured and the value was 0.0613 mr/hr per mc/meter of circumference.

Table 3. Type 4106 vehicle.

Position	Ground 1	Ground 2	Ground FO	Total Ground	PF
L1.1	2.79	8.61	9.90	21.30	2.1
L1.2	7.28	9.26	14.81	31.35	1.4
L2.1	6.76	8.93	10.74	26.43	1.7
L3.1	9.96	6.80	10.06	26.82	1.7
L3.2	8.91	7.46	11.44	27.81	1.6
L4.1	6.21	6.63	9.34	22.18	2.0
L5.1	5.70	8.43	8.49	22.62	2.0
L5.2	7.54	11.90	10.93	30.37	1.5
R1.1	6.62	8.11	10.20	24.93	1.8
R1.2	5.85	8.76	12.03	26.64	1.7
R2.1	9.52	7.10	10.46	27.08	1.7
R3.1	11.14	6.63	10.06	27.83	1.6
R3.2	8.24	7.63	11.44	27.31	1.6
R4.1	10.07	10.27	9.80	30.14	1.5
R5.1	6.10	6.12	9.34	21.56	2.1
R5.2	4.93	7.96	11.65	24.54	1.8
C-1	11.25	7.46	9.97	28.68	1.6
C-2	8.60	7.43	12.14	28.37	1.6
C-3	6.88	9.11	13.64	29.63	1.5

*Unpublished data to be published later as CEX-63.8.

Table 4. Type 4107 vehicle.

Position	Ground 1	Ground 2	Ground FO	Total Ground	PF
L1.1	5.61	9.18	10.06	24.85	1.8
L1.2	5.54	10.02	11.70	27.26	1.6
L2.1	6.54	8.31	9.36	24.21	1.9
L3.1	9.02	7.37	10.30	26.69	1.7
L3.2	7.47	8.68	11.70	27.85	1.6
L4.1	5.66	7.88	10.30	23.84	1.9
L5.1	4.43	8.93	10.30	23.66	1.9
L5.2	4.85	9.47	11.93	26.25	1.7
R1.1	6.47	8.46	9.59	24.52	1.8
R1.2	6.27	9.44	11.93	27.64	1.6
R2.1	6.20	7.80	10.30	24.30	1.8
R3.1	8.89	7.01	10.30	26.20	1.7
R3.2	7.33	7.33	11.70	27.36	1.6
R4.1	8.60	7.15	10.33	26.08	1.7
R5.1	6.10	7.62	10.76	24.48	1.8
R5.2	5.88	8.71	11.70	26.29	1.7
C-1	10.30	7.48	8.42	26.20	1.7
C-2	8.09	8.49	11.93	28.51	1.6
C-3	6.30	7.95	13.10	27.35	1.6

Table 5. School bus.

Position	Ground 1	Ground 2	Ground FO	Total Ground	PF
L1	7.61	6.91	9.85	24.37	1.8
L2	8.65	7.23	12.11	27.99	1.6
L3	9.40	7.54	12.31	29.25	1.5
L4	8.88	7.36	12.18	28.42	1.6
L5	8.82	7.57	12.25	28.64	1.6
L6	8.60	8.78	12.11	29.49	1.5
R1	8.38	7.50	12.21	28.09	1.6
R2	9.17	7.50	12.09	28.76	1.6
R3	8.97	7.40	12.25	28.62	1.6
R4	8.78	7.80	12.09	28.67	1.6
R5	8.40	9.04	12.40	29.84	1.5
C-1	10.75	6.47	12*	29.22	1.5*
C-2	9.15	7.71	12*	28.86	1.6*
C-3	7.76	8.65	12*	28.41	1.6*

*Estimated values.

Table 6. Free-field measurements one meter above ground.

Position	Ground 1	Ground 2	Total Close-in	Ground FO	Total
1 meter	19.95	10.50	30.45	14.35*	44.8*

*14.35 = 44.8 - 30.45. All values in this table have units of mr/hr per mc/sq meter.

Table 7. Information used in correcting and normalizing data.

Data in Table No.	Type of Run	Exposure Time (Hrs)	Average Temp (°C)	Average Pressure (mm Hg)	Area (Sq m)	Source Activity (Curies)
3	Ground 1	0.21	22	655	154	0.418
3	Ground 1	0.147	22	650	154	0.418
3	Ground 2	0.482	23.5	655	1234	0.418
3	Ground FO	0.298	28	655	628.3 m	113.0
3	Ground FO	0.301	28	655	628.3 m	113.0
4	Ground 1	0.17	35	655	154	0.418
4	Ground 2	1.086	34	655	1234	0.418
4	Ground FO	0.642	32	655	628.3 m	113.0
5	Ground 1	0.185	40	655	154	0.418
5	Ground 2	1.01	36	655	1234	0.418
5	Ground FO	0.643	31	655	628.3 m	113.0
6	Ground 1	0.18	35	655	154	0.418
6	Ground 2	0.806	34	655	1234	0.418
6	Ground FO	0.336	37	655	628.3 m	113.0

Fig. 6. Protection factors of the 4106 vehicle.

* A = ABDOMEN
C = CHEST

Fig. 7. Protection factors of the 4107 vehicle.

*C= CHEST

Fig. 8. Protection factors of the school bus.

Fig. 9. Relative exposures, angular distribution at 1 meter for two ^{60}Co source configurations.

4. RESULTS

To evaluate the protective qualities of a vehicle and to give the protection quantitative expression, the term protection factor (PF) is used. This is a number indicating the protective value of a vehicle, and it provides a measure of how much less the radiation level would be at a given point inside the vehicle than outside in an unprotected area. In technical terms it is the ratio of the exposure-rate one meter above a smooth infinite plane uniformly contaminated with radioactive material to the exposure rate at a specific point in question, assuming the same source distribution. Accordingly,

$$PF = \frac{D_{\infty}}{D}$$

where D_{∞} is the total infinite plane exposure rate and D is the exposure rate in question.

To accurately determine a protection factor, it is necessary to simulate fallout radiation on the ground surrounding the vehicle out to an infinite distance. Since this is impractical, simulation in these experiments was limited to the immediate vicinity of the vehicles, where results would be helpful in estimating protection factors. The contribution from those areas not simulated was analytically estimated by using experimental data as guide lines.

Type 4106 buses show a range of protection factors from 1.4 to 2.1, with an average of 1.7.

Type 4107 buses show a range of protection factors from 1.6 to 1.9, with an average of 1.7.

School buses show a range of protection factors from 1.5 to 1.8, with an average of 1.6.

These protection factors are expected to be accurate to within a standard deviation of $\pm 6\%$. The accuracy of the data is within a standard deviation of $\pm 5.3\%$. The D_{∞} was taken as $\pm 3\%$. (Reference 3 contains a detailed error analysis of a similar experiment.) Very little difference is noted for the abdomen and chest areas.

Both the measurements and the reference (D_{∞}) were taken above a smooth plane. If both were above a rough plane, which is more realistic, the resulting protection factors would be only slightly different (probably 1.8 instead of 1.7).

The difference between fallout protection factors and ^{60}Co protection factors is negligible for thin shields (as in this experiment). For this reason, the protection offered by these transportation vehicles, as measured in this experiment, can be used for planning possible evacuation of personnel from or through fallout-contamination areas.

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