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HAZARDS CONTROL QUARTERLY REPORT NO. 18

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CONTENTS

Page No.

Theoretical Variation of Stage Constants with Volumetric Flow Through the Andersen Sampler

J. J. Cohen

A curve for a six-stage Andersen cascade impactor has been plotted to show the effective cutoff diameter of unit-density particles as a function of flow rate for each stage

1

Whole-Body Counter Calibration for Potassium 40

C. T. Schmidt and R. V. Griffith

Phantom calibration methods and results of 58 human measurements for potassium-40 are presented

6

An Apparatus for Growing Five Single Crystals of Dosimeter-Grade LiF Simultaneously

D. E. Jones and R. D. Taylor

A furnace has been built and successfully operated to simultaneously grow five single crystals of LiF with selected impurities

11

Range and Relative Stopping Power of Pu²³⁹ Alpha Particles in Various Materials

K. R. Kase

Maximum and mean ranges and relative stopping powers of Pu²³⁹ alpha particles in various materials are presented

14

Evaluation of a Neutron REM Dosimeter

S. Block and K. F. Petrock,

A neutron REM counter has been evaluated and found to read RBE dose rate to $\pm 10\%$ in the intermediate energy region

17

A Sequential Air Sampler

D. N. Montan and J. L. Cate, Jr.

A 12-station, portable sequential air sampler for radioiodine was designed and built

26

CONTENTS (Continued)

Page No.

Use of Diffusion Coefficient Measurements for Phase Definition of Radioiodine Aerosols

C. L. Lindeken

A simple, rapid method for determining diffusion coefficients serves to detect particulates in radioiodine aerosols

29

The Laser Eye Protection Program at LRL

D. E. Jones and M. Sykos

A description is given of the LRL laser eye protection program including a discussion of eye protective devices and the importance of operator training

34

New Hydraulic Equations for Fire Hose

R. G. Purington

Tests by Underwriters Laboratory reveal that fire hose quality has improved; this results in new friction characteristics

39

A Sensitization Test for Materials Used in Perchloric Acid Enclosures

J. R. Gaskill, C. R. Veith, and W. K. Benefield*

A test developed to determine the early sensitivity to perchloric acids of organic materials has been applied to a number of products used or proposed for use in perchloric acid enclosures

46

Evaluation and Testing of a Remotely Operated Explosive-Atmosphere Meter

J. R. Gaskill and R. L. Shaw

With the cooperation of the Johnson-Williams Company, an instrument has been developed which appears to be suitable for remote monitoring of explosive atmospheres in programs involving underground test detonations

49

*Summer employee from University of Maryland, College Park, Maryland.

CONTENTS (Continued)

Page No.

Weathering and Light-Traffic Effects on Side-Walk Test Patches

J. R. Gaskill and C. R. Veith

Exposure of flooring materials, sealants, and adhesives to outdoor weathering and light traffic for periods of up to four years shows (1) that epoxy formulations and certain vinyl strip coats are quite durable, and (2) that epoxy-presealed concrete will protect a linoleum-adhesive bond against failure through water intrusion

55

HAZARDS CONTROL
QUARTERLY REPORT NO. 18

(July-September 1964)

Lawrence Radiation Laboratory, University of California
Livermore, California

THEORETICAL VARIATION OF STAGE CONSTANTS WITH VOLUMETRIC
FLOW THROUGH THE ANDERSEN SAMPLER

The Andersen sampler (Fig. 1) is a six-stage cascade impactor, useful for aerosol sampling and particle size analysis. Existing calibration data on the characteristics of this sampler are based on a sampling rate of 1.0 cfm.^{1, 2} For other sampling rates the collection characteristics of each stage will be altered since flow rate affects flow velocity, which is a parameter of collection efficiency in impaction.

Fig. 1. The Andersen six-stage cascade impactor.

The collection characteristics for a given impactor stage are described as the stage constants. Those most commonly used are the "effective cutoff diameter" (ECD) and the "mass median diameter" (MMD). The ECD is defined as the particle diameter for which the collection efficiency on that stage is

0.5 (50% collected). The MMD is the diameter of a particle whose mass is the median mass of all particles on that given stage.

¹A. A. Andersen, "New Sampler for the Collection, Sizing, and Enumeration of Viable Airborne Particles," *J. Bacteriol.* 76, 471-484 (1958).

²K. R. May, "Calibration of a Modified Andersen Bacterial Aerosol Sampler," *Appl. Microbiol.* 12, 37-43 (1964).

Detailed discussions of stage constants have been presented by Mercer^{3,4} in which he concludes that the ECD is superior to the MMD for purposes of interpreting impactor data. Hence this report will be limited to ECD's for the various stages of the sampler relative to volumetric flow.

Impaction efficiency is a function of a dimensionless inertial parameter, ψ , defined by⁵:

$$\psi = \frac{C \rho_p V_0 D_p^2}{18 \mu D_c}$$

where

C = empirical correction factor for the resistance of fluids to the movement of small particles (for air at normal room temperature and pressure $C = 1.00 + 0.16 \times 10^{-4}/D_p$),

ρ_p = density of aerosol particle, g/cc,

V_0 = velocity of aerosol jet, cm/sec,

D_p = effective diameter* of aerosol particles, cm,

μ = viscosity of air, poises (for air at 297° K, $\mu = 1.8 \times 10^{-4}$ g/sec-cm),

D_c = diameter of round jet or width of rectangular jet, cm.

Each stage of the Andersen sampler is perforated with 400 holes of uniform diameter.¹ The hole diameters decrease with increasing stage number as shown in Table I. To determine the relation between volumetric flow and ψ , let

Q = volume flow rate through sampler in cc/sec,

A = total cross-sectional open area in cm²;

therefore, for any particular stage

³T. T. Mercer, "The Stage Constants of Cascade Impactors," O. T. S., U. S. Dept. of Commerce, Washington, D. C., TID-4500.

⁴T. T. Mercer, "On the Calibration of Cascade Impactors," Ann. Occupational Hyg. 6, pp. 1-14.

⁵W. E. Ranz and J. B. Wong, "Jet Impactors for Determining the Particle Size Distribution of Aerosols," Arch. Ind. Hyg. Occupational Med. 5, 464-477 (1952).

*The effective diameter of a particle is the diameter of a sphere of equal density having the same terminal settling velocity.

$$V_0 = \frac{Q}{A} = \frac{Q}{400(\pi D_c^2/4)} = \frac{Q}{314 D_c^2}$$

Table I. Stage characteristics of Andersen cascade impactor.

Stage No.	Hole diam, D_c , cm	$0.15 D_c^3$
1	0.1180	2.47×10^{-4}
2	0.0915	1.14×10^{-4}
3	0.0710	5.35×10^{-5}
4	0.0534	2.28×10^{-5}
5	0.0343	6.05×10^{-6}
6	0.0254	2.45×10^{-6}

Since calibration data for impactors are normally expressed in terms of unit-density particles, let $\rho_p = 1.00$. Substituting for V_0 , ρ_p , and μ :

$$\psi = \frac{C \left(\frac{Q}{314 D_c^2} \right) D_p^2}{3.2 \times 10^{-3} D_c} = \frac{C Q D_p^2}{1.045 D_c^3}$$

A plot of the empirical correction factors for fluid resistance, C , as a function of particle size, D_p , is shown in Fig. 2. From this graph it is apparent that the necessary correction is minute for particles greater than 1.0μ (micron) in diameter but becomes substantial for smaller particles. For example: for $0.1\text{-}\mu$ particles, $C = 2.6$; for $1.0\text{-}\mu$ particles, $C = 1.16$; and for $10\text{-}\mu$ particles, $C = 1.016$.

From the data of Ranz and Wong,⁵ it is noted that for round holes the 0.5 efficiency point occurs under conditions where $\sqrt{\psi} = 0.38$. Substituting for ψ :

$$0.144 = \frac{C Q D_p^2}{1.045 D_c^3}$$

or

$$Q = \frac{0.15 D_c^3}{C D_p^2}$$

Fig. 2. Correction factor for resistance of a fluid to the movement of small particles. ($C = 1.00 + 0.16 \times 10^{-4}/D_p$.)

Fig. 3. Relationship between Q and ECD for the various stages of the Andersen impactor.

The relationship between Q and ECD for the various stages of the Andersen sampler are shown in Fig. 3. At a flow rate of 1.0 cfm, these data essentially agree with those determined theoretically and experimentally by May² for those stages which were unmodified. It is assumed the relationship is valid at other flow rates.

WHOLE-BODY COUNTER CALIBRATION FOR POTASSIUM 40

Introduction

The LRL shadow shield whole-body counter has been described in Hazards Control Quarterly Report No. 17, UCRL-12004. In this counting facility, the subject is placed on a shadow-shielded motor-driven moving bed. Above the bed is a shielded, stationary NaI(Tl) radiation detector 5 in. in diam by 4 in. thick. This paper describes the calibration procedure for potassium 40 and presents results of measurements on 58 human subjects for body content of K^{40} .

Procedure

Potassium 40 is a naturally occurring radioisotope, and potassium is a normal constituent of the body. It has been found that body potassium content per unit body weight is a function of subject age, when averaged over many subjects.⁶ For a male, age 33, the average specific potassium content is 2.0 g per kg of body weight, or about 150 g potassium for an average subject. This corresponds to an emission of 530 gammas/sec due to K^{40} ($E_{\gamma} = 1.46$ MeV). Thus K^{40} is helpful in whole-body counter calibration since it is normally present in the body in known amounts.

Calibration for K^{40} was performed using a vinyl resuscitation dummy⁷ as a phantom. The phantom was filled with deionized water for background measurements; a water solution of KCl was used for K^{40} measurements.

As a result of the phantom measurements, the following counting method was adopted. The subject is scanned lengthwise a distance of 1.12 m during a 20-minute count time. Scan velocity is constant. The midpoint of the scan is at 0.57 of the subject's height (measured from the subject's feet). For K^{40} , counts are integrated over a 160-keV range centered at 1460 keV. The detector resolution is 92 keV (FWHM) at 1460 keV.

⁶P. N. Dean and E. C. Anderson, Los Alamos Biological and Medical Research Group Annual Report July 1962 through June 1963, LAMS-3034, pp. 143-151.

⁷Obtained from California Safety Supply Co.

Background Measurement

The correct background spectrum must be obtained with the phantom in place since the phantom has considerable effect on the background because of absorption and scatter. For example, the background in the K^{40} photopeak region is 1583 ± 11 counts/20 min with the phantom in place and filled with deionized water. Removal of the phantom increases the background to 1854 ± 14 counts/20 min, in the same region. Background obtained with the phantom is shown in Fig. 4.

Potassium Measurement

The phantom was filled with KCl solution so as to contain 1042 g potassium. The sum in the K^{40} photopeak region was 5667 ± 34 counts per 20-min scan, averaged over five scans. The sensitivity for potassium is therefore 3.92 ± 0.04 counts per 20-min scan per gram of potassium.

Subject Height Corrections

Using a fixed scan distance, the K^{40} sensitivity is lower for tall subjects than for short. To correct for this variation, the following method was used. The 1.52-m, 39.41-kg phantom was filled with KCl solution and counted at several fixed positions. The results are shown by the data points in Fig. 5. The solid line is a normal error curve centered at 0.87 m with a standard deviation of 0.445 m. We now make the following assumptions for a subject of any height, h :

- 1) The maximum of the counting rate curve occurs at a position proportional to the subject's height, i. e., at $0.57 h$.
- 2) The standard deviation of the count rate curve is proportional to the subject's height, i. e., $\sigma = 0.292 h$.

On the basis of the above assumptions, subjects of the same weight (and same K^{40} content) but differing heights will have identical count-rate curves if the origin is shifted to $0.57 h$ and the abscissa is expressed in σ units. During a fixed-distance scan centered at $0.57 h$, the total counts observed will be the integral of the count rate curve over the proper limits.

With the scan distance D fixed at 1.12 m, the limits of the integration expressed in σ units are

$$\pm \frac{1}{2} \frac{D}{\sigma} = \pm \frac{1}{2} \frac{1.12}{0.292 h} = \pm \frac{1.92}{h}.$$

Fig. 4. Average whole-body counter background with phantom in place (calibration 10 keV/channel).

Fig. 5. K^{40} photopeak counting rate with detector at various positions along the phantom.

We can now calculate the effect of subject height using tabulated values of the normal error curve integral. The result is linear with subject height within 0.2%. Using the linear approximation and normalizing to unity for the phantom height of 1.52 m, the height sensitivity is

$$S_H = 1 - 0.350(h - 1.52).$$

Subject Weight Corrections

Heavy subjects will emit fewer gammas per gram of potassium than light subjects because of body attenuation. Los Alamos Scientific Laboratory has made a study of this effect using K^{42} as a tracer in volunteer subjects.⁸ The results showed an average decrease in photopeak efficiency of 0.007 per kg body weight. The standard deviation of an individual subject was $\pm 5.1\%$ from the least-squares linear relation. Accepting these results and normalizing to unity for phantom weight of 39.4 kg, the weight sensitivity is

$$S_W = 1 - 0.007(w - 39.4).$$

Conclusion

Combining the corrections for height and weight and the phantom sensitivity of 3.92 counts per scan per gram of potassium, we find

$$\begin{aligned} S &= 3.92 (S_H + S_W - 1) \\ &= 3.92 (1.808 - 0.350 h - 0.007 w) \text{ counts/scan-g(K)} \end{aligned}$$

for subject of height h and weight w .

Results

To date 58 male subjects have been measured in the whole-body counter. Table II summarizes our results for body potassium content as compared to the Los Alamos results.

⁸P. N. Dean and M. A. Van Dilla, LAMS-3034, pp. 152-161.

Table II. Average body content of potassium in males (grams per kg of body weight).

Age group	20-29	30-39	40-49
Mean g K/kg (LASL results)	2.07	1.98	1.88
Mean g K/kg (this study)	1.99 ± 0.08	1.89 ± 0.06	1.93 ± 0.09
Number measured	20	23	15
Standard deviation of a single observa- tion, g K/kg	± 0.35	± 0.29	± 0.34

AN APPARATUS FOR GROWING FIVE SINGLE CRYSTALS OF DOSIMETER-GRADE LiF SIMULTANEOUSLY

Introduction

In the course of development of an LiF thermoluminescent dosimeter, studies have been made of LiF doped with various kinds and amounts of impurities (Hazards Control Quarterly Reports, UCRL-7571, -7637, and -7811). We are presently engaged in parameter studies of growing LiF single crystals with various mixtures of our most sensitive dopants.

Procedure

Figure 6 is a sketch of the crystal growing apparatus. The central tube is very pure recrystallized alumina 7.6 cm o. d. by 92 cm long. For the diffusion studies the furnace was used horizontally. Three pairs of heating elements maintained a relatively long "flat" zone of temperature during this work.

The holder with five graphite crucibles (Fig. 7) is suspended on platinum wire attached to one end of a stainless steel cable. Since the growth time of a crystal is long, five crystals are grown simultaneously to speed up the investigation. At the other end of the cable is a counterbalance. The holder and crucibles are lowered through a nickel heat shield into the freezing zone at approximately 3 mm/hr. A nylon pulley, used as a friction drive, is coupled to a 1-revolution-per-day Cramer synchronous motor. The temperature gradient was measured by placing thermocouples just above and below the heat shield. The indicated temperatures were 890 and 840°C over 1.5 to 2.0 cm of space centered on the heat shield. Argon is introduced from the bottom of the furnace to maintain the desired inert atmosphere and act as a purge for impurity vapors.

Early runs of LiF with and without impurities have produced excellent crystals. Figure 8 shows pieces cleaved from five samples prepared in a single run. Cleavage is performed with a sharp knife. In almost all cases the samples have been formed into single crystals. Failures have appeared from a few that have been heavily doped or prepared with one or two "stubborn" impurities.

Spectrographic analyses of a limited number of samples were made to check for impurity diffusion and for nickel or other unwanted contamination. The results indicated that little or no diffusion or contamination occurred.

Fig. 6. Apparatus for growing dosimeter-grade LiF crystals five at a time.

Fig. 7. Graphite holder and crucible.

Fig. 8. Pieces cleaved from five samples.

RANGE AND RELATIVE STOPPING POWER OF Pu²³⁹ ALPHA PARTICLES IN VARIOUS MATERIALS

Introduction

With the increasing experimental use of Pu²³⁹, questions concerning the interaction of its 5.147-MeV alpha particle with various absorbers frequently arise. Specifically there is a need to know the maximum range and the $-dE/dx$ (or stopping power) of the alpha particle in a variety of commonly used materials. Data of the maximum range, mean range, and relative stopping power presented in tabular form would be most helpful.

Discussion

The data presented in Table III were obtained by using several equations⁹⁻¹¹ dealing with alpha particle range. These semiempirical equations yield the range to an accuracy of $\pm 10\%$. This has been confirmed by comparing these results with published theoretical range-energy data in Al, Cu, Ag, and Pb.¹² The equations used include:

For air:

$$R = 1.24E - 2.62 \text{ (ref. 9),}$$

$$\bar{R} = 0.318E^{3/2} \text{ (ref. 11).}$$

For any material Z*:

$$R_Z = 0.90 + 0.0275 Z + (0.06 - 0.0086 Z) \log \frac{E}{M} \text{ (ref. 10),}$$

⁹Radiological Health Handbook (U. S. Dept. of Health, Education, and Welfare, Washington, D. C., 1960).

¹⁰G. Friedlander, and J. W. Kennedy, Nuclear and Radiochemistry (John Wiley and Sons, Inc., New York, 1955).

¹¹I. Kaplan, Nuclear Physics (Addison-Wesley Publishing Co., Inc., Reading, Mass., 1958).

¹²W. A. Aron, B. G. Hoffman, and F. C. Williams, "Range-Energy Curves," AECU-663 (Second Revision, 1949).

*For elements with $Z < 10$, certain slight modifications are made.

Table III. Range and relative stopping power for 5.147-MeV alpha particles in various materials.

Material	Density, g/cc	Maximum range		Mean range		Relative stopping power
		microns	mils	microns	mils	
Air	0.001293	3.76×10^4	1.48×10^3	3.66×10^4	1.44×10^3	1.00
K	0.87	79.0	3.11	76.9	3.02	476
Na	0.972	59.9	2.36	58.3	2.29	629
Polyethylene	0.94	38.9	1.53	37.8	1.49	966
Ba	3.78	30.8	1.21	30.0	1.18	1220
Si	2.42	25.7	1.01	25.1	0.988	1460
Al	2.7	22.6	0.887	22.0	0.869	1660
Glass	2.6	22.0	0.865	21.4	0.843	1710
C (graphite)	2.25	21.6	0.854	21.0	0.830	1740
Mica	2.8	19.4	0.765	18.9	0.742	1940
B	2.53	19.3	0.760	18.8	0.739	1950
As	5.73	15.2	0.596	14.8	0.581	2480
Pb	11.35	13.2	0.522	12.8	0.506	2850
Zn	6.92	12.0	0.471	11.7	0.459	3140
PuO ₂	11.4	11.5	0.453	11.2	0.441	3270
Ag	10.49	10.0	0.394	9.74	0.384	3760
Ni	8.75	9.16	0.361	8.92	0.352	4100
Cu	8.92	9.15	0.360	8.90	0.352	4110
Ta	16.6	8.61	0.339	8.40	0.330	4360
Pu (alpha phase)	19.8	8.51	0.335	8.30	0.326	4410
Au	19.3	7.56	0.298	7.36	0.290	4970
Pt	21.27	6.76	0.266	6.60	0.260	5550

where

Z is the atomic number of the absorber,

E is the initial alpha-particle energy, MeV,

M is the mass number of the alpha particle,

R and $\bar{R}$ are the maximum and mean ranges of the alpha particle in air, cm,

R_Z is the maximum range of the alpha particle in the absorber, mg/cm².

For a compound or mixture of elements, the range must be determined from the range of the alpha particle in each individual element:

$$\frac{1}{R_T} = \frac{W_1}{R_1} + \frac{W_2}{R_2} + \frac{W_3}{R_3} + \dots \quad (\text{ref. 10})$$

where W_1 , W_2 , etc., are the weight percentages of the individual elements in the compound or mixture.

To determine the mean range for an alpha particle in a material it is necessary to calculate the relative stopping power of the material S'_Z with respect to air. This is done by taking the ratio of the range of the particle in air to its range in the material:

$$S'_Z = R/R_Z$$

where now R_Z is the maximum range of the particle in material Z, in cm. Then the mean range in the material is found from:

$$\bar{R}_Z = \bar{R}/S'_Z.$$

The upper limit on the maximum range of a 5.15-MeV alpha particle in several materials was calculated from Bethe's equation for dE/dx and in all cases was greater than the calculated R_Z .

$$-\frac{dE}{dx} = \frac{4Z^2 e^4 N Z}{M_0 v^2} \left[\ln \frac{2m_0 v^2}{I} \right]. \quad (\text{ref. 11})$$

The glass listed in Table III is ordinary crown glass. The compositions of the glass and mica are given in Table IV.

Table IV. Composition of glass and mica.

	Material	Wt %
<u>Glass</u>	SiO ₂	67
	Na ₂ O	12
	K ₂ O	5
	B ₂ O ₃	3.5
	BaO	10.6
	ZnO	1.5
	As ₂ O ₃	0.4
<u>Mica</u> [H ₂ KAl ₃ (SiO ₄) ₃]	H	0.5
	K	9.8
	Al	20.4
	Si	21.1
	O	48.2

EVALUATION OF A NEUTRON REM DOSIMETER

Introduction

We have built and evaluated a neutron REM dosimeter (Fig. 9) similar to the one reported by Andersson and Braun.¹³ They calibrated their instrument using only thermal neutrons and neutrons in the energy range from 25 keV to 15 MeV to determine the neutron sensitivity relative to an ideal rem response. They computed theoretically the response of their REM counter from thermal to 25 keV. Since this region contains neutrons in the intermediate energy range,¹⁴ we studied the response of our detector to a source rich in intermediate neutrons.

Calibration of Detector

We used a Pu^{238}Be neutron source ($N = 1.54 \times 10^7$ n/sec) to calibrate the instrument. The neutron yield was measured to $\pm 3\%$ by the manganese sulfate bath technique. The spectral distribution was resolved by exposing Ilford nuclear plates to the source and scanning 1000 tracks.¹⁵ Table V shows the energy distribution of the source neutrons and the corresponding dose distribution.

The RBE dose rate for the source was determined by summing the product $\phi(E) \times D(E)$ for all energy intervals at a point of interest. ($\phi(E)$ is the neutron flux, equal to $\frac{N}{4\pi R^2} N(E)$, and $D(E)$ is the multiple-collision RBE dose rate per unit flux.) At the point $R = 70$ cm, $D_{70} = \sum \phi(E) \times D(E) = 33.6$ mrem/hr.

Note that by using the average energy $\bar{E}$ of this distribution (4.076 MeV) and the RBE dose rate per unit flux corresponding to this energy (0.137 mrem/hr per $\text{n/cm}^2\text{-sec}$), and $\sum \phi(E) = 250 \text{ n/cm}^2\text{-sec}$, we get about the same result (34.2 mrem/hr). This is because most of the neutrons are in the region

¹³I. O. Andersson and J. Braun, "A Neutron REM Counter," AE-132.

¹⁴NBS Handbook 63, "Protection Against Neutron Radiation up to 30 MeV," defines intermediate neutrons as "neutrons of energy between 0.5 eV and 10 keV."

¹⁵Hazards Control Quarterly Report No. 14, UCRL-7571, p.29.

Fig. 9. Neutron REM dosimeter (after Andersson and Braun¹³).

Fig. 10. Multiple-collision RBE dose rate per unit flux as a function of energy.

Table V. Pu^{238}Be neutron source energy and dose distribution.

$\bar{E}$, MeV	N(E), percent of source neutrons in each energy group	D(E), ^a $\frac{\text{mrem/hr}}{\text{n/cm}^2\text{-sec}}$
0.5-1.0	10.7	0.104
1.0-1.5	9.1	0.137
1.5-2.0	8.6	0.130
2.0-2.5	6.4	0.127
2.5-3.0	5.1	0.126
3.0-3.5	7.0	0.130
3.5-4.0	6.0	0.134
4.0-4.5	6.0	0.137
4.5-5.0	6.4	0.138
5.0-5.5	7.6	0.140
5.5-6.0	6.6	0.141
6.0-6.5	4.6	0.145
6.5-7.0	3.8	0.145
7.0-7.5	3.2	0.146
7.5-8.0	3.2	0.147
8.0-8.5	2.6	0.147
8.5-9.0	1.4	0.147
9.0-9.5	1.1	0.147
9.0-10.0	0.5	0.147
10.0-10.5	0.3	0.167
10.5-11.0	0.4	0.208

^a Taken from ref. 14.

1 to 10 MeV where the REM dose per flux is essentially constant (Fig. 10).

Using this point, a linear plot of the REM dosimeter rate meter scale was made.

We applied this procedure to a Pu^{238}Li neutron source. Here the energy distribution is considered essentially the same as PoLi , so that the theoretical plot of the neutron spectrum derived by Hess¹⁶ is used to calculate

¹⁶ Wilmot Hess, "Neutrons from (α , n) Sources," UCRL-3839.

the RBE dose rate. This calculated dose rate of 10.2 mrem/hr agreed very well with the measured value of 10 mrem/hr. Again it is noted that the $\bar{E}$ of the source (~450 keV) and the neutron flux can be used to accurately compute the REM dose rate.

An SbBe photoneutron source giving monoenergetic neutrons of about 0.025 MeV showed about 0.5 mrem/hr on the dose meter while the calculated dose rate was 0.46 mrem/hr. Prior to this measurement, we found the REM dosimeter to have no gamma response when exposed to a Cs^{137} source to 500 R/hr.

All meter readings were average values of the ratemeter response.

Measurement of Complex Neutron Spectra

To check the response to intermediate energy neutrons, the Pu^{238}Be source was placed alternately in three spheres of D_2O moderators of 6, 15, and 25 cm radius, respectively. Monte Carlo calculations have been made of the spectral distribution of leakage neutrons from the spheres,¹⁷ using the unmoderated spectrum. Tables VI, VII, and VIII were prepared to calculate the dose distribution as a function of energy. Column 1 lists the energy groups of the code used for the Monte Carlo calculation; column 2 is the number of neutrons in the group per source neutron; column 3 is the product of column 2 and the total source leakage neutrons ($250 \text{ n/cm}^2\text{-sec}$ at the point of interest); column 4 is the RBE dose rate per unit neutron flux taken from Fig. 10; column 5 is the product of columns 3 and 4.

The leakage dose rate taken from column 5 as $\sum \phi' D(E)$ is tabulated in Table IX. The summation is broken down into three components: thermal (0.025 eV), intermediate (0.5 eV to 10 keV), and fast ($> 10 \text{ keV}$), and expressed as percentages. Dose contribution from thermal to intermediate energies (0.025 to 0.5 eV) is negligible.

The agreement between the calculated and measured doses exceeded our expectations. For comparison, Table IX also includes the dose rate computed from the $\bar{E}$ of the spectrum and ϕ . Observe the gross error that can be made using this method for computing the dose.

¹⁷J. Bryan and D. N. Montan, "Monte Carlo Calculation of Spectral Distributions of Neutron Sources in Moderators," Hazards Control Quarterly Report No. 14, UCRL-7571.

Table VI. Pu^{238} Be neutron source in 6-cm D_2O sphere, $\bar{E} = 2.83$ MeV.

Average energy, $\bar{E}$, eV	$d(n) = f$	$f\phi = \phi'$, $\text{n/cm}^2\text{-sec}$	$\frac{D(E)}{n/\text{cm}^2\text{-sec}}$, mrem/hr	$\phi' \times D(E)$, mrem/hr
(1)	(2)	(3)	(4)	(5)
4.486×10^{-2}	7×10^{-5}	1.750×10^{-2}	3.731×10^{-3}	0.065×10^{-3}
1.794×10^{-1}	7×10^{-5}	1.750×10^{-2}	3.731×10^{-3}	0.065×10^{-3}
7.178×10^{-1}	4×10^{-4}	1.000×10^{-1}	3.731×10^{-3}	0.373×10^{-3}
2.871	5×10^{-4}	1.250×10^{-1}	3.731×10^{-3}	0.466×10^{-3}
1.148×10^{-1}	1.1×10^{-3}	2.750×10^{-1}	3.731×10^{-3}	1.026×10^{-3}
4.594×10^{-1}	2.2×10^{-3}	5.500×10^{-1}	3.371×10^{-3}	2.052×10^{-3}
1.838×10^{-2}	5.6×10^{-3}	1.400	4.950×10^{-3}	6.930×10^{-3}
7.350×10^{-2}	6.67×10^{-3}	1.668	4.673×10^{-3}	7.795×10^{-3}
2.940×10^{-3}	1.68×10^{-2}	4.200	4.425×10^{-3}	18.585×10^{-3}
1.176×10^{-4}	3.26×10^{-2}	8.150	5.814×10^{-3}	47.384×10^{-3}
3.267×10^{-4}	3.11×10^{-2}	7.775	1.316×10^{-2}	102.319×10^{-3}
6.403×10^{-4}	3.07×10^{-2}	7.675	2.212×10^{-2}	169.771×10^{-3}
1.307×10^{-5}	5.81×10^{-2}	14.525	3.676×10^{-2}	533.939×10^{-3}
2.561×10^{-5}	5.00×10^{-2}	12.500	5.556×10^{-2}	694.500×10^{-3}
4.234×10^{-5}	4.14×10^{-2}	10.350	7.813×10^{-2}	808.646×10^{-3}
6.324×10^{-5}	4.13×10^{-2}	10.325	1.042×10^{-1}	1075.865×10^{-3}
8.833×10^{-5}	4.23×10^{-2}	10.575	1.250×10^{-1}	1321.875×10^{-3}
1.176×10^{-6}	4.51×10^{-2}	11.750	1.388×10^{-1}	1630.900×10^{-3}
1.694×10^{-6}	9.480×10^{-2}	23.700	1.316×10^{-1}	3118.920×10^{-3}
2.530×10^{-6}	9.180×10^{-2}	22.950	1.250×10^{-1}	2868.750×10^{-3}
3.533×10^{-6}	9.860×10^{-2}	24.650	1.250×10^{-1}	3081.250×10^{-3}
4.704×10^{-6}	1.159×10^{-1}	28.975	1.316×10^{-1}	3813.110×10^{-3}
6.042×10^{-6}	9.714×10^{-2}	24.285	1.388×10^{-1}	3370.758×10^{-3}
7.547×10^{-6}	5.57×10^{-2}	13.925	1.471×10^{-1}	2048.368×10^{-3}
9.220×10^{-6}	2.37×10^{-2}	5.925	1.471×10^{-1}	871.568×10^{-3}
1.106×10^{-7}	1.49×10^{-2}	3.725	2.500×10^{-1}	931.250×10^{-3}
1.255×10^{-7}				
1.359×10^{-7}				

$$\sum \phi' D(E) = 26,526.530 \times 10^{-3} \text{ mrem/hr}$$

Table VII. Pu²³⁸Be neutron source in 15-cm D₂O sphere, $\bar{E} = 1.39$ MeV.

Average energy, $\bar{E}$, eV	$d(n) = f$	$f\phi = \phi'$, n/cm ² -sec	$D(E)$, mrem/hr n/cm ² -sec	$\phi' \times D(E)$, mrem/hr
(1)	(2)	(3)	(4)	(5)
2.5×10^{-2}	4.2×10^{-2}	10.500	3.73×10^{-3}	3.72×10^{-3}
4.486×10^{-2}	1.02×10^{-2}	2.550	3.371×10^{-3}	9.514×10^{-3}
1.794×10^{-1}	1.39×10^{-2}	3.475	3.731×10^{-3}	12.965×10^{-3}
7.178×10^{-1}	1.91×10^{-2}	4.775	3.731×10^{-3}	17.816×10^{-3}
2.871	2.27×10^{-2}	5.675	3.731×10^{-3}	21.173×10^{-3}
1.148×10^1	3.04×10^{-2}	7.600	3.731×10^{-3}	28.356×10^{-3}
4.594×10^1	3.65×10^{-2}	9.125	3.731×10^{-3}	34.045×10^{-3}
1.838×10^2	4.65×10^{-2}	11.625	4.950×10^{-3}	57.443×10^{-3}
7.350×10^2	5.10×10^{-2}	12.750	4.673×10^{-3}	59.581×10^{-3}
2.940×10^3	7.040×10^{-2}	17.600	4.425×10^{-3}	77.880×10^{-3}
1.176×10^4	8.240×10^{-2}	20.600	5.814×10^{-3}	119.768×10^{-3}
3.267×10^4	5.11×10^{-2}	12.775	1.316×10^{-2}	168.119×10^{-3}
6.403×10^4	4.06×10^{-2}	10.150	2.212×10^{-2}	224.518×10^{-3}
1.307×10^5	5.54×10^{-2}	13.850	3.676×10^{-2}	509.126×10^{-3}
2.561×10^5	3.59×10^{-2}	8.975	5.556×10^{-2}	498.651×10^{-3}
4.234×10^5	2.35×10^{-2}	5.875	7.813×10^{-2}	459.014×10^{-3}
6.324×10^5	2.29×10^{-2}	5.725	1.042×10^{-1}	596.545×10^{-3}
8.833×10^5	2.15×10^{-2}	5.375	1.250×10^{-1}	671.875×10^{-3}
1.176×10^6	2.21×10^{-2}	5.525	1.388×10^{-1}	766.870×10^{-3}
1.694×10^6	4.93×10^{-2}	12.325	1.316×10^{-1}	1621.970×10^{-3}
2.530×10^6	5.07×10^{-2}	12.675	1.250×10^{-1}	1584.375×10^{-3}
3.533×10^6	5.02×10^{-2}	12.550	1.250×10^{-1}	1568.750×10^{-3}
4.704×10^6	5.21×10^{-2}	13.025	1.316×10^{-1}	1714.090×10^{-3}
6.042×10^6	4.64×10^{-2}	11.600	1.388×10^{-1}	1610.080×10^{-3}
7.547×10^6	2.66×10^{-2}	6.650	1.471×10^{-1}	978.215×10^{-3}
9.220×10^6	1.29×10^{-2}	3.225	1.471×10^{-1}	474.398×10^{-3}
1.106×10^7	6.1×10^{-3}	1.525	2.500×10^{-1}	381.250×10^{-3}
1.255×10^7				
1.359×10^7				

$$\sum \phi' D(E) = 14,266.387 \times 10^{-3} \text{ mrem/hr}$$

Table VIII. Pu²³⁸Be neutron source in 25-cm D₂O sphere, $\bar{E} = 0.582$ MeV.

Average energy, $\bar{E}$, eV	$d(n) = f$	$f\phi = \phi'$, n/cm ² -sec	$D(E)$, mrem/hr n/cm ² -sec	$\phi' \times D(E)$, mrem/hr
(1)	(2)	(3)	(4)	(5)
2.5×10^{-2}	3.0×10^{-1}	75.0	3.73×10^{-3}	27.9×10^{-2}
4.486×10^{-2}	2.85×10^{-2}	7.125	3.731×10^{-3}	2.658×10^{-2}
1.79×10^{-1}	3.61×10^{-2}	9.025	3.731×10^{-3}	3.367×10^{-2}
7.178×10^{-1}	3.85×10^{-2}	9.625	3.731×10^{-3}	3.591×10^{-2}
2.871	4.02×10^{-2}	10.050	3.731×10^{-3}	3.750×10^{-2}
1.148×10^1	4.78×10^{-2}	11.950	3.731×10^{-3}	4.459×10^{-2}
4.594×10^1	4.50×10^{-2}	11.350	3.731×10^{-3}	4.235×10^{-2}
1.838×10^2	4.87×10^{-2}	12.175	4.950×10^{-3}	6.027×10^{-2}
7.350×10^2	5.21×10^{-2}	13.025	4.673×10^{-3}	6.087×10^{-2}
2.940×10^3	5.21×10^{-2}	13.025	4.425×10^{-3}	5.764×10^{-2}
1.176×10^4	4.94×10^{-2}	12.350	5.814×10^{-3}	7.180×10^{-2}
3.267×10^4	2.65×10^{-2}	6.625	1.316×10^{-2}	8.719×10^{-2}
6.403×10^4	1.74×10^{-2}	4.350	2.212×10^{-2}	9.622×10^{-2}
1.307×10^5	2.47×10^{-2}	6.175	3.676×10^{-2}	22.699×10^{-2}
2.561×10^5	1.24×10^{-2}	3.100	5.556×10^{-2}	17.224×10^{-2}
4.234×10^5	9.20×10^{-3}	2.300	7.813×10^{-2}	17.970×10^{-2}
6.324×10^5	8.93×10^{-3}	2.233	1.042×10^{-1}	23.268×10^{-2}
8.823×10^5	8.27×10^{-3}	2.068	1.250×10^{-1}	25.850×10^{-2}
1.176×10^6	8.53×10^{-3}	2.133	1.388×10^{-1}	29.606×10^{-2}
1.694×10^6	2.15×10^{-2}	5.375	1.316×10^{-1}	70.735×10^{-2}
2.530×10^6	2.08×10^{-2}	5.200	1.250×10^{-1}	65.000×10^{-2}
3.533×10^6	2.09×10^{-2}	5.225	1.250×10^{-1}	65.313×10^{-2}
4.704×10^6	2.10×10^{-2}	5.250	1.316×10^{-1}	69.090×10^{-2}
6.042×10^6	1.69×10^{-2}	4.225	1.388×10^{-1}	58.643×10^{-2}
7.547×10^6	1.24×10^{-2}	3.100	1.471×10^{-1}	45.601×10^{-2}
9.220×10^6	5.7×10^{-3}	1.425	1.471×10^{-1}	20.962×10^{-2}
1.106×10^7	2.9×10^{-3}	0.725	2.500×10^{-1}	18.125×10^{-2}

$$\sum \phi' D(E) = 643.445 \times 10^{-2} \text{ mrem/hr}$$

Table IX. Pu²³⁸Be source in D₂O spheres.

D ₂ O sphere, radius	6 cm	15 cm	25 cm
Thermal neutrons (0.025 eV), %	0	4	30
Intermediate energy neutrons (0.5 eV to 10 keV), %	7	40	36
Fast neutrons (>10 keV), %	93	56	34
Calculated mrem/hr for 250 n/cm ² -sec	26.5	14.3	6.4
Measured mrem/hr with REM meter	26	13	6.8
Average energy $\bar{E}$ of leakage neutrons, MeV	2.83	1.39	0.582
Calculated dose rate using $\bar{E}$ and 250 n/cm ² -sec	31	34.6	25

Discussion

A neutron instrument has been judiciously designed¹³ to measure REM dose rate. Tests at LRL show that this instrument is capable of measuring a complex neutron spectrum rich in intermediate energy neutrons to within $\pm 10\%$ of the theoretical dose rate.

The sensitivity of our neutron REM counter is from 2 to 200 mrem/hr full scale on three ranges. (The BF₃ tube we use is 1 in. in diam, has an active length of 2 in., and is filled at a pressure of 60 cm Hg.) It is gamma insensitive to >500 R/hr of Cs¹³⁷ gamma radiation. Directional dependence is shown in Fig. 11. The instrument weighs 21.6 lb including the electronics.

Fig. 11. Directional dependence of LRL-built REM counter.

A SEQUENTIAL AIR SAMPLER

Introduction

An automatically operated sequential air sampler was developed to collect gaseous radioiodine for field operations at the Nevada Test Site. Specifications required that the unit be self-contained (except for a power supply), conveniently portable, rugged enough for continuous use in the field, and capable of handling a minimum of 12 two-hour samples.

Our survey of commercially available samplers revealed no such unit. Samplers using motor-driven rotary valves and relying on sliding rubber seals are considered too delicate for field use under desert conditions. We chose an alternate plan utilizing a bank of solenoid-operated valves and an electrical sequence programmer.

Description of Sampler

Figure 12 is a schematic of the sampler. It is housed in a sturdy case, measuring $25 \times 23 \times 12$ in., with 20-in. legs available to raise it off the ground.

Fig. 12. Schematic of sequential air sampler.

The sample enters through a feed-through hose barb (suitable for connection with 3/8-in. Tygon tubing), and goes into a stainless steel manifold that supports 12 MSA in-line filter holders containing activated charcoal cartridges. This manifold is of sufficient volume to act as a surge chamber for the system. Each filter holder is assembled to one of 12 normally closed solenoid valves that are connected in parallel to a common line to the inlet of a Gast-type 0211 carbon-vane vacuum pump. The air is exhausted through a Dwyer flow gauge and another feed-through in the instrument case. The sampling rate is 0.9 cfm, as measured with a Brookes rotameter.

The solenoid valves are opened one at a time for the sequence programmer. This unit contains an Eagle "Cycl-Flex" interval timer, which is a quick-change, plug-in device, with ranges available from a few seconds to many hours. The appropriate range timer is plugged in and the desired sampling interval selected. The programmer is set at position one and started up. At the end of the sampling period, the timer advances a stepping relay which in turn opens the next solenoid valve, routing the air flow to the next filter. This cycle is repeated 11 times, but on position 12 the sampler will be collected until manually shut off. This maintains constant monitoring without cross-contamination of earlier samples in the event the sampler is required to remain "on" beyond the programmed time. A manual advance button is supplied for resetting from position 12 to 1, or to any other particular position.

Figure 13 shows the unit ready to connect up and operate. Visible are the programmer, the manifold and filter holders, the air pump, flow gauge, and ventilating louvers for the pump compartment. The legs for raising the instrument above ground are clipped to the underside of the lid. Figure 14 shows the manifold and filter cartridges removed to allow change of filters and access for servicing the solenoid valves and associated plumbing. Also note that a spare (alternate time range) timer is stored in the pump compartment.

The unit is designed to operate over a wide range of environmental conditions with only minimal protection. Laboratory tests have been successfully completed. The unit is to be delivered to NTS for field evaluation.

Fig. 13. Assembled sequential air sampler ready for operation.

Fig. 14. Sequential air sampler with manifold removed.

USE OF DIFFUSION COEFFICIENT MEASUREMENTS FOR PHASE DEFINITION OF RADIOIODINE AEROSOLS

Introduction

Radioiodine collectors often show anomalies in performance that have been attributed to changes in the physical form of the iodine. Retention efficiency of activated charcoal, for example, differs if the iodine is specifically present as elemental gas, or as a solid (or gas attached to particulate matter), or in a chemically combined form. Most iodine test aerosols are generated with the intent of producing the elemental gaseous form. If the comparison of a series of iodine collectors is to be meaningful, the phase definition of the test aerosol must not change. Certainly if variations do occur, a technique for detecting these changes would be valuable.

When an aerosol moves through a narrow channel under laminar flow conditions, random Brownian motion causes particles (or molecules) to be displaced from their original air streamline positions. It is assumed that those reaching the walls adhere and are retained. As a result the aerosol concentration is lower for the effluent than for the influent, and the diffusion coefficient can be calculated from this difference.

The diffusion coefficient for gaseous elemental iodine at 25° C is 0.085 cm²/sec.¹⁸ For a 0.01-micron-diameter particle the diffusion coefficient is 5×10^{-4} cm²/sec. This marked difference can serve as a useful analytical tool in defining the phase composition of the aerosol and detecting possible variations between successive aerosol generations. It is the purpose of this report to discuss the techniques for measuring diffusion coefficients and to describe a simple system with which measurements can be obtained.

Diffusion Coefficient Measurements

Among the first applications of the diffusion method to aerosol particle sizing was work reported by Nolan and Guerrini,¹⁸ who were investigating the radii of atmospheric condensation nuclei. Townsend,¹⁹ using channels of

¹⁸J. J. Nolan and V. H. Guerrini, Proc. Roy. Irish Acad. 32A, 5 (1935).

¹⁹J. S. Townsend, Phil. Trans. Roy. Soc. (London) 193A, 129 (1900).

circular cross section, developed the theory of mass transfer to the channel walls by diffusion. Gormley and Kennedy²⁰ developed the equations currently used for calculating the diffusion coefficient.

Browning *et al.*²¹ have described a method for determining diffusion coefficients of submicron particles and vapors of radioiodine by measuring the distribution of activity on the walls of cylindrical channels previously exposed to these materials. Copper or silver-plated copper diffusion tubes are used having an inside diameter of 0.8 cm and a length of 60 cm. Sample flow rate through the tubes is maintained at 0.44 cc/sec. After collection, the tubes are advanced stepwise through a gamma spectrometer. Activity is plotted as a function of the distance from tube entry, and the diffusion coefficient is calculated from the slope of this plot. Because the plot is based on a large number of measurements, quite accurate results can be obtained. If the aerosol contains particulates, these show up as a change in the slope of the plot after the gaseous iodine has been deposited. The apparent particle size of particulate iodine can be estimated from this portion of the plot. Thus the percentage of gaseous and particulate activity can both be estimated. Because low flow rates are necessary to permit deposition of both gaseous and small particulate forms of iodine in reasonable lengths of tubing, long sampling periods (~ hours) may be required. This is the principal disadvantage of the method, since during a test significant changes in the phase distribution can take place.

The "Wetted-Wall" Diffusion Channel

A simpler, more rapid method for determining the diffusion coefficient is the "wetted-wall" technique based on work described by Thomas.²² This method uses a glass tube about 3 cm in diameter and 100 cm long. The tube is in three sections, fitted together with ground glass joints. It is sketched in Fig. 15. The center section contains a filter paper cut to fit the inside wall

²⁰P. G. Gormley and M. Kennedy, Proc. Roy. Irish Acad. 52A, 163 (1949).

²¹W. E. Browning *et al.*, ORNL-3262 (1962), p. 180.

²²J. W. Thomas, ORNL-1648 (1953).

Fig. 15. "Wetted-wall" diffusion channel.

of the tube and is wetted with an aqueous solution of sodium thiosulfate. The iodine aerosol to be analyzed is drawn through the tube at a flow rate between 1 and 10 liters/min. Two samples are collected simultaneously, one upstream and the other downstream from the wetted section. The sampling period depends on the iodine concentration but is usually 2 to 10 minutes. A blank run is made to correct for iodine deposition on the glass walls.

Calculations

The diffusion coefficient is calculated from the fraction n/n_0 of iodine removed in passing through the wetted wall section, where n_0 and n represent upstream and downstream measurements, respectively. Using the equation of Gormley and Kennedy,²⁰

$$n/n_0 = 0.82 e^{-3.66 \mu} + 0.097 e^{-22.2 \mu} + 0.0135 e^{-53 \mu};$$

μ is obtained from Table X, which is a tabulation of μ for values of n/n_0 from 0.10 to 0.78 (the upper limit of application of the equation).

The diffusion coefficient D (cm^2/sec) is related to μ by

$$D = \frac{\mu Q}{\pi X}$$

where

X = length of the wetted wall, cm,

Q = flow rate, cc/sec.

Table X. Selected values of μ as a function of n/n_0 .^a

n/n_0	μ	n/n_0	μ	n/n_0	μ	n/n_0	μ
0.10	0.575	0.28	0.294	0.46	0.160	0.64	0.0757
0.11	0.549	0.29	0.284	0.47	0.154	0.65	0.0720
0.12	0.525	0.30	0.275	0.48	0.148	0.66	0.0684
0.13	0.503	0.31	0.266	0.49	0.143	0.67	0.0649
0.14	0.483	0.32	0.257	0.50	0.138	0.68	0.0615
0.15	0.464	0.33	0.249	0.51	0.133	0.69	0.0582
0.16	0.446	0.34	0.241	0.52	0.127	0.70	0.0549
0.17	0.430	0.35	0.233	0.53	0.123	0.71	0.0518
0.18	0.414	0.36	0.225	0.54	0.118	0.72	0.0487
0.19	0.400	0.37	0.218	0.55	0.113	0.73	0.0457
0.20	0.386	0.38	0.211	0.56	0.109	0.74	0.0428
0.21	0.372	0.39	0.204	0.57	0.104	0.75	0.0400
0.22	0.360	0.40	0.197	0.58	0.100	0.76	0.0372
0.23	0.347	0.41	0.190	0.59	0.0954	0.77	0.0345
0.24	0.336	0.42	0.184	0.60	0.0913	0.78	0.0319
0.25	0.325	0.43	0.176	0.61	0.0872		
0.26	0.314	0.44	0.171	0.62	0.0833		
0.27	0.304	0.45	0.165	0.63	0.0794		

^aFrom $n/n_0 = 0.82 e^{-3.66 \mu} + 0.097 e^{-22.2 \mu} + 0.0135 e^{-53 \mu}$.

In contrast to the method of Browning, diffusion coefficients found by the wetted-wall method are apparent or average values only, with no information as to the size of particulates present. The decrease in the observed gaseous diffusion coefficient caused by particulates is a function of the size of the particulates and their relative amount. However, Table XI shows a large difference between the diffusion coefficient for the elemental gas and for particles with diameters larger than 0.01 micron. If the iodine is equally divided between elemental gas and 0.01-micron particles, the apparent diffusion coefficient (estimated on the basis of arithmetical averages) reduces the coefficient to $0.085 \times 0.5 + 5 \times 10^{-4} \times 0.5 = 0.0428$. The same concentration of 0.10-micron particle will produce an apparent diffusion coefficient of $0.085 \times 0.5 + 6.7 \times 10^{-6} \times 0.5 = 0.0425$. This difference is too small to detect. As a result, estimation of the fraction of particles present in the aerosol

Table XI. Diffusion coefficients for submicron particles.

Particle diam, microns	Diffusion coeff, cm^2/sec
0.005	1.9×10^{-3}
0.01	5×10^{-4}
0.02	1.3×10^{-4}
0.05	2.75×10^{-5}
0.10	6.7×10^{-6}

directly from the observed "apparent" diffusion coefficient is not seriously affected by the influence of particle size.

Preliminary evaluation of the method has been made using stable elemental iodine vaporized into the system (Fig. 15). Upstream and downstream samples were collected in gas bubbles containing potassium iodide solutions as an absorber. Iodine concentrations were determined from the optical density of these solutions. Results are shown in Table XII. Although an accuracy of $\pm 10\%$ is about as good as can be expected, the reasons for high results are being investigated.

Table XII. Iodine diffusion coefficient measurements.

Run No.	Flow rate, cc/sec	Wetted wall length, cm	n/n_0	μ	Diffusion coefficient, cm^2/sec
1	24.0	16	0.382	0.208	0.099
2	23.1	16	0.405	0.193	0.088
3	23.8	16	0.391	0.202	0.096
4	21.0	16	0.375	0.215	0.090
Average =					0.093

The "wetted wall" does not give as much information as the diffusion channel described by Browning. However, the fact that no specialized equipment is required suggests the possibility of considerably wider application, particularly where aerosol quality control monitoring is of primary interest. Although quality control is our intended application, we also plan to use this technique to evaluate different methods for iodine aerosol generation.

THE LASER EYE PROTECTION PROGRAM AT LRL

Introduction

In previous Hazards Control Quarterly reports (UCRL-12004, -7811, -7571, - 7193) we have discussed the hazards of laser operation and criteria which could be used in calculating eye protection requirements. The purpose of this report is to outline how these criteria have been combined with protective devices to provide an eye protection program.

Education

Perhaps the most important thing that can be done to protect the eyes of those who work with lasers is to make them aware of the possible dangers. The need for adequate eye protection is on the increase as more and more people are working with lasers. For this reason we feel that considerable effort must be spent in training. The training should give the eye protection criteria and method of calculation in simple forms that are easy to use and remember, and without reference to other papers and calculations. We give the criteria in terms of level of laser energy (or power) that is "safe," or allowable, to enter the eye.

The small pupillary diameter implies that in nearly all cases the light entering the eye will be approximately parallel. Assuming parallel light results in the simplification that the image size is fixed for a given wavelength. The criterion can then be stated that a given energy (or power) level can be allowed to enter the eye for a specified spectral region. If the laser operator is given this number along with an assumed pupillary opening, e. g., 6 mm, he can quickly estimate the necessary precautions to take. If the operation appears marginal or unsafe, a more careful estimate can then be made.

For the purpose of providing the necessary information, training sessions have been undertaken. During these sessions three main topics are discussed. The first of these involves the medical aspects of retinal damage. It is stressed that central vision is mainly the result of a very small portion of the retina. Secondly, the eye protection criteria and the method of calculation are discussed. A brief description of the experimental basis of the criteria is included in this topic. Also presented are the attenuation characteristics of the two types of glass. Lastly, we show the configurations in which these two glasses may be provided (Fig. 16). Questions and open

discussion of any of the topics or special problems are encouraged. We have found these sessions and the protective devices to be well received.

Glasses Provided

For general laser use it is desirable that eye protective devices have the following characteristics: good visibility throughout the visible spectrum wherever attenuation is not required; sufficient attenuation for the lasers of interest; maintenance of integrity and protection even during an intense exposure; and dependability and availability in suitable quantity and configurations. Most of these requirements can be fulfilled with two types of glass for the lasers in common use. These two glasses are the Schott and Gen BG-18 glass and the AO-570 glass.

The BG-18 glass is approximately 4.5 mm thick and has an optical density of 10 at 694 $m\mu$. Due to its absorption characteristics it is then satisfactory for the wavelength region from 694 $m\mu$ to 1.3 μ which includes the two most common pulsed lasers. Using the criteria for pulsed lasers (UCRL-7811 and UCRL-12004) this would appear to be satisfactory for a 100-joule laser pulse. The work of Straub²³ indicates that the glass may not retain its integrity with such an exposure. For this reason we are recommending a limit of 20 joules for this glass over the spectral region given above. At this point it should be repeated that no direct viewing of pulsed lasers is allowed regardless of the eye protection used.

At 694 $m\mu$ the BG-18 glass is increasing its transmission rapidly with decreasing wavelength. It therefore is not applicable for the common HeNe gas laser operating at 633 $m\mu$. For continuous lasers we use the AO-570 glass. This glass has an appreciable attenuation at 633 $m\mu$ with an optical density of about 4.2. Using the criteria given in UCRL-7811 this glass would then attenuate sufficiently for lasers of about 30 mW at this wavelength. In actual practice we are recommending the glass for use at power levels up to 100 mW over the spectral region from 633 $m\mu$ to 1.0 μ . This was done because our value of 10^{-6} watt entering the eye contains somewhat more safety factor than is necessary for this portion of the spectrum.

²³Harold W. Straub, "Protection of the Human Eye from Laser Radiations," Harry Diamond Laboratories, TR-1153, 10 July 1963.

We feel that these two glasses cover the common laser operations and allow the researchers considerable freedom to work in laser areas without undue control. Both types of glass have been subjected to pulses from a ruby laser with and without focusing and have shown excellent resistance to gross damage.

Frames

One of the shortcomings of the two glasses is that they are not obtainable in prescription lenses. This indicates two types of protection may be necessary, one for people who require prescription lenses and another for those who do not. The AO-570 glass is available in a standard safety glass frame with side shields. This is comfortable and convenient where prescription is not necessary. The BG-18 has been purchased and ground to fit a similar frame. These two frames are of different color to allow easy

Fig. 16. Configurations in which glasses are provided.

identification by the wearer. For people who wear prescription lenses the best protection is provided by a cover goggle with a plate of the glass similar to a welding plate. Unfortunately some wearers may object to this solution due to discomfort or inconvenience. In this circumstance we provide the two glasses in an alternative configuration. A 52-mm lens has been found to completely cover all sizes of safety glasses issued at LRL. A clip-on frame containing the glasses ground to this size has been modified by adding plastic side shields. These can then be individually fitted to the wearer's safety glasses to insure maximum coverage. These clip-on frames are relatively light and comfortable and provide good protection. The side shields are color-coded to match the other frames for easy identification. All the configurations shown in Fig. 16 are labeled to indicate the limits of their applicability.

Special Problems

In addition to the general eye protection covered above, special problems are to be expected which fall outside the limits of this simple approach. We feel these problems can nearly always be handled using the methods indicated in UCRL-7811. As an example a simple case is given here.

A researcher with a ruby laser feels it would greatly facilitate his work to be able to observe the beam on a diffuse reflecting screen. This enables him to quickly tell whether or not the equipment is lasing. He can put an upper limit on the output which could be obtained with the experimental setup. With simplifying assumptions, e. g., the MgO screen is a perfectly reflecting diffuse surface, the reflected beam is a point source, and neglecting the slight divergence of the reflected light entering a 6-mm pupil, an estimate of the attenuation needed can be made. With 10 J maximum output and a minimum distance from the screen of 2 m we estimate the light energy entering the unprotected eye to have a maximum value of about 2.2×10^{-5} J per pulse. This level is such that a 2-mm-thick sample of BG-18 with an optical density of about 3.5 attenuates sufficiently to keep the radiation entering the eye below the recommended 10^{-8} J. The addition of a narrow-band pass filter for 694 mμ to cut down the stray visible light from the flashlamps allowed easy, yet safe, viewing of the screen.

It is anticipated that other special problems can be handled in like manner, and the provision of "standard" glasses for general use will allow more effort to be concentrated upon these problems.

Summary

We feel the laser program described above is a practical one. There are other features of the safety program which have not been considered here. These include control of electrical and mechanical hazards as well as controlled access to the laser areas. The general aspects of the overall safety program, including eye protection, are covered in a laboratory-wide operating procedure. Another feature of the eye safety program is that all workers are given an eye examination before participating in laser research. In addition, periodic eye checks are planned.

The philosophy at LRL is to limit eye protection devices to as few basic types as possible to minimize the danger of error in choice. Any special protective gear such as described under Special Problems above must be clearly marked and preferably limited to the related experimental setup.

There is a possibility that the requirements for eye protection may be lessened as more is learned about eye damage. This is particularly true for the continuous laser where we have been rather conservative. Another area of interest is extremely fast laser pulses, i. e., of duration shorter than 30 nsec. For such pulses we have made no specific recommendations for the additional reduction below 10^{-8} J which may be necessary. Neither have specific recommendations been made for lasers of shorter wavelength than 633 m μ . For purposes of calculations the previous approach would be used except that in the green spectral region the allowable energy level of 10^{-8} J might be reduced slightly due to the shorter wavelength and increased absorption in the pigment epithelium.

NEW HYDRAULIC EQUATIONS FOR FIRE HOSE*

Introduction

Through improvements in fire hose quality, it is now possible for fire service personnel to reap additional benefits — more accurate and simpler friction-loss equations and better engine pressure-nozzle pressure equations. Tests conducted by the Underwriters Laboratories, Inc.,²⁴ have shown that friction loss in 1-1/2-inch and 2-1/2-inch cotton-jacketed, rubber-lined hose is less than previously thought. This loss applies to both single- and double-jacketed hose.

New Friction-Loss Equation for 2-1/2-in. Cotton-Jacketed Hose

The new friction-loss equation for 2-1/2-inch cotton-jacketed, rubber-lined hose is²⁵

$$F_L = 2Q^2L \quad (1)$$

where

F_L = friction loss per 100 feet of hose, psi,

Q = flow, in hundreds of gallons per minute,

L = number of 100-foot lengths of hose.

Equation (1) is simpler and more accurate than the familiar equation $F_L = 2Q^2 + Q$. The new equation has an average error of -7.3% compared to +15.0% for the old equation (see Table XIII). Note that the old equation gives values that are too high. This could result in excessive and consequently unsafe nozzle pressures. On the other hand, the new equation tends to be on the low, or safe side. Also note that the new equation applies to both single- and double-jacketed hose.

*This report is a revision of UCRL-12112.

²⁴"Hydraulic Friction Loss in 1-1/2-inch and 2-1/2-inch Cotton Rubber-Lined Fire Hose," Underwriters Laboratories, Inc., Bulletin of Research No. 12, September, 1939.

²⁵First suggested by the Underwriters Laboratories staff in correspondence with R. G. Purington.

Table XIII. Comparison of new and old friction loss equations with tests, for 2-1/2-in. cotton-jacketed, rubber-lined hose.

Flow, gpm	Q	Q ²	Friction loss per 100 ft hose, psi		Test average	Percent error	
			New equation, F _L = 2Q ²	Old equation, F _L = 2Q ² + Q		New equation	Old equation
100	1.0	1	2.0	3.0	2.3	-13.1	+30.4
150	1.5	2.25	4.5	6.0	5.0	-10.0	+20.0
200	2.0	4	8.0	10.0	8.9	-10.1	+12.4
250	2.5	6.25	12.5	15.0	13.2	-5.3	+13.6
300	3.0	9.0	18.0	21.0	18.6	-3.2	+12.9
350	3.5	12.25	24.5	28.0	25.7	-4.7	+9.0
400	4.0	16	32.0	36.0	33.5	-4.5	+7.5
Average error:						-7.3%	+15.0%

New Friction-Loss Equation for 1-1/2-in. Cotton-Jacketed Hose

The new equation for friction loss in 1-1/2-inch cotton-jacketed hose is

$$F_L = 30Q^2L \quad (2)$$

where L and Q are defined as in Eq. (1).

A previously suggested equation was²⁶

$$F_L = \left(2Q^2 + \frac{1}{2}Q \right) L' \quad (3)$$

where

L' = K_HL is the equivalent length of 2-1/2-inch hose,

K_H = the conversion constant, usually taken as 13 (L' = 13 L);

hence

$$F_L = 13 \left(2Q^2 + \frac{1}{2}Q \right) L.$$

This equation applies to flows less than 100 gpm. For flows greater than 100 gpm, the equation becomes

$$F_L = 13 \left(2Q^2 + Q \right) L \text{ psi/100 feet.} \quad (4)$$

²⁶Fred Shepherd, "Fire Service Hydraulics," Reuben H. Donnelley Corp., New York, N. Y., 1941, p. 54.

Another common equation is²⁶

$$F_L = 40C \left(2Q^2 + \frac{1}{6}Q \right) L \text{ psi/100 feet} \quad (5)$$

where C is a constant depending on the diameter of the hose (for 1-1/2-inch hose, C = 0.4), and L is the number of 100-foot lengths of 1-1/2-inch hose.

Table XIV compares the results of each of the equations with the test results and shows that Eq. (2) has an average error of 6.7%, while the old equations (4) and (5) have average errors of 20.2% and 13.8%, respectively. As with 2-1/2-inch hose, the new equation applies to both single- and double-jacketed fire hose.

Table XIV. Comparison of new and old friction loss equation with tests, for 1-1/2-in. cotton-jacketed, rubber-lined hose.

Flow, gpm	Q	Q ²	Friction loss per 100 ft of hose, psi				Percent error		
			Eq. (2)	Eq. (4)	Eq. (5)	Test average	Eq. (2)	Eq. (4)	Eq. (5)
25	0.25	0.0625	1.875	3.25	2.66	2.2	14.8	52.2	20.9
50	0.5	0.25	7.5	9.75	9.28	8.25	9.1	18.2	12.1
75	0.75	0.563	16.89	19.5	20.00	18.05	6.6	7.8	10.6
100	1.0	1.0	30.00	32.5	34.6	31.1	3.6	4.5	11.2
125	1.25	1.56	46.8	56.81	52.8	47.1	0.6	20.5	12.2
Average error:							6.7	20.7	13.8

Engine Pressure-Nozzle Pressure Equation

Through the use of the flow equation²⁶

$$q = 29.7 d^2 \sqrt{NP}$$

where

q = flow, gpm,

d = diameter of the nozzle, in.,

NP = pressure at the base of the nozzle,

and Bernoulli's equation, a relationship between the engine pressure and nozzle pressure may be derived for fire hose on level ground. Bernoulli's equation for this situation may be shown graphically as in Fig. 17. If the hose couplings at the pumper and the nozzle are the same, the velocity energy remains constant between the pump and the nozzle couplings. Thus from Fig. 17 we can write

$$EP = NP + F_L$$

where

EP = engine pressure, psi,

NP = nozzle pressure, psi,

F_L = friction loss, psi per 100 feet of hose.

Fig. 17. Bernoulli's equation in graphical form for fire hose on level ground.

Since

$$F_L = 2Q^2 L,$$

$$EP = NP + 2Q^2 L.$$

But

$$q = 29.7 d^2 \sqrt{NP}$$

and

$$q^2 = 880 d^4 NP.$$

Since $q = 100Q$ and $q^2 = 10^4 Q^2$,

$$Q = \frac{880 d^4}{10^4} NP.$$

Substituting

$$\begin{aligned} EP &= NP + (2) \frac{880}{10^4} d^4 (NP) L \\ &= NP \left(1 + 1.76 \frac{d^4}{10} L \right). \end{aligned}$$

If a nozzle constant K_N is defined as $K_N = d^4/10$, then (see Table XV)

$$EP = NP(1 + 1.76 K_N L). \quad (6)$$

Table XV. Nozzle factors.

Nozzle diam, d, in.	$K_N = \frac{d^4}{10}$	Nozzle diam, d, in.	$K_N = \frac{d^4}{10}$
1/2	0.00621	1-1/4	0.244
5/8	0.0153	1-3/8	0.358
3/4	0.0317	1-1/2	0.506
7/8	0.0592	1-5/8	0.697
1	0.1	1-3/4	0.93
1-1/8	0.160	2	1.60

However, it has been the custom to consider the length of hose lay in terms of the number of 50-foot lengths of hose. In this case, since $L = 2l$ (l = number of 50-foot lengths of hose),

$$\begin{aligned} EP &= NP(1 + 1.76 K_N \times 2l) \\ &= NP(1 + 3.52 K_N l). \end{aligned}$$

Example

To illustrate the two methods of determining the engine pressure, and to show a comparison, the following problem is calculated by both

$$EP = NP + F_L \quad (\text{where } F_L = 2Q^2)$$

and

$$EP = NP(1 + 1.76 K_N L).$$

Given: 200 feet of 2-1/2-inch hose connected to a 1-inch-diam nozzle with 100 psi nozzle pressure. Find engine pressure.

Method 1

From Eq. (1)

$$EP = NP + F_L.$$

$$F_L = 2Q^2 L.$$

Since $q = 29.7 d^2 NP$,

$$q = (29.7) (1)^2 \sqrt{100} = 297 \text{ gpm}, \quad Q = 2.97,$$

$$F_L = (2)(2.97)^2 L.$$

Since $L = 2$

$$F_L = (2)(8.8)(2) = 35.2 \text{ psi.}$$

Thus

$$EP = NP + F_L = 100 + 35.2 = 135.2 \text{ psi.}$$

Method 2

From Eq. (6)

$$EP = NP(1 + 1.76 K_N L).$$

Now, $K_N = 0.1$ (for 1-inch nozzle), $L = 2$, and $NP = 100$ psi. Thus

$$\begin{aligned} EP &= 100 [1 + (1.76)(0.1)(2)] \\ &= 100(1.352) = 135.2 \text{ psi.} \end{aligned}$$

EP - NP Equation for 1-1/2-in. Hose

Comparing the friction loss equation for 2-1/2- and 1-1/2-inch hose,

$$F_L = 2Q^2 L (2-1/2\text{-inch hose})$$

and

$$F_L = 30Q^2 L (1-1/2\text{-inch hose}).$$

We see that the friction loss per 100 feet of 1-1/2-inch hose is 15 times greater than the friction loss in 2-1/2-inch hose, with the same quantities of water flowing.

Inserting this factor into the 2-1/2-inch EP - NP equation:

$$\begin{aligned} EP &= NP(1 + 15 \times 1.76 K_N L) \\ &= NP(1 + 26.4 K_N L). \end{aligned} \tag{7}$$

Summary

The equation for friction loss,

$$F_L = 2Q^2 L \text{ (2-1/2-inch hose),}$$

$$F_L = 30Q^2 L \text{ (1-1/2-inch hose),}$$

and the engine pressure-nozzle pressure equations,

$$EP = NP \left(1 + 1.76 K_N L \right) \text{ (2-1/2-inch hose),}$$

$$EP = NP \left(1 + 26.4 K_N L \right) \text{ (1-1/2-inch hose),}$$

will not work in all situations. Inaccuracy occurs because factors that have been considered constant, such as hose diameter and hose friction factor, actually vary slightly. Also, the friction-loss equations are based on averages and have been modified slightly for simplicity. Despite this, the new equations are more nearly correct and simpler than the old ones, and they provide results exact enough for fire-service use.

The new equations are not simple enough for fire ground calculation. However, they should be used as the basis of "rule-of-thumb" equations. They are useful in preplanning water-supply requirements.

A SENSITIZATION TEST FOR MATERIALS USED IN PERCHLORIC ACID ENCLOSURES

Introduction

The Chemistry Department of LRL routinely uses perchloric acid as an oxidant in the dissolution of samples preparatory to chemical investigations. This acid is known to be unstable and to cause explosions on contact with organic materials.²⁷ In some cases²⁸ within the AEC complex personal injuries and a fatality have occurred.

The Plant Engineering, Chemistry, and Hazards Control Departments are designing a new hood for use with perchloric acid. This hood will incorporate a washdown system, the use of chemically inert materials, and careful attention to ventilation efficiency. However, it will be some time before the prototype is tested and modified and the final operational design is installed new or as replacements.

It is therefore of interest to examine the reactivity of materials used in existing hoods or proposed for use in enclosures in which perchloric acid oxidations are carried out.

Work Done

With the cooperation of Arthur Langhorst (Chemistry Department) a number of such materials were collected. They were tested by the following scheme:

1. Duplicate samples of each material were exposed, in an outside test apparatus, to vapors of boiling perchloric acid for 100 hours.
2. A piece of new material and an exposed piece were each doused with 25 ml of boiling perchloric acid.
3. Another piece of new material and the other exposed piece were each subjected to a 5-second impingement by an acetylene flame.

These tests simulated respectively the effects of a spill of hot concentrated perchloric acid or a fire in an enclosure made of new materials or in one which had been used for perchloric acid digestions.

²⁷J. C. Schumacher, et al.; Perchlorates: Their Properties and Uses, (Reinhold, New York, 1960).

²⁸AEC Accident and Safety Information Bulletins 1959 and 1962.

Results

The appearances of the materials after the 100-hour exposure, and the results of the acid-dousing and flame impingement, were noted and are detailed in Table XVI.

1. In summary, two materials — the gasket putty and the flexible ducting — were sensitized by the acid-vapor exposure. It was evident that the putty contained an easily oxidizable component since new putty flashed when doused with hot perchloric acid. However, putty exposed to the acid vapors reacted even more vigorously when contacted by the hot acid. The sensitizing effect was obvious in the flame impingement test.

2. Of the other materials tested only the two halocarbon films showed any adverse effects either to the exposure or subsequent treatments. The new adhesive backing on one flamed when doused with hot acid; such flaming did not occur after the vapor exposure. The other film, whether exposed to the acid vapors or not, curled up or melted when exposed to hot acid or a flame.

3. None of the remaining materials exhibited any sensitizing effect by the acid-vapor exposure. Further, they all showed little or no reaction to the acid-splash or flame impingement.

Discussion

From the studies reported by Schumacher and his collaborators,²⁷ it is evident that no one test or series of tests can be used to determine the inertness of a material to perchloric acid under the various conditions encountered in actual practice. We make no claim that the tests described in this report are exhaustive. Rather, we suggest that they be considered as screening tests which are useful in discovering bad actors before harm can result from their use.

Table XVI. Effects of flame and of hot perchloric acid on enclosure materials.

Material description	Appearance after 100-hour exposure to hot HClO ₄ vapors	Effects of hot perchloric splash		Effect of 5-sec flame impingement	
		New material	Exposed material	New material	Exposed material
<u>Ducting</u>					
Flexible, wire-coil-stiffened, rubber-impregnated fiberglass	Darkened, embrittled	Neg.	Flashed vigorously	Normal charring	Immediate flaming
Rigid polyvinyl chloride	No change	Neg.	Neg.	Normal charring	Normal charring,
<u>Coatings</u>					
Modif. phenolic 1	Darkened	Neg.	Neg.	Neg.	Neg.
Modif. phenolic 2	Darkened	Neg.	Neg.	Neg.	Neg.
Furane-phenolic epoxy	No change	Neg.	Neg.	Neg.	Sl. charred
Epoxy-polyamide	No change	Neg.	Neg.	Charred ^a	Charred ^a
PVF film, adhesive backing	Darkened	Backing material flamed	Neg.	Backing burned	Backing burned
<u>Gasketing</u>					
Rubberlike putty	Hardened, embrittled	Flashed	Flashed, burned	Neg.	Immediate flaming
Synthetic rubber sheets	No change	Neg.	Neg.	Normal burn, self-extinguish	Normal burn, self-extinguish
Halocarbon film	No change	Neg., sl. curling	Neg., sl. curling	Charred melted	Charred melted
Silicone O-ring	Skin hardening	Neg.	Neg.	Some discoloration	Some discoloration
<u>Sealants</u>					
Silicone 1	No change	Neg.	Neg.	Sl. charred	Sl. charred
Silicone 2	Sl. surface chalking	Neg.	Neg.	Sl. charred	Sl. charred
Fluoro-silicone 1	No change	Neg.	Neg.	Sl. charred	Sl. charred
Fluoro-silicone 2	No change	Neg.	Neg.	Sl. charred	Sl. charred
Aluminum-filled epoxy	No change	Neg.	Neg.	Normal burn, self-extinguish	Normal burn, self-extinguish
<u>Transparent plate</u>					
Methacrylate, 5/16 in.	No change	Neg., surface became opaque	Neg., surface became opaque	Blistered	Blistered

^aTen-second flame impingement.

EVALUATION AND TESTING OF A REMOTELY OPERATED EXPLOSIVE-ATMOSPHERE METER

Introduction

The program related to the peaceful uses of atomic energy includes the detonation of nuclear and conventional explosives in underground test tunnels. This poses the problem of atmospheric safety for postshot inspection and data recovery teams. One facet of underground atmospheric safety is the determination and measurement of explosive atmospheres. Such environments might be generated by the partial decomposition of the explosive or measuring equipment or by the opening of a seam of natural combustible gas. The Hazards Control Department therefore decided to see what could be done to develop a workable system for measuring such gases that would be consistent with safety and test-operating procedures.

Instrument Criteria

Preferably, an explosive atmosphere meter designed for the purpose indicated above should be able to be incorporated into the RAMS (Remote Area Monitoring System) employed in the testing program. This requires the use of a series of sensors located at the points of interest, data transmission lines, and a readout system. Further, the maximum distance between the farthest sensing head and the readout point is estimated at 3 miles.

These considerations rule out the use of portable instruments except as auxiliary devices employed by the recovery team. They also preclude the use of either type of commercially available remote explosive-atmosphere monitor, those that sample atmospheres and pump the sample back to the readout location, or those that sense atmospheres and transmit an electric potential back to the readout point. The remote sampler would involve an unacceptable time delay between sampling and readout; further, if a sample tube should be damaged by accident or the test explosion, information would be unavailable from the point in question. The remote sensor requires about 40+ volts of electrical potential to power it. Voltages this high are forbidden for safety reasons in the test tunnels, because rupture of such a power line might induce a spark-generated explosion.

Other requirements, relating to instrument reliability, are given in the following tabulation:

<u>Requirement</u>	<u>Comments</u>
Dust and humidity resistance	A test tunnel may be very damp or very dusty. A sensor should operate reliably under either environment.
Shock resistance	A sensor should operate reliably after exposure to a 5-g shock.
Explosive-atmosphere resistance	The sensor should operate without failure during a 24-hour continuous exposure to high-explosive gas concentrations; it should subsequently give a correct and reliable signal when the gas concentration has been reduced to readable limits.

The above-noted requirements suggested that we ascertain whether commercial instruments could be adapted to our needs. The Johnson-Williams Company indicated that they could modify their equipment, and they lent us a test sensing head for evaluation.

Description of the Instrument

Explosive-atmosphere meters are generally based on the original development of Johnson and Williams in the 1920's. The system consists of a Wheatstone bridge circuit in which two arms are glowing platinum-coil filaments. One filament, used as a reference, is not exposed to the atmosphere under test; the other is exposed. Combustible gases in air will burn in the presence of hot platinum, thus raising the temperature and electrical resistance of the exposed filament. The degree of unbalance this causes in the circuit is read on the bridge meter which is calibrated in terms of explosion limits of the combustible under consideration. The essentials of the system are diagrammed below: the filaments are usually enclosed in several layers of fine mesh screen, which act as a flame arrester to prevent the ignition of an explosive atmosphere.

Instrument Calibration

Pertinent combustion data for gases of interest are given in Table XVII.

Table XVII. Combustion data for gases of interest.

Gas	Gross heat of combustion, Btu/cu. ft	Explosive limits, vol %	Heat of combustion of air-gas mixture at lower explosive limit, Btu/cu. ft
Hydrogen	325	4.1 - 74.2	13
Carbon monoxide	323	12.5 - 74.2	40
Methane	1012	5.3 - 14.0	54
Ethane	1762	3.3 - 10.6	58
Propane	2509	2.3 - 7.3	58
Butane	3261	1.6 - 6.5	52

Note that the heat of combustion of a cubic foot of hydrogen-air mixture is 13, and that of carbon monoxide is 40. Corresponding values for the lower saturated hydrocarbons are 55 ± 3 . Theoretically, therefore, instruments should be calibrated for the gas or gas mixture they are intended to measure. This is done in practice. However, the actual calibration differences are not so great as would appear from the values given in Table XVII because combustion efficiencies and heat transfer rates are not ideal.

Hydrogen is an especially hazardous gas because of its wide explosive limits, relatively fast diffusion rate, odorless quality, and the violence of its explosions when mixed with air. Further, this gas can be formed by the decomposition of materials in test explosions. Hence we decided to use hydrogen as a standard in our environmental tests.

Environmental Testing

The J-W test instrument was subjected to simulated environmental tunnel conditions as outlined in the earlier section on Instrument Criteria and as detailed in the following subsections. The instrument consisted of a diffusion head containing the platinum filaments, and a modified readout system and power supply actuated by a 110-volt power source. Only the diffusion head was subjected to the environmental tests.

Before and after each test, the instrument was checked by zeroing the needle and immersing the head in a 3% (vol) hydrogen atmosphere. If the same reading was obtained (0.79 of full scale), the head was judged to have passed the test. In all tests the instrument was turned on and allowed to operate during the test period.

Humidity Test

The head was placed in a glove box maintained at 99% relative humidity and room temperature for 72 hours. Result: no adverse effect.

Dusty Atmosphere Test

The head was placed in a glove box maintained at a low relative humidity by the use of a desiccant. Ten grams of a standard dust (Arizona Road Dust obtained from A. C. Spark Plug Div. of Gen. Motors Co.) were blown about the interior of the box continuously by means of a circulating fan for 96 hours. Result: no adverse effect.

Hydrogen Atmosphere Test

The head was placed in a large jar containing a circulating fan. A 40% (vol) hydrogen atmosphere (balance, air) was introduced, and the closed system was allowed to stand for 18 hours. The test was repeated twice for 3- and 18-hour periods, respectively. Results: The meter needle immediately read off scale, but gradually returned to the on-scale position after several hours as the hot filament burned off the hydrogen (safely) and reduced the concentration to less than 4%. When subsequently tested in a 3% hydrogen atmosphere, the meter read correctly.

In another test, the head was exposed to various hydrogen atmospheres ranging from 4 to 100%. As expected, the meter read off scale between 5 and 50+% hydrogen, and then read on scale at 60 to 100% hydrogen, where the oxygen concentration was low enough to inhibit combustion. The data obtained are:

<u>% H₂</u>	<u>Scale reading</u>
4	1.00
5	1.20
10 - 40	Off scale
60	~1.25
70	0.74
80	0.24
90	0.08
100	<0.05

Shock Tests

Three sets of shock tests were made, corresponding respectively to the x, y, and z axes of the diffusion head. The z-axis was parallel to the coil axis of the filaments; x and y axes were mutually perpendicular to the filament coil axis and to each other (see sketch below).

The head was tested on a variable vibration tester in which the frequency was varied from 0 to 1000 cps over a 2-minute period, and the shock loading increased to 5 g's at 14 cps and remained constant thereafter. Prior to test the meter was "zeroed" to midscale so that one could determine which filament broke — the needle would move off scale to the right or the left depending upon which filament failed. Results of these tests were as follows:

1. In the z-axis test, no change was observed in the meter reading.
2. In the x- and y-axis tests, a small change occurred at about 200 cps and large changes occurred at 500 cps.
3. Subsequent examination of the filaments showed that they had become somewhat uncoiled or snarled. These effects significantly changed the zero reading. However, when the instrument was later rezeroed and tested in a 3% H₂ atmosphere, all except one of the damaged

filaments yielded a correct reading. The exception (snarled filament) read almost correctly.

Upon checking further, it has been determined that for 5-g ground shocks, frequencies in excess of 50 cps are quite unlikely for detonations in the 2- to 20-kt range. It thus appears that the diffusion head will perform satisfactorily with respect to shock. Sketches of the proposed J-W package design and schematic diagram are shown below.

WEATHERING AND LIGHT-TRAFFIC EFFECTS ON SIDE- WALK TEST PATCHES

Introduction

Four years ago a series of test patches of coatings, sealants, and flooring materials was applied to a sidewalk between Bldgs. 175A and 175B. The purpose of these applications was to test the effects of weathering and light foot, cart, and motor-vehicle traffic on these materials. The original schedule of test materials was listed in Hazards Control Quarterly Report No. 2 (UCRL-6172). Since that time annual examinations and reports have been made (in Hazards Control Quarterly Reports UCRL-6650, -7143, and -7571) of the aging effects of the original test patches and on additions that have been made.

At this time we report on the results of another year's aging. This will be the final report on this project because the sidewalk will shortly be removed to make way for new construction. The results, detailed in Table XVIII, are summarized as follows:

Patches Four Years Old

1. Epoxy-sand troweling and patching compounds and adhesives are in sound condition; little change in these has occurred in the past two years.
2. Specially formulated monolithic floors designed by LRL or outside manufacturers age-hardened a year ago and have shown little change since except for a noticeable increase in crazing.
3. Three strippable vinyl coatings are still sound and hand-peel about as well as originally.
4. Epoxy-sealed linoleum joints are still sound although the linoleum has deteriorated noticeably.

Patches Three to Four Years Old

An epoxy-polyamide floor enamel applied to smooth and to broom-finish concrete has dulled slightly but is still sound. An epoxy-sand mixture feathered to old concrete is still in good condition.

Patches Two and One-Half to Three Years Old

1. Patches of battleship linoleum and vinyl sheet goods bonded to sealed or unsealed concrete all show some age hardening. Where the concrete was

presealed with an epoxy-polyamide enamel the adhesive bonds are still tight. Where no sealer or a silicone sealer was used the burlap backing on the linoleum has become water-soaked, thus destroying the bond. Asbestos-backed sheet goods on unsealed concrete are still tightly bonded. A viscous epoxy adhesive still adheres to the linoleum but has broken away from smooth unsealed concrete probably because of lack of penetration.

2. An epoxy-base antislip troweling compound is in good condition. It has shown no noticeable wear during the past two years. A latex-base analog, however, has worn away noticeably.

Patches Less Than One Year Old

Two patches of a competitive epoxy polyamide floor enamel are in good condition after seven months of exposure.

Table XVIII. Conditions of coatings, sealants, and flooring materials exposed to weather and light traffic.

Patch No.	Material description	Age 10/1/64, months	Condition
1	Epoxy-bitumen mixed with sand	50	Good, few gouges, NC-12 ^a
2	Epoxy floor topping-sand mixture	50	Good, NC-24 ^a
3	Furane-epoxy basecoat	50	Adhesive good, surface good
	Latex-sand antislip compound	31	Surface good
7	Modified epoxy paint-sealer, primer and top coat	50	Top coat worn away
9	Linoleum sheet: water-proof adhesive, joints sealed w/epoxy	50	Edge failure of adhesive, NC-24
10	Linoleum sheet-epoxy adhesive	50	Cracks; adhesive good, NC-24
11	Epoxy-polyamide floor enamel on rough concrete	41	Dull, otherwise sound, NC-24
12	Epoxy-sand troweling compound	41	Good, NC-24
13	Plasticized epoxy/resilient flooring coat	49	Considerable crazing, NC-12

Table XVIII. (Continued)

Patch No.	Material description	Age 10/1/64, months	Condition
14	Proprietary resilient conductive flooring	50	Considerable age hardening, NC-12
16	Linoleum conductive matting, proprietary adhesive	50	Noticeably pock-marked; adhesive good, NC-12
17	Conductive rubber shelving, contact cement	50	Age cracks; sound bond, NC-12
20	LRL-263 resilient flooring	50	Age hardened, NC-12
21	Proprietary resilient flooring	34	Fair
22	MAP	34	Good, NC-24
24	Epoxy-Thiokol patching compound	49	Adhesion good, NC-12
25	Similar to No. 24	49	Sound joint, NC-12
26	Epoxy-silicone resin	48	Fair, some chalking, NC-12
27	Epoxy troweling compound	49	Good, NC-24
28	M-vinyl strip coat	49	Dull appearance, NC-12
30	Epoxy-polyamide floor enamel on smooth concrete	47	Good
32	A - heavy duty linoleum, rubber base adhesive; epoxy polyamide concrete sealer	28	Age cracking, very good bond, NC-12
33	P - exterior epoxy paint	50	Good, NC-24
34	T - epoxy-sand flooring compound	49	Good, NC-24
35	AP - medium duty linoleum, rubber base	28	Some cracks, very good bond, NC-12
36	505 epoxy flooring compound	49	Good, NC-24
37	348 epoxy concrete patching compound	49	Sound bond, NC-24
39	F - latex-grit antislip compound	31	Slight wear, NC-24
40	A - heavy duty linoleum; rubber base adhesive; no concrete sealer	28	Bond failure because of moisture penetration of burlap backing

Table XVIII. (Continued)

Patch No.	Material description	Age 10/1/64, months	Condition
41	Same as 40 but with silicone concrete sealer	28	Similar to 40 but not so pronounced
42	AP - medium duty linoleum; rubber base adhesive; no concrete sealer	28	Good bond
43	AT - medium duty linoleum, otherwise same as 42	--	Removed at 23 months: Separation between linoleum and backing; base-bond very good
44	333 - easy-to-strip vinyl coating	51	Good strippability; some embrittlement, NC-12
45	501 - moderately hard-to-strip vinyl coating	51	Good strippability, NC-12
46	560 - hard-to-strip vinyl coating	51	Some embrittlement, strip-pable
47	Epoxy polyamide same as 11, but on smooth concrete	41	Sl. dulling; otherwise good, NC-12
48	Epoxy-sand troweling compound	41	Good, NC-12
49	P - epoxy-sand antislip compound	31	Good, NC-24
50	F - latex-grit antislip compound	31	Noticeable wear
51	A - heavy duty linoleum; epoxy adhesive, no concrete sealer on smooth concrete	28	Bond failure between adhesive and concrete
52	LRL-364, plasticized epoxy flooring compound	48	Age-hardened and crazed
53	LRL-262, urethane flooring compound	48	Age-hardened and crazed
55	G - epoxy-sand troweling compound	47	Good, NC-24
57	Same as 30, but on rough finish concrete	7	Good

^aNC-12 means no change in 12 months; NC-24, no change in 24 months.

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