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Hazards Control Progress Report No. 58 April through September 1979

R. V. Griffith:
Scientific Editor

February 22, 1980

Lawrence
Livermore
Laboratory

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FOREWORD

This report is divided into three major sections. The first section, Progress Reports, covers the status of activities undertaken or continuing during the period; additional reports or separate publications will cover the final results of these activities. The second section, Technical Notes, contains reports on interesting activities of a more limited scope on which further reporting is not anticipated. The third section lists recent publications.

Readers who are interested in more detail regarding any item may contact the authors of the reports listed in the Contents.

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PROGRESS REPORTS

RADIATION PROTECTION

BASIC Computer Programs for Counting Room Automation

Six radiation counters are used daily to process approximately 3500 samples per month in the Hazards Control counting laboratory. Because of the large number of samples and their diversity, data analysis has become cumbersome. To alleviate this problem and to reduce the time required for reporting sample results, we have generated computer programs that enable us to process and store radiation-counting data on a PDP11 computer system. These programs, written in BASIC to facilitate operator interaction and program modification, also provide hard copy reports of the counting results.

The configuration of the PDP11 computer system used by the counting laboratory is shown in Fig. 1.¹ Currently, there are six radiation counters in use: four alpha-beta counters and two liquid scintillation counters automated to count varying numbers of samples in each counter cycle. After a sample is counted, gross counts and sample identification information are transmitted to a teletype (TTY) and to a file on an LSI-11 microprocessor by an interface. After all the samples have been counted, the file, which is unique to the counter run, is closed and stored on a floppy disk. When the data for the run are ready for processing, the file is accessed by the LSI-11 data link and stored on a high-speed hard disk interfaced to the PDP11-10 computer. The data are then processed by the analysis programs described here.

A data sheet having a format compatible with quick teletype entry into the computer (Fig. 2) records sample data collected by the technician, the analytic laboratory, and the counting laboratory (e.g., sample type, sample identification, and sample volume). This information is then entered into the computer manually and stored in a file identifiable with the file containing the counting results. The analysis programs use these two files to process the

sample data and create a permanent file containing all pertinent information and results for a particular counter run. A program generates a hard copy report from this file, which is initially stored on a disk and later transferred to magnetic tape or floppy disk for permanent storage.

The automation program includes 17 individual subprograms that are chained together in a modular sequence to complete the data analysis, the permanent file, and the hard copy report (Fig. 3). The chained modular sequence is advantageous because it allows us to alter one subprogram without altering another and to add other counters by adding the appropriate data-formatting program to the sequence—e.g., a TAPE program. A summary of the various subprogram functions is given in Table 1.

Figures 4 and 5 illustrate the program-file manipulation sequence for alpha-beta counters and liquid scintillation counters, respectively. Program CRDATA initiates the data processing and writes a temporary file (CTR) containing a six-digit file code for the permanent file. The file code includes the one-digit counter identification (A, B, C, D, E, or F), the three-digit Julian date, and the two-digit run number. At this point one of two programs (SHEETA in Fig. 4 and SHEETD in Fig. 5) is automatically chained in to accept the teletyped input from the data sheet. This program formats the data sheet information, transfers it to a temporary file, SHEET(X) (Fig. 4) or SHEET(Y) (Fig. 5), and then creates an additional temporary file, BKPOS(X) (Fig. 4) or BKPOS(Y) (Fig. 5). The additional temporary file contains the sample start position in the counter, the counter position for background samples, and the number of samples. A program that opens the data link and transfers the counter results onto the PDP11-10 hard disk from the floppy disk file, FILEA(X) (Fig. 4) or FILEA(Y) (Fig. 5), is then chained in. This program, TAPE(X) in Fig. 4 or TAPE(Y) in Fig. 5, can also accept paper tape input from the counter teletypes if the data link or the counter interfaces are nonfunctional. During the

FIG. 1. Configuration of the PDP11 computer system used for the collection and analysis of counting data.

HAZARDS CONTROL RADIOACTIVITY SAMPLING RECORD

Check Box for Bulk Samples Only

HEALTH AND SAFETY TECHNICIAN

Check One Only	(6) Sample Type	Check One Only	(7) Priority	Check One Only	(8) Special I.D.
0	Air	0	Routine	0	No Entry
1	Liquor	1	Special	1	Oilfield Swipes
2	Swipe	2	Health	2	Workshop Swipes
3	Soil	3	Soil	3	SRV
4		4		4	NEI Tank
5		5		5	DR
6	Noise Swipe	6		6	ST-100
7	Per N	7		7	Environmental
8	URINA	8		8	Source Calib.
9	Misc.	9		9	Spent Monitor

ANALYTICAL LAB

Check One Only	(9) Special I.D.
0	No Entry
1	Iodine
2	Rn & C
3	SRV
4	Misc.
5	Alpha Beta
6	Low Dose
7	Low Dose
8	Site 300
9	

COUNTING LABORATORY

Check One Only	(10) Sample Geometry	Check One Only	(11) Special I.D.
0	No Entry	0	No Entry
1	Std. 100mm Diam.	1	Recount
2	Std. 100mm. Pellet	2	Perun
3	25mm Diameter (17)	3	Quality Control
4	31mm Diameter (27)	4	LPA Study
5	100mm x 25mm (27)	5	Intercomparison
6	100mm x 25mm (27)	6	II 132 Daily Air
7		7	
8		8	
9		9	

DATE ON (Air Sampling Only)

DATE OFF

HEALTH AND SAFETY TECHNICIAN

DATE ON	DATE OFF	DATE ON	DATE OFF
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30		

ANALYTICAL LAB

DATE RECEIVED	DATE SENT
1	2
3	4
5	6
7	8
9	10
11	12
13	14
15	16
17	18
19	20
21	22
23	24
25	26
27	28
29	30

COUNTING LABORATORY

DATE RECEIVED	DATE RECEIVED
1	2
3	4
5	6
7	8
9	10
11	12
13	14
15	16
17	18
19	20
21	22
23	24
25	26
27	28
29	30

FIG. 2. Data sheet for collecting pertinent sample information.

FIG. 3. Chained sequence of BASIC computer programs used in the counting room. X is the one-digit counter identification for counters A, B, C, and F; Y is the one-digit counter identification for counters D and E.

transfer process, the counter data are reformatted so that subsequently chained programs can handle the same data format for all similar counters. (Data generated by the alpha-beta counters are substantially different from data generated by the liquid scintillation counters.) At this point, all the data to be processed reside in the temporary disk files.

If the data are from one of the two liquid scintillation counters, the samples, particularly the low-level ones, may have been cycled several times in an attempt to achieve an acceptable channel ratio. The program RCCL (Fig. 5) is chained in to step through the cycles, strip the background counts from the gross counts, test the channel ratios, and build a single cycle of sample data with acceptable channel ratios.

Actual data analysis begins with program CTR2 for the alpha-beta counters (Fig. 4) or program CTR2(Y) for the liquid scintillation counters (Fig. 5). This program pulls in the files BKPOS, FILEA, and CTR and calculates limits of sensitivity, errors, and efficiencies. These data are stored in temporary file DATA(X) for CTR2 and on floppy disk FILEC(X) for CTR2(Y). The final count rate calculations are completed in the next chained program, FORMTA (Fig. 4) or FORMTD (Fig. 5), which formats all the sample data and stores them in the permanent disk file (F\$). The format of this permanent disk file is kept constant for the subsequent retrieval of mass data, and its name is added to a directory file, DIRECT, which keeps a record of files that have been generated. As permanent files are transferred to a mass storage unit, such as magnetic tape, this directory file is purged of the file names. A separate program, DTFIL, not part of the analysis sequence, is used to effect the transfer of the permanent files and the updating of the directory file.

The final program of the chained sequence, OUTPTA (Fig. 4) or OUTPTD (Fig. 5), opens the permanent disk file and generates a hard copy report of the sample counting results for the particular counter run (Fig. 6). The format of the report is rigid but can be easily changed by modifying certain features of OUTPTA or OUTPTD. The format of the processed permanent data file remains unchanged.

The Hazards Control counting laboratory began using the automation program we have described in April 1977; since then all the subprograms have undergone considerable modification. All counter data since January 1, 1977 have been processed by this program and reside in permanent data files on magnetic tape or floppy disk. Hence, they can be retrieved for cumulative data analysis and used for monthly and yearly reports or systematic studies. We expect that the program will continue to be modified as needs or practices in the

TABLE 1. Summary of counting room automation subprograms and their functions.

Subprogram	Primary function
CRDATA	Initiates the automation program, writes file code to temporary disk file, chains in SHEET(X) ^a .
SHEET(X)	Accepts teletype input of sample sheet information, formats and writes this data to a temporary disk file, chains in TAPE(X).
TAPE(X)	Accesses appropriate counter data from the paper tape or the DATA LINK, reformats as necessary, writes the data to a temporary disk file, chains in RCCL or CTR2(X).
RCCL	Steps through additional counter cycles for the liquid scintillation counters, constructs a single cycle of data with acceptable channel ratios, chains in CTR2(X).
CTR2(X)	Calculates errors, limits of sensitivity, and efficiencies; chains in FORMT(X).
FORMT(X)	Completes count rate calculations, formats and writes processed data to a permanent disk file, adds the file code to a disk directory, chains in OUTPT(X).
OUTPT(X)	Accesses the permanent file, reformats the data into the desired report format, prints two copies of the report, terminates the automation program.

^a(X) indicates that there is more than one such subprogram and that the appropriate one to be chained into the sequence is specified by the file code.

counting laboratory change, but the modular sequence of chained subprograms should make such modification reasonably easy. A separate report that includes specific descriptions of individual programs, flowcharts, variable lists, program listings, and file format is being prepared.

A Computing Portable Neutron Spectrometer

In the past we have made field measurements of neutron sources for source characterization or verification.²⁻⁵ These measurements required transporting cumbersome electronics to the field and an inconvenient transfer of data from the analyzer to the computer for unfolding. Sometimes a long turnaround time was necessary between data acquisition and final output. Also, during long counts in low-intensity fields, our NIM module-type electronics were adversely affected by wide temperature variations. To overcome these inconveniences and problems, we built a computing por-

table neutron spectrometer that can acquire and reduce data to differential neutron spectra.

The spectrometer has two parts, a commercial Tracor-Northern TN 1705 multichannel analyzer and a 47 × 66 × 25-cm suitcase containing a DEC LSI-11 microprocessor with 28K words of MOS memory, a cassette tape deck, a keypad, and an LED readout (Figs. 7 and 8). The suitcase also contains power supplies, a linear amplifier, and the pulse-shape discrimination circuitry necessary to operate various NE213 neutron detectors. The whole assembly weighs 23.5 kg.

Hardware. The spectrometer system accommodates any of several NE213 or Stilbene detectors that have sensitivities to cover the range of neutron fluences to be measured (Table 2). The linear signal from the tenth dynode of the photomultiplier tube is fed through a preamplifier to an amplifier in the suitcase. The anode timing signal is fed to a constant friction discriminator⁶ and a pulse-shape

TABLE 2. Detectors compatible with the computing portable neutron spectrometer.

Detector number	Scintillator			Useful neutron intensity range, $n/cm^2 \cdot s$
	Length, cm	Diameter, cm	Material	
101	5.08	11.4	NE213	$0.1 - 10^3$
103	7.62	3.81	NE213	$0.5 - 10^4$
105	5.08	5.08	NE213	$0.5 - 10^4$
104	2.54	2.54	NE213	$5 - 10^3$
102	1.27	1.27	NE213	$50 - 10^6$
401	1.0	1.3	Stilbene	$50 - 10^6$

FIG. 4. Schematic of the program-file manipulation sequence for alpha-beta counters.

FIG. 5. Schematic of the program-file manipulation sequence for liquid scintillation counters.

BLDG. NO: 332

HP: HANKINS

H&S TECH: SAUNDERS 29630

DATE DN/DFF 0168/0168

AIR ROUTINE STR, 100MM DIAM.,

		BKGD.		COUNTING EFFICIENCY				L.O.S. (GROSS)	
ALPHA		.6 CPM		31.4 %				1.7 CPM	
BETA		12.43 CPM		40.2 %				16.4 CPM	
ROOM NO.	SAM LOC #	SAMP I.D.	SIZE M ³	ALPHA ACTIVITY UCI/CM ²	2SIGMA ERROR +/- %	BETA ACTIVITY UCI/CM ²	2SIGMA ERROR +/- %	ANAL. LAB #	SAMPLE POSITION #
1313	03		40.80	1.4 E-13	35.9	3.9 E-13	27.6		11
1314	08		40.80	1.2 E-13	39.9	4.4 E-13	25.0		12
1321	14		40.80	7.4 E-14	53.7	3.4 E-13	30.9		13
1322	20		40.80	1.3 E-13	36.5	3.3 E-13	31.7		14
1329	22		40.80	8.9 E-14	47.7	4.2 E-13	26.2		15
1330A	27		40.80	6.3 E-14	59.7	3.3 E-13	31.3		16
1330	28		40.80	1.3 E-13	37.1	5.0 E-13	22.6		17
1337	29		40.80	4.9 E-14	71.4	3.3 E-13	31.3		18
1338	35		40.80	2.8 E-14	<=LOS	3.0 E-13	33.9		19
1345	41		40.80	4.6 E-14	75.4	3.4 E-13	30.9		20
1346	44		40.80	4.2 E-14	60.1	3.2 E-13	32.4		21
1353	48		40.80	3.5 E-14	<=LOS	4.0 E-13	27.2		22
1354	55		40.80	5.6 E-14	64.9	3.0 E-13	34.7		23
1361	59		40.80	8.1 E-14	50.5	3.2 E-13	32.2		24
1362	62		40.80	4.2 E-14	80.1	3.0 E-13	34.2		25
1369	68		40.80	4.2 E-14	80.1	3.9 E-13	27.6		26
1370	71		40.80	6.3 E-14	57.7	3.4 E-13	30.9		27
HALL	73		40.80	6.7 E-14	57.5	4.0 E-13	27.1		28
1377	75		40.80	6.0 E-14	62.1	3.2 E-13	32.2		29
1378	78		40.80	7.4 E-14	53.7	3.7 E-13	28.7		30
1051	102		40.80	5.6 E-14	64.9	3.8 E-13	28.0		31
1050	104		40.80	1.1 E-13	42.4	4.1 E-13	26.5		32
1006	106		40.80	2.8 E-14	<=LOS	3.2 E-13	37.6		33
1006	108		40.80	2.1 E-14	<=LOS	2.6 E-13	38.4		34
1010	110		40.80	1.1 E-14	<=LOS	3.2 E-13	32.9		35
1010	114		40.80	3.2 E-14	<=LOS	3.3 E-13	31.7		36
1011	120		40.80	6.0 E-14	62.1	3.1 E-13	33.4		37
1011	122		40.80	7.8 E-14	52.0	4.2 E-13	26.2		38
1007	124		40.80	9.2 E-14	46.5	3.9 E-13	27.7		39
1007	125		40.80	4.2 E-14	80.1	3.2 E-13	32.2		40
HALL	127		40.80	1.7 E-13	31.3	5.5 E-13	21.1		41
BSHT	135		40.80	5.3 E-14	67.9	3.3 E-13	31.9		42

FIG. 6. A hard copy report of the sample counting results generated by the final program in the chained sequence, OUTPTA or OUTPTD.

discriminator⁷ to determine whether a pulse is a gamma or a neutron. The pulse-height analyzer has been slightly modified so that it will not store the output of the analog-to-digital converter (ADC) unless the microcomputer sends a store flag. A switch on the front panel of the suitcase selects the mode to send a flag for neutrons, gammas, or both. A time-to-amplitude converter analyzes the rise-time signals for the proper setup of the pulse-shape discrimination circuitry.⁸

We chose a DEC LSI-11 microcomputer because of its versatile computational ability, because it is readily available at the Laboratory, and because it fits in a suitcase. Also, its 28K words of MOS memory fit on one card, allowing us to write programs in MACRO or FORTRAN. A small cassette tape deck was added to the system to store data and programs. A hexadecimal keypad and a four-digit LED display were provided so that we could communicate with the system. The keypad

FIG. 7. The computing portable neutron spectrometer.

FIG. 8. Schematic of the computing portable neutron spectrometer.

FIG. 9. Rise-time spectrum of neutrons (right peak) and gamma rays (left peak) for ^{22}Na and $^{238}\text{PuBe}$ sources.

FIG. 10. The ^{22}Na calibration spectrum.

allows us to transfer data between the microcomputer and the analyzer or the cassette tape, enter the gain stabilization window numbers, start and stop data acquisition with or without gain stabilization, enter unfolding parameters, and run the unfolding program.

Software. The system is written in assembly language. It handles data transfer, keypad and readout control, and ADC data control. The gain stabilization software is written partly in assembly language and partly in FORTRAN. Gamma events around the Compton-edge from a ^{22}Na source are summed, the mean calculated, and the high voltage adjusted to keep the average constant.⁹

The unfolding routine, an adaptation of the derivative unfolding program NUTSPEC,¹⁰⁻¹² is written in FORTRAN. It reads a 256-channel recoil proton spectrum and calculates the absolute differential neutron flux and the integral of the dose

equivalent. The neutron flux data are normalized, put into a 120-channel spectrum, and transferred to the analyzer for easy viewing. The normalization exponent, the energy of the first channel, the energy per channel, and the integral dose are put into channels 121-130. Execution time for the unfolding program is 30 s.

The various software source programs reside on a DEC PDP11-10 computer. They are assembled and compiled, linked together in an LDA format, and a paper tape is punched with the executable program. The paper tape is then transferred to the cassette tape on the portable spectrometer for permanent storage.

Instructions for a typical run procedure are as follow:

1. Connect various cables between the analyzer, microcomputer, and detector.
 2. Plug in and turn on the microcomputer and the analyzer. The system requires 117 V at 1.5 A. (Note that the diagnostics on a ROM are executed automatically to check the instruction set and memory.)
 3. When the diagnostics are done, read in the program from the cassette tape. Read-in requires about 2 min.
 4. If neutrons are present, check the pulse-shape discrimination by observing the rise-time spectrum (Fig. 9).
 5. Check the calibration with a ^{22}Na source (Fig. 10).
 6. Enter gain stabilization window channel numbers on the keypad.
 7. Start neutron spectral data acquisition.
 8. Key in the threshold, the ^{22}Na calibration channels, and the diameter and length of the detector for unfolding. These numbers may be entered during data acquisition. Any calibration and any size cylindrical NE213 or Stilbene detector may be used since the unfolding parameters are entered by the operator.
 9. When data acquisition is complete, transfer the data from the analyzer to the microcomputer for unfolding and to the cassette tape for storage.
 10. Unfold the spectrum.
 11. Transfer the unfolded spectrum from the microcomputer to the cassette tape for storage and to the analyzer for viewing (Fig. 11a).
- The whole procedure, excluding the acquisition of neutron spectral data, requires about 10 min.

Operational Experience. Measurements of a calibrated $^{238}\text{PuBe}$ source were made for doses from 7 to 210 mrem using a 5.08×5.08 -cm NE213 detector. The spectra showed that approximately 30 mrem is the minimum dose required to see definite spectral structure and to obtain an integrated dose that agrees with the spectrometer's calculation. Figures 9, 10, and 11a and b show results of the 210-mrem count. The peak energies and intensities agree favorably with those found by DeGuarrini and Malaroda,¹³ Rubbino *et al.*,¹⁴ and Anderson and Neff.¹⁵

Measurements were also made at a 14-MeV rotating target neutron source through a 7-ft concrete shield wall. The gamma-to-neutron ratio was about 1000 to 1, which would make a 0.1% gamma leakage into the neutron spectrum unacceptable. Unfortunately, such a leakage did occur because of a slight misadjustment of the pulse-shape discrimination circuitry, so our results were inconclusive. The problem has since been corrected, and the measurement will be repeated.

We took the portable neutron spectrometer to the Calvert Cliffs Nuclear Power Reactor (Maryland) to measure spectra inside the reactor containment vessel for the U.S. Nuclear Regulatory Commission. Measurements were made at 100% power. Despite a high noise level and a high vibration level, and a temperature of 110-130°F, the spectrometer performed well. It ran its diagnostics, loaded the program from the cassette, and acquired a ^{22}Na calibration spectrum. Unfortunately, the pulse-shape discrimination circuitry stopped sending signals during the count. A minor adjustment has corrected this problem.

Conclusions. The computing portable neutron spectrometer can be easily carried to a field location for neutron spectral measurements over a wide range of fluences. The system can be set up quickly and easily, and if problems occur, they are easily detectable. Our laboratory measurements show that its calculations are reliable, but we have scheduled more testing to verify this.

Preliminary Measurements of the Neutron Energy Response of CR-39 Carbonate Plastic

Measuring dose-equivalent levels from fast neutrons as low as 10 mrem continues to be a

FIG. 11. Data from the neutron spectrometer for a 210-mrem exposure to a $^{238}\text{PuBe}$ source. (a) Raw pulse-height data. (b) The unfolded spectrum, showing the energy of each peak.

problem in personnel monitoring because we still do not have a dosimeter that can (1) detect such low doses and (2) provide a neutron energy response proportional to established dose-equivalent conversion curves.¹⁶ There is, however, encouraging news in dosimetry research. Recent work with etched plastics has shown that, when CR-39 carbonate plastic is used as a nuclear track detector and treated properly, it can detect low doses of protons¹⁷⁻¹⁹—a key step in the development of a neutron dosimeter that is sensitive, accurate, and has an energy response proportional to established dose-equivalent conversion curves.

Our initial studies with CR-39 carbonate plastic involved electrochemical etching.²⁰⁻²² In this technique, an AC field is applied across the surface of a sample, and the sample is positioned as a dielectric between two volumes of caustic electrolyte.

Etching takes place in two distinct steps²⁰: first a latent track is enlarged by conventional etching until it becomes a conductive needle directed inward from the surface of the material; then a breakdown occurs at the point of the needle, forming a subsurface void or tree 50-100 μm or more in diameter (Fig. 12). This is considerably larger than the conventionally etched track—a pit only a few microns in diameter—thus making optical counting of exposed samples much easier.

Electrochemical etching has been used for some time to study the potential of polycarbonate plastic as a fast neutron detector. Hence, we began studying the neutron detection properties of CR-39 by adopting the electrochemical etching parameters for polycarbonate plastic. We used a 2-kHz power source with a gradient of 31.5 kV/cm² across the sample surface and an electrolyte of 28% potassium hydroxide. Etching was performed at room temperature for 5 h. With these parameters, the shape of the etched tracks in CR-39 was slightly different from the shape of the etched tracks in polycarbonate plastic (Fig. 13).

One problem with electrochemical etching is that surface defects such as scratches can act as sites for tree formation and thereby increase background track density. The polycarbonate plastic we used for electrochemical etching had a polyethylene covering on each side to protect its surface and lower background track density. However, if we had used a polycarbonate plastic of poorer surface quality without a protective covering, we could have reduced track density by chemical pre-etching.²³ In pre-etching, the sample is first conventionally etched for a period of time and then electrochemically etched. The pre-etching polishes the

FIG. 12. Profile of an electrochemically etched tree resulting from a neutron interaction in polycarbonate.

FIG. 13. Electrochemically etched tracks (X 255) in polycarbonate (top) and in CR-39 (bottom).

surface: any scratches or other surface defects that could provide a subsurface breakdown site are etched until they become too smooth to do so.

When we began studying CR-39, we experienced difficulty with high background. In using chemical pre-etching to reduce it, we found an extraordinary additional benefit. When the material was pre-etched in 6N KOH for 5 h at 60°C, the neutron-induced track density increased by a factor of 50-100 over what it was when the material was not pre-etched. We believe that, since the LET of recoil protons is close to the registration threshold of CR-39, etching proton tracks to the breakdown point takes longer than it does for more highly ionizing heavy recoils (carbon, nitrogen, and oxygen tracks). Pre-etching accelerates this process so that electrochemical etching can tree the proton

tracks in the time allowed. We made a few measurements using a ^{252}Cf spontaneous fission source to demonstrate that CR-39 could detect fast neutron doses as low as 10 mrem after being pre-etched and etched.

In August of 1979 we made a series of measurements with the Lawrence Livermore Laboratory tandem accelerator to determine the neutron energy response of CR-39 that had been etched using the two-step process. Previous measurements have been made with conventionally etched CR-39 samples, and the resulting surface-pit densities have been counted optically.²⁴ Also, theoretical calculations have been made to predict this response and to describe how the thickness of a hydrogenous radiator affects material sensitivity.

We made our measurements by placing samples of the material on a supporting ring 20 cm in diameter (Fig. 14). The ring was placed on the end of the accelerator beamline and the neutron-producing target at the center of the ring (Fig. 15). We used beams of protons and deuterons focused on targets of ^7Li and tritium to produce neutrons from 50 keV to 18.3 MeV. These exposures were done in six separate runs, the first five of which had overlapping energies to provide normalization. Unfortunately, there was—and still is—a gap from 9 to 12.5 MeV that we could not fill because of excessive neutron contamination from other reactions in the target backing.

The flux as a function of position on the ring was predicted by a calculation based on the energetics of the reaction. Flux monitoring was provided by a precision de Pangher long counter,^{25,26} indium activation foils using the $^{115}\text{In}(n,n')^{115\text{m}}\text{In}$ reaction, and a spherical remmeter (used primarily for guidance on the proper amount of irradiation time). In addition, an NE213 liquid scintillator was placed at a 45-deg angle, 1 m from the accelerator beamline, to monitor the quality of the neutron spectrum. We found, for example, that interference from low-energy neutrons caused such high contamination in run 5 that we could not use the measurements with much confidence (Fig. 16).

After the samples were irradiated, they were etched and counted optically using a microscope and a television projection system. Track densities obtained from measurements on the first set of samples and the neutron fluence values obtained from our monitoring systems were used to generate a

FIG. 14. Samples of CR-39 placed on a 10-cm radius ring for irradiation.

FIG. 15. Sample ring in place on beam line with the target positioned at the center of the ring.

preliminary response curve for detection as a function of neutron energy. Figure 17 shows the neutron response in tracks per neutron as a function of energy. Figure 18 shows the same data but as a function of dose equivalent, resulting in the dose-equivalent response curve for these detectors. At this point it should be noted that the only proton radiator used for this experiment was the 0.001-in. thick polyethylene covering protecting the material.

We etched samples with and without pre-etching. The pre-etched samples showed an enhanced sensitivity of a factor of 50-100 at 2 MeV and a resulting sensitivity to neutrons as low as

FIG. 16. Relative neutron spectra from NE213 measurements at 45° to the beam line, 1 m from the target. (a) Run 4: $^3\text{H}(p,n)$, 7.00-MeV protons. (b) Run 5: $^3\text{H}(p,n)$, 10.00-MeV protons. (c) Run 6: $^3\text{H}(d,n)$, 2.00-MeV deuterons.

160 keV, characteristics not found in the samples that were not pre-etched.

At a first approximation, the curves obtained for electrochemically etched polycarbonate and CR-39 samples without pre-etching appear quite

similar (Fig. 19). Since we know that the energy response of polycarbonate is caused entirely by heavy recoils, this apparent similarity is further evidence that pre-etching is required to develop electrochemically etched proton tracks within reasonable etching times. Also, since pre-etching does improve the quality of the background significantly, our initial purpose for using it has been achieved.

Although the results presented here are preliminary because more samples must be etched and counted, the potential use of CR-39 as part of a personnel dosimetry system is certainly attractive. Because the material responds to sensitivities as low as 10 mrem, it can be used as a fast neutron detector. With CR-39 we can reduce the energy threshold for personnel dosimetry by a factor of 10, something we cannot do with a more conventional detector like electrochemically etched polycarbonate. We are currently studying the use of CR-39 as one component of a dosimetry system that would consist of a simple albedo detector, etched polycarbonate, and LR159 cellulose nitrate. The etched polycarbonate would serve as a high energy threshold detector and the cellulose nitrate as a neutron detector that is particularly sensitive to 14-MeV neutrons.

INDUSTRIAL HYGIENE

Effect of High-Expansion Foam on Self-Contained Breathing Apparatuses

We have been testing self-contained breathing apparatuses (SCBAs) to determine how effectively they operate in various fire environments. Our most recent test evaluated their performance in a room or building filled with detergent-based high-expansion foam. A 2-ft³ Lucite box filled with high-expansion foam simulated the foam-filled room or building.

The foam tests were performed on two of each of the following SCBA makes or models: The Scott 9000, the Scott 4.5, the Survivair, the Globe Guardsman, and the MSA 401. All were either new or maintained in top working condition by manufacturer-certified personnel; however, each was checked and tested for leaks before being set up in the Lucite box.

The facepiece of the SCBA was mounted on a dummy head and the entire apparatus was connected to a mechanical breathing machine located outside the box. The breathing machine was set on a

FIG. 17. Neutron energy response of electrochemically etched CR-39 normalized to neutron fluence.

FIG. 18. Neutron energy response of electrochemically etched CR-39 normalized to neutron dose equivalent.

FIG. 19. Comparison of the neutron response of electrochemically etched polycarbonate and CR-39 (without pre-etching).

moderate-to-heavy work rate of 52.5l of air/min to simulate a firefighter at work. The difference between atmospheric pressure and internal facepiece pressure was measured with a calibrated pressure transducer and monitored on a strip-chart recorder. The SCBA was activated for 1 min to ensure that it was working properly and to measure its normal operating pressures. The box was then filled with foam (Fig. 20) and the SCBA exposed for the length of time it took to empty the air cylinder.

The Scott 9000, the Scott 4.5, and the Globe Guardsman were not affected by the high-expansion foam, but the Survivair and the MSA 401 went negative on inhalation (Table 3). This occurred when foam was drawn inside the regulator through pressure-equalizing vent holes in the regulator diaphragm covers (Figs. 21 and 22). We believe that when the foam was drawn into the regulator, it caused the top of the diaphragm to adhere to the inside of the regulator cap. As a result, greater inhalation pressure than usual was required to operate the regulator. In measuring this pressure with a probe-equipped pressure transducer, we found that a vacuum was created inside the regulator upon inhalation and that, over a period of operational time, this vacuum caused the regulator to fill with foam.

We recommend that any time a self-contained breathing apparatus is used in a foam-filled room or building, care should be taken to keep the immediate area around the apparatus' regulator free from foam.

Permeation of Organic Solvents Through Glove Samples

Introduction. For many years occupationally induced skin disease, e.g., dermatitis, has been recognized by the industrial hygiene profession as a significant problem in the workplace. For handling potentially hazardous materials, the industrial hygienist relies on gloves of various materials, not knowing whether the gloves will effectively protect the skin. Therefore, selecting a glove for a specific workplace task is usually done by trial and error: if the glove wearer experiences pain or develops dermatitis, or the glove dissolves, a different glove is substituted. This procedure is repeated until a satisfactory glove is found.

Attempts to calculate a glove's effectiveness in protecting the skin are hampered either by the lack of fundamental permeation data or by the errors introduced by an unknown interaction between the

FIG. 20. Foam-filled Lucite test box containing the SCBA. The SCBA was exposed to the foam for the length of time it took to empty the air cylinder.

TABLE 3. Foam test results for five SCBAs.^a

Exposure time, min	Breathing function	Pressure, inches of water				
		Scott 9000	Globe gasdiver	Scott 4.5	Survivair	MSA 401
1.0 ^b	Exhalation	3.28	1.66	1.60	1.94	1.88
1.0 ^b	Inhalation	0.18	0.40	0.22	0.30	-0.45
4.0	Exhalation	3.48	1.66	1.72	1.92	1.88
4.0	Inhalation	0.26	0.38	0.22	0.30	-0.85
12.0	Exhalation	3.50	1.71	1.78	1.98	1.88
12.0	Inhalation	0.30	0.42	0.20	-0.80	-2.15
16.0	Exhalation	3.25	1.82	1.82	1.98	1.98
16.0	Inhalation	0.32	0.47	0.24	-0.90	-3.40

^aAll SCBAs tested are pressure demand.^bThe approximate ambient exposure time for a baseline reading.

solvent and the glove membrane. Also many gloves are bonded in layers or have inner liners, which further hampers the calculation. Thus, the best method of ensuring personnel safety is to measure experimentally the rate at which a solvent permeates a glove.^{27,28}

Theoretical Considerations. The permeation of gas through a polymeric material is basically a diffusion process that occurs because of the concentration gradients between the inner and the outer surface of the material. The quantity of gas, q , diffusing through a membrane is based on Fick's law

FIG. 21. Survivair regulator diaphragm filled with high-expansion foam. Foam drawn into the regulator caused the top of the diaphragm to adhere to the inside of the regulator cap, resulting in greater inhalation pressure than usual.

FIG. 22. MSA 401 regulator diaphragm filled with high-expansion foam. Foam drawn into the regulator caused the top of the diaphragm to adhere to the inside of the regulator cap, resulting in greater inhalation pressure than usual.

and can be calculated²⁹ using the equation

$$q = \frac{A}{x} (p_1 - p_0) P_0 e^{-E/RT}$$

where

q = the permeation rate (cm^3/min)

A = the area of the membrane (cm^2)

x = the membrane thickness (cm)

p_1 = the solvent vapor pressure on the outer glove surface (Pa)

p_0 = the solvent vapor pressure on the inner glove surface (Pa)

P_0 = the permeation constant ($\text{cm}^3/\text{s} \cdot \text{cm}^2 \text{Pa}/\text{cm}$)

E = the activation energy required to move the molecule through the membrane

R = the gas constant (2.0 cal/mole-K)

T = the temperature (K).

Although the equation appears relatively simple, its solution is difficult, primarily because we have no method for computing the activation energy or the permeation constant.

Experimental. A schematic of the permeation measurement system is shown in Fig. 23. A cross section and an exploded view of the permeation cell is shown in Fig. 24. For our experiment a 5.4-cm sample was cut from the palm or the back of a glove using a cookie cutter type punch. The sample was weighed and the thickness measured in three places to ensure surface uniformity. The test sample was then placed over the "O" ring on the base assembly, and the top cap and pressure plate were placed on top and held with three washers and three hex nuts tightened to 15 in.-lb. We used a torque wrench to ensure uniform tightening because uneven plate pressure yielded inconsistent results.

The permeation cell was placed in the system shown in Fig. 23, and 10 ml of the test solvent was added. The system's flow-temperature-humidity control device³⁰ kept the purified air flowing through the cell at a constant 25 l/min and maintained air temperature at 25°C and relative humidity at 50%. An overflow trap was placed behind the cell to trap any liquid escaping a membrane that was destroyed by solvent. The airborne vapors were passed through a Wilks Miran 1A infrared gas analyzer to measure concentration. The analytical wavelength we chose matched the strongest absorption band of the solvent being tested. A strip chart recorder monitored the progress of the solvent's permeation through the glove as a function of time; 60 min was arbitrarily chosen as the test time.

The permeation rate of a two-component solvent mixture was also measured using the system shown in Fig. 23. However, to obtain the gas concentrations of each component simultaneously, we used two infrared gas analyzers.

Results and Discussion. The physical characteristics of the 28 gloves tested are summarized in Table 4. The weight and thickness values include any floc or fabric liner that might be present. Figure 25 shows the five types of permeation behavior observed. Type A, the most typical, occurs when the specimen remains physically unchanged during the test. The glove offers complete protection until initial breakthrough is observed at point i. The permeation rate continues to increase in the characteristic S-shaped curve until a maximum rate, point m, is obtained. The rate then stabilizes at this equilibrium value.

Type B behavior is essentially the same as

FIG. 23. Schematic of the permeation measurement system.

FIG. 24. Experimental setup for permeation experiments. (a) A cross section of the permeation cell. (b) An exploded view of the permeation cell.

TABLE 4. Physical characteristics of glove samples.

Glove number	Average thickness, mm	Average weight, ^a g	Glove composition	Number of layers	Interior liner
01	0.030 ± 0.005	0.07 ± 0.01	Polyethylene	1	None
02	0.076 ± 0.005	0.17 ± 0.03	Polyethylene	1	None
03	0.12 ± 0.02	0.34 ± 0.06	Polyvinyl chloride	1	None
04	0.13 ± 0.02	0.39 ± 0.07	Polyvinyl chloride	1	None
05	0.31 ± 0.04	0.91 ± 0.13	Polyvinyl chloride	1	None
06	0.20 ± 0.05	0.58 ± 0.19	Polyvinyl chloride	1	None
07	0.11 ± 0.02	0.31 ± 0.04	Vinyl	1	None
08	0.13 ± 0.02	0.35 ± 0.08	Vinyl	1	None
09	0.15 ± 0.03	0.44 ± 0.12	Vinyl	1	None
10	0.21 ± 0.01	0.51 ± 0.03	Latex	1	None
11	0.31 ± 0.02	0.76 ± 0.02	Latex	1	None
12	0.47 ± 0.05	1.15 ± 0.10	Latex	1	None
13	0.45 ± 0.04	1.12 ± 0.11	Latex-neoprene	blend	Floc
14	0.52 ± 0.14	1.37 ± 0.16	Latex	1	Floc
15	0.29 ± 0.04	1.13 ± 0.12	Neoprene	2	None
16	0.47 ± 0.05	1.59 ± 0.42	Neoprene	1	None
17	0.46 ± 0.11	1.72 ± 0.43	Neoprene	2	None
18	0.77 ± 0.18	1.75 ± 0.55	Neoprene	1	Fabric
19	0.70 ± 0.07	2.36 ± 0.05	Neoprene	2	None
20	0.70 ± 0.05	1.41 ± 0.05	Neoprene	1	Fabric
21	0.80 ± 0.03	2.59 ± 0.26	Neoprene	1	None
22	0.35 ± 0.02	0.89 ± 0.03	Buna-N	1	None
23	0.37 ± 0.07	0.92 ± 0.03	Buna-N	1	Floc
24	0.55 ± 0.06	1.40 ± 0.18	Buna-N	1	None
25	0.32 ± 0.11	0.97 ± 0.18	Acrylonitrile	1	None
26	0.45 ± 0.02	1.07 ± 0.04	Natural rubber	1	None
27	0.59 ± 0.07	1.48 ± 0.26	Natural rubber	1	Floc
28	0.31 ± 0.02	0.75 ± 0.04	Nitrile rubber	1	None

^aFor a 22.9-cm sample.

type A except that after point m is reached, the permeation rate slowly increases or decreases. This phenomenon occurs when the sample is structurally modified by the solvent, either by a chemical reaction or a physical deformation.

Type C behavior occurs when the glove exhibits a catastrophic breakthrough. The glove behaves normally until point x is reached. At this time, a full-scale analyzer response is observed and the sample dissolves, admitting the entire volume of test solvent into the overflow trap.

Type D behavior occurs when the maximum permeation rate is achieved normally. The rate decreases sharply, attains an equilibrium value at point y, and eventually stabilizes at a time near point y. A sample exhibiting type D behavior is moderately to heavily swollen.

The double S shape of type E behavior shows an inflection at point z, which occurs when the sample becomes extremely swollen. Although a similar

pattern was observed by Weeks and Dean,²⁷ no satisfactory explanation has been postulated.

Table 5 lists the two key values noted from our permeation experiments: the time until initial breakthrough, observed at point i, and the maximum permeation rate, which occurs at point m. Most gloves exhibited type A behavior, but a few exhibited type B, C, D, or E, and these are noted in Table 5. The data in this table show that no one glove offers total protection from the solvents tested.

Four permeation tests were conducted on gloves of various thicknesses. Samples from each glove were tested with each solvent. An extra thick sample was obtained by using multiple layers of the sample. The results are shown in Fig. 26. All four tests showed the permeation rate to be inversely proportional to glove thickness. In other words, if the thickness is doubled, the permeation rate is reduced by half.

FIG. 25. Five types of permeation behavior.

FIG. 26. The effect of glove thickness on the permeation rate.

FIG. 27. The effect of a chloroform-toluene mixture on the permeation rate. Individual permeation rates can be predicted if the permeation rates of the components are known.

The results of simultaneously measuring the permeation rate of the two-component solvent mixtures are shown in Figs. 27 and 28. In Fig. 27, a mixture of chloroform and toluene was tested on a neoprene glove (glove No. 15, Table 4). The dashed line, which shows the sum of the permeation rates of individual components, indicates that only minimal synergistic effects occur. In other words, if the permeation rates of individual components are known,

TABLE 5. Solvent breakthrough times and permeation rates for protective gloves.^a

Solvent	Glove number													
	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Acetone	>60 ^b (<30) ^b	4.0 (2)	C (C)	—	C (C)	C (C)	—	—	C (C)	2.2 (210)	5.2 (110)	6.0 (82)	5.0 (100)	8.0 (46)
Aniline	>60 (<40)	1.0 (—)	3.0 (180)	—	18 (160)	9.0 (160)	—	—	—	>60 (<40)	>60 (<40)	—	—	5.2 (15)
Benzene ^c	0.1 (0.25)	4.0 (0.05)	0.5 B (3.5) ^B	0.4 D (4.1) ^D	2.2 (1.3)	2.2 B (1.6) ^B	0.1 D (4.7) ^D	0.3 D (3.6) ^D	0.1 D (4.9) ^D	1.5 (5.6)	2.2 (3.2)	3.0 (2.6)	3.0 (2.8)	5.2 (2.8)
Butyl acetate	2.0 (20)	12 (6)	1.0 D (6000) ^D	1.0 (6900)	2.4 D (3300) ^D	2.0 D (4300) ^D	0.5 C (C)	1.5 D (6400) ^D	1.5 D (4100)	2.0 (12900)	4.0 (1400)	6.4 (940)	6.4 (640)	9.2 (640)
Carbon tetrachloride ^c	1.5 (0.5)	8.0 (0.08)	0.8 D (1.0) ^D	1.5 D (2.0) ^D	8.4 B (0.6) ^B	2.3 B (0.8) ^B	1.2 D (2.1) ^D	1.0 D (2.3) ^D	1.2 D (2.0) ^D	1.5 (6.0)	3.8 (1.6)	5.0 (5.1)	4.0 (4.6)	10 (3.1)
Chloroform ^c	0.6 (1.6)	2.8 (1.0)	0.4 D (15) ^D	0.4 D (27) ^D	0.4 D (3.4) ^D	0.8 D (11) ^D	0.4 D (15) ^D	0.7 D (12) ^D	0.6 D (13) ^D	0.8 (15)	1.6 (4)	2.6 (7.6)	2.8 (7.0)	6.4 (6.4)
m-Cresol	>60 (<1)	>60 (<1)	12 (67)	14 (59)	>60 (<1)	14 (63)	8 (44)	7.5 (53)	7.0 (56)	14 (15)	36 (—)	30 (2)	30 (2)	>60 (<1)
Cyclohexane	1.6 (100)	10 (28)	1.6 (500)	2.5 D (340) ^D	16 (100)	5.6 (200)	2.0 D (310) ^D	0.8 D (450) ^D	2.4 (300)	1.7 (1500)	— (10)	8.0 (1300)	5.0 (1400)	—
Dimethyl sulfoxide	>60 (<10)	—	3.2 (380)	—	42 (300)	34 (320)	—	—	—	>60 (<10)	>60 (<10)	—	—	—
Dioxane	1.2 (300)	10 (60)	1.6 D (3700) ^D	0.8 D (4000) ^D	6.4 B (1500) ^B	3.3 B (1100) ^B	1.0 D (5000) ^D	1.2 D (3800) ^D	1.1 D (4000) ^D	2.4 (800)	8.8 (420)	12 (340)	17 (340)	18 (220)
Ethanol	—	>60 (<4)	3.0 (43)	5.0 (37)	20 (28)	11 (43)	3.5 (28)	3.2 (34)	2.0 (57)	12 (14)	28 (4)	>60 (<4)	—	>60 (<4)
Ethylene dichloride ^c	1.0 (0.91)	5.2 (0.01)	0.6 D (11) ^D	0.8 D (9.7) ^D	2.0 D (4.5) ^D	1.0 D (6.9) ^D	0.4 C (C)	0.6 D (13)	0.8 D (7.8) ^D	1.2 (3.1)	0.4 (1.6)	4.6 (1.3)	4.8 (1.3)	0.4 (1.3)
Ethylene glycol	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)
Freon TF	4.8 (10)	>60 (<10)	2.4 (3400)	5.2 (2200)	11 (190)	7.6 D (240) ^D	2.4 B (2600) ^B	2.5 B (3000) ^B	2.8 (1900) ^B	2.2 (3000)	8.8 (1000)	17 (820)	16 (700)	16 (790)
Isomyl acetate	2.0 (20)	>60 (<10)	1.0 (3300)	1.0 (3300)	4.8 (1600)	2.0 B (2500) ^B	1.0 (C)	1.0 (4500)	2.0 B (2100) ^B	2.0 (1900)	5.6 (1100)	9.6 (790)	9.6 (760)	12 (1730) ^B

TABLE 5. (Continued.)

Solvent	Glove number													
	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Methanol	>60 ^b (4)	>60 (4)	1.3 ^B (36)	2.0 ^B (34)	2.8 ^B (18)	3.0 ^B (23)	1.3 ^B (54)	1.3 ^B (38)	3.2 (30)	2.0 (18)	20.0 (8)	>60 (4)	—	24 (4)
Methyl ethylketone	>1.0 (10)	9.6 (3)	C	—	C	C	—	—	C	1.2 (800)	2.4 (600)	7.2 (320)	5.6 (310)	9.2 (230)
Acetyl iodide ^c	0.7 (1.1)	2.4 (0.3)	C	—	C	C	—	—	C	1.5 (21)	1.5 (13)	2.8 (8.1)	2.0 (6.9)	5.6 (5.3)
Methylene chloride ^c	0.4 (0.3)	2.0 (0.1)	C	—	C	C	—	—	C	0.8 (13)	1.3 (8.2)	3.0 (4.5)	2.7 (4.6)	4.2 (3.4)
Pentane	0.4 (400)	3.2 (70)	0.8 ^E (1100)	0.4 ^D (17)	1.4 ^D (12)	0.72 ^D (17)	0.3 ^D (77)	0.3 ^D (29)	0.4 ^D (24)	0.8 (13)	1.3 (8.2)	3.6 (1100)	4.0 (1800)	1.6 (2300)
Phenol	>60 (400)	>60 (3)	3.2 ^B (190)	8.0 (120)	32 (7)	15 ^B (100)	6.0 ^B (170)	6.2 (120)	3.8 (120)	1.6 (45)	2.4 (23)	7.6 (10.4)	6.4 (0.4)	13.6 (0.3)
Pyridine ^c	>60 (400)	>60 (3)	C	—	C	C	C	C	C	1.2 (1.2)	2.4 (23)	3.6 (21)	3.6 (21)	5.0 (2.1)
Tetrachloroethane ^c	>60 (400)	>60 (3)	1.0 ^D (5.4)	1.2 ^D (6.0)	6.1 ^B (2.5)	2.1 ^D (4.0)	0.7 ^C (4.1)	1.2 ^D (4.1)	1.9 ^B (3.3)	2.0 ^B (5.6)	6.4 (2.6)	5.6 (2.9)	9.2 (3.2)	18.4 (1.4)
Tetrahydrofuran ^c	0.8 (0.2)	3.2 (0.002)	0.4 ^C (8.8)	0.4 ^C (5.1)	2.0 ^C (2.1)	1.2 ^C (2.1)	6.4 ^C (3.2)	6.4 ^C (3.2)	C	1.1 (34)	2.4 (25)	3.6 (21)	3.6 (21)	1.2 (2.1)
Toluene ^c	0.5 ^D (2.2)	2.0 (0.6)	C	—	C	C	C	C	C	0.5 (4.7)	2.0 (4.7)	3.5 (2.7)	—	5.0 (3.8)
1,1,1-Trichloroethane ^c	2.0 (0.1)	12 (0.1)	C	—	C	C	C	C	C	0.8 (9.2)	1.6 (2.6)	2.8 (3.1)	2.8 (3.1)	4.6 (5.9)
Trichloroethylene ^c	0.4 (1.5)	2.2 (0.4)	0.6 ^D (11)	0.6 ^D (9)	3.1 ^D (3.8)	0.8 ^D (8.2)	0.7 ^D (13)	0.4 ^D (13)	0.8 (6.2)	0.8 (26)	1.6 (9.4)	2.8 (7.6)	2.8 (7.3)	4.6 (5.9)
Trifluoroethanol	>60 (400)	>60 (3)	4.5 ^E (1200)	7.1 ^E (1900)	15 (1300)	6.6 ^E (1100)	2.6 ^E (1000)	4.5 ^E (300)	2.6 ^E (900)	>60 (400)	>60 (400)	>60 (400)	>60 (400)	>60 (400)
Xylene ^c	—	—	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)	1.5 ^D (3.0)

TABLE 5. (Continued.)

Solvent	Glove number													
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Acetone	16 ^b (140) ^b	19 (140)	33 (90)	2.5 (180)	32 (170)	2.2 (310)	57 (86)	5.2 (2000)	5.0 (800)	13 (800)	3.0 (1500)	15 (66)	27 (45)	4.0 (800)
Aniline	>60 (<40)	>60 (<40)	>60 (<40)	—	—	>60 (<40)	—	96 (120)	—	—	18 (180)	>60 (<40)	>60 (<40)	—
Benzene ^c	4.8 (1.8)	11.1 (1.0)	16 (0.8)	1.2 (0.95)	16 (1.1)	24 (0.3)	—	63 (0.4)	19 (0.85)	46 (0.51)	4.4 (1.3)	3.7 (2.2)	7.4 (1.6)	9.0 (1.1)
Butyl acetate	11 (830)	29 (320)	>60 (<21)	5.2 (220)	52 (320)	3.6 (320)	>60 (<21)	33 (480)	40 (450)	58 (250)	20 (350)	8.0 (880)	14 (510)	—
Carbon tetrachloride ^c	13 (0.8)	34 (0.8)	23 (0.9)	30 (0.1)	41 (0.9)	4.6 (0.5)	>60 (<0.006)	>60 (<0.006)	>60 (<0.006)	12.8 (<0.006)	>60 (<0.006)	30 (0.8)	11 (1.6)	>60 (<0.006)
Chloroform ^c	3.6 (4.4)	9.6 (3.2)	10 (2.5)	1.2 (2.7)	13.6 (2.8)	0.7 (6.8)	21.6 (2.0)	4.8 (9.4)	2.4 (9.9)	12.8 (3.6)	4.4 (7.0)	3.2 (5.6)	2.8 (7.0)	—
m-Cresol	>60 (<1)	>60 (<1)	>60 (<1)	>60 (<1)	>60 (<1)	—	>60 (<1)	>60 (<1)	>60 (<1)	>60 (<1)	>60 (<1)	>60 (<1)	>60 (<1)	—
Cyclohexane	72 (100)	>60 (<10)	29 (100)	—	—	9.6 (70)	—	>60 (<10)	>60 (<1)	>60 (<1)	>60 (<10)	9.6 (1100)	18 (800)	>60 (<1)
Dimethyl sulfoxide	>60 (<10)	>60 (<10)	60 (<10)	—	—	>60 (<10)	—	>60 (<10)	—	—	28 (350)	>60 (<10)	>60 (<10)	—
Dioxane	15 (350)	44 (300)	28 (370)	8.4 (220)	44 (240)	5.2 (330)	107 (150)	25 (860)	27 (820)	63 (3)	17 (710)	10 (280)	27 (150)	—
Ethanol	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	—
Ethylene dichloride ^c	3.6 (1.8)	16 (0.7)	8.6 (1.0)	1.6 (0.7)	28 (0.8)	2.4 (0.8)	42 (0.3)	6.4 (3.8)	7.1 (3.9)	17 (2.6)	4.9 (3.9)	3.6 (2.5)	9.7 (0.8)	—
Ethylene glycol	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	—	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	—
Freon TF	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	180 (20)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	>60 (<10)	16 (700)	29 (590)	—
Isoamyl acetate	16 (540)	30 ^B (350) ^B	30 ^B (310) ^B	12 ^B (140) ^B	—	5.6 (120)	>60 (—)	>60 (—)	65 (63)	>60 (—)	42 (130)	10 (660)	19 ^B (470) ^B	—

TABLE 5. (Continued.)

Solvent	Glove number													
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Methanol	>60 ^b (<4) ^b	>60 (<4)	>60 (<4)	17.6 (6)	>60 (<4)	23 (5)	>60 (<4)	69 (23)	54 (36)	>60 (<4)	39 (29)	18 (4)	>60 (<4)	—
Methyl ethylketone	4.0 (900)	8.0 (600)	10 (600)	17 (200)	27 (330)	2.4 (500)	39 (230)	6.4 (3100)	6.0 (2200)	12 (1900)	9.6 (1500)	8.0 (400)	16 (200)	3.6 (2800)
Methyl iodide ^c	2.2 (7.9)	4.4 (6.3)	4.4 (3.6)	15 (1.4)	12 (3.7)	0.7 (4.6)	17 (2.9)	0.4 (6.6)	5.6 (6.0)	8.0 (8.0)	1.5 (11)	2.2 (9.2)	3.7 (6.9)	— (8.2)
Methylene chloride ^c	2.0 (4.8)	4.4 (3.5)	6.3 (2.8)	8.0 (1.1)	9.0 (2.6)	0.8 (2.8)	13 (2.0)	2.6 (12)	2.4 (13)	6.6 (8.2)	1.5 (1.9)	2.0 (4.8)	3.2 (3.8)	—
Pentane	20 (21)	65 (10)	38 (16)	6.4 (25)	>60 (<2)	6.8 (24)	>60 (<2)	>60 (<2)	>60 (<2)	>60 (<2)	5.6 ^D (10) ^D	3.5 (1800)	5.2 (1600)	—
Phenol	>60 (<3)	>60 (<3)	>60 (<3)	>99 (<3)	>60 (<3)	—	>60 (<3)	56 (300)	32 (300)	>60 (<3)	36 (<250)	>60 (<3)	>60 (<3)	—
Pyridine ^c	4.0 (1.7)	20 (0.9)	26 (0.7)	39 (0.2)	38 (0.6)	1.6 (0.7)	51 (0.4)	11 (3.2)	9.6 (3.5)	15 (3.0)	10 (2.4)	12 (0.5)	26 (0.3)	5.6 (4.0)
Tetrachloroethane ^c	9.6 (2.2)	32 (1.1)	18 (1.4)	6.0 (0.5)	50 (1.0)	5.2 (0.6)	>64 (<0.02)	22 (3.2)	13 (3.1)	74 (>0.3)	19 ^B (2.2) ^B	10 ^B (1.4) ^B	21 (1.3)	—
Tetrahydrofuran ^c	2.7 (23)	3.2 (16)	4.8 (14)	1.6 (8.0)	14 (11)	1.3 (9.6)	20 (9.0)	6.2 (3.7)	4.7 (4.3)	6.0 (2.7)	2.6 (3.5)	2.6 (3.5) ^B	6.7 ^B (2.4) ^B	—
Toluene ^c	4.0 (2.5)	14 (1.4)	17 (0.9)	2.0 (1.0)	26 (1.3)	1.0 (2.6)	32 (0.7)	19 (0.7)	36 (0.5)	>60 (<0.3)	10 (0.8)	3.0 (3.6)	4.1 (2.8)	— (0.4)
1,1,1-Trichloroethane ^c	16 (1.0)	19 (1.0)	25 (0.9)	4.0 (1.0)	48 (0.8)	2.2 (0.7)	—	11 (4.1)	56 (<0.05)	>60 (<0.01)	3.7 (2.6)	7.4 (1.8)	13 (1.2)	36 —
Trichloroethylene ^c	3.3 (4.2)	8.1 (2.3)	12 (1.9)	1.6 (1.9)	15 (2.1)	1.6 (1.8)	23 (1.3)	9.2 (2.0)	9.6 (2.1)	26 (0.9)	7.5 (1.6)	2.8 ^E (6.8) ^E	4.8 (5.3)	—
Trifluoroethanol	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	>60 (<4)	20 (1900)	17 (2300)	58 (1100)	7.1 (3100)	>64 (<4)	>99 (<4)	—
Xylene ^c	5.2 (3.4)	14 (1.3)	23 (0.8)	3.4 (0.5)	18 (1.4)	3.0 (0.6)	44 (0.7)	48 (0.1)	57 (0.1)	>60 (<0.05)	28 (0.3)	5.0 (2.8)	7.9 (2.4)	—

^aMost of the breakthrough curves exhibit type A behavior; those exhibiting type B, C, D, or E behavior are indicated by B, C, D, or E.^bTop values are breakthrough times (min); values in parentheses are permeation rates ($\mu\text{g}/\text{min}/\text{cm}^2$).^cPermeation rates for these solvents are in $\text{mg}/\text{min}/\text{cm}^2$.

the permeation rate of the whole mixture will be directly proportional to the volumetric concentration of each solvent. This observation is surprising because the neoprene sample is extremely swollen during the test period.

Figure 28 shows the effects of a pentane-trichloroethylene mixture on a polyethylene glove (glove No. 2, Table 4). Although the glove sample remained essentially unaffected during the test, we noticed a large positive synergism (shown by the dashed line) as the mixture approached a 50:50 ratio. This indicates that the permeation rate of each component has to be known to predict the permeation rate of the mixture accurately.

Summary. Because there are no valid data for solvent activation energies and permeation constants, solvent permeation rates can only be obtained experimentally. Our experiments identified five permeation breakthrough types. Of the 28 gloves tested, none was found to be a satisfactory deterrent to the solvents tested. The solvent permeation rate was found to be indirectly proportional to glove thickness. We also noted that the permeation rate of a solvent mixture is the result of a large positive synergism.

FIG. 28. The effect of a pentane-trichloroethylene mixture on the permeation rate. The dashed line denotes a large positive synergism for a 50:50 mixture.

TECHNICAL NOTES

RADIATION PROTECTION

Determining Neutron Dose Rates and 9-to-3-in. Sphere Ratios from a Moderated ^{252}Cf Source in the LLL Calibration Facility

We have been using the low-scatter exposure facilities in building 255 to compare the relative response of albedo neutron dosimeters exposed to various moderated-neutron spectra. Albedo neutron dosimeters are highly energy dependent and their response to a moderated source, for a given dose equivalent, can vary by more than an order of magnitude.²¹ This extends over the response regions most commonly encountered in field work, including the response to the low-energy spectra observed at power reactors.

For the comparison, we use a moderated ^{252}Cf source. The moderators are polyethylene, aluminum, water, and deuterium oxide spheres that fit over the end of the "rabbit" source transfer tube. The sphere sizes vary from 10 to 25 cm in diameter

(see Table 6). Other spheres of polyethylene, water, and deuterium oxide are also available but were not used in this study.

The calibration of an albedo neutron dosimeter is normally based on the dose-rate reading obtained from a spherical neutron remmeter 9 in. in diameter. This is done either by (1) determining the dose rate at the calibration point and then exposing the dosimeter for a known time on a phantom located at that point or (2) determining the calibration factor using the 9-to-3-in. sphere technique, the more frequently used method. The first measurement is made at the calibration point with a 9-in. diameter remmeter; the second is made with the probe inserted inside a 10-mil cadmium-covered polyethylene sphere 3 in. in diameter. The ratio of the response of these spheres has been found to be closely related to the calibration factor required for interpreting the albedo neutron dosimeter. Hence, an experimentally determined curve^{32,33} is used to find the calibration factor from the 9-to-3-in. sphere ratio.

TABLE 6. Remmeter dose rates and 9-to-3-in. sphere ratios for the bare and moderated ^{252}Cf source.

Moderator	Relative dose rate at			Sphere ratio at		
	50 cm	1 m	2 m	50 cm	1 m	2 m
Bare source	3.51	1.000	0.312	2.38	1.96	1.24
10-cm deuterium oxide sphere		0.490	0.155		0.424	0.356
25-cm deuterium oxide sphere		0.144	0.0470		0.197	0.188
25-cm water sphere		0.0540	0.0172		0.866	0.648
20-cm aluminum sphere		0.748	0.231		0.997	0.702
10-cm polyethylene sphere		0.229	0.0727		0.752	0.596

Because we were aware that the large range of calibration factors obtainable in the LLL facility would be of interest to outside organizations participating in dosimetry intercomparison studies, we determined the dose rate and sphere ratio as accurately as possible, at distances of 1 and 2 m from the moderated ^{252}Cf source. Previously we had determined dose rates and sphere ratios during each calibration and found them to vary because of counting statistics, errors in distance measurements, scatter from other instruments or materials in the room (such scatter is especially influential in the 3-in. sphere measurement), etc.

The first step in determining the 9-to-3-in. sphere ratios was to remove all neutron-scattering materials from the center of the exposure cell. The spheres were then placed sequentially, at a distance of 1 m from the center of the source, and four series of three or more 1-min counts were obtained (depending on the counting rates). The 9-to-3-in. sphere ratio for each series of counts was calculated relative to the preceding count, giving a total of seven determinations of the ratio. The seven determinations were then averaged and the procedure repeated at distances of 2 m.

Determining sphere ratios in this manner eliminates errors caused by changes in instrument sensitivity over the measurement time and errors caused by a single distance measurement (the spheres were repeatedly removed and replaced on the stand, and a new distance measurement was determined each time). Table 6 shows the ratios determined using this procedure; they are believed to be accurate within $\pm 2\%$.

The dose rates obtained with the moderating spheres in place were determined relative to the bare ^{252}Cf source, again by using a sequential technique. The counting rate of the instrument for the bare

source, located at 1 m from the source, was determined using a series of 1-min counts. A moderating sphere was then placed around the source, and the counting rate was determined at 1 and 2 m. The sphere was removed and the counting rate for the bare source was again determined. This procedure was repeated, resulting in three determinations of the counting rate for the bare source (beginning, middle, and end) and two determinations of the counting rate for the moderated source. Table 6 shows the dose rates relative to the bare source reading, which was normalized to 1.000 at a distance of 1 m. They are believed to be accurate within $\pm 2-3\%$.

The dose-equivalent rate of the ^{252}Cf source changes each day because of radioactive decay; therefore, the relative readings in Table 6 are thought to be more appropriate than the readings for a particular day. Also, the dose-equivalent rate of our source is based on calculations using a quality factor of 8.9 (weighted over the neutron spectrum for a bare ^{252}Cf source according to the values given in NCRP Report No. 38).³⁴ The relative dose-equivalent rates given for the moderated source are the dose rates determined using a 9-in. sphere, which is known to overrespond to low-energy neutrons. For deuterium oxide-moderated spectra, this overresponse increases—it is 43% greater than the overresponse obtained by ANISN calculations and 35% greater than that obtained by Bonnersphere measurements.³⁵

The relative dose-equivalent values given here are for use with albedo neutron dosimeters. For future dosimetry intercomparison studies, we will use the relative dose rates and the 9-to-3-in. sphere ratios given in Table 6. This will reduce considerably the time required for an intercomparison and provide an accurate determination of dose rates and 9-to-3-in. sphere ratios.

FIG. 29. Schematic of the AERIN code model.

Application of the AERIN Computer Code to Two Americium Inhalation Exposures

The AERIN computer code,³⁶ developed at Lawrence Livermore Laboratory, is a mathematical expression of the lung model developed by the International Commission on Radiological Protection (ICRP).³⁷ It computes the burden of radioactivity and absorbed dose for organs of the body that have been exposed to inhaled radionuclides and predicts the amount of radioactivity excreted in the urine and feces as a function of time.

The code (represented schematically in Fig. 29) has been used to review internal exposures resulting from the inhalation of transuranic isotopes (TRU). We recently used it to estimate two internal exposures resulting from the inhalation of americium.

The input data for these exposures were *in vivo* lung counts and urine and fecal analyses. All data were normalized to protect the individuals involved. The normalization did not, however, change the significant health physics aspects of either exposure.

The particle size of the inhaled material was selected from a data bank of 13 diameters ranging from 0.01 to 50.00 μm activity mean aerodynamic diameter (AMAD), and the solubility of the deposited material—i.e., the time it takes for the inhaled material to dissolve and move into the bloodstream—was described in terms of years (Y), weeks (W), or days (D). Urine activity, U , was calculated using the power function

$$U = IS_0 t^{-m}$$

*These values can be altered if desired.

where f is the fraction of the systemic burden S_0 and t is the time in days.

Employees AB and CD inhaled essentially pure ^{241}Am oxide. Sufficient americium was deposited in the lungs to allow an *in vivo* count of the material moving from the lungs to other organs. (Indeed, with *in vivo* head counts, we are beginning to detect the translocation of americium to the skeleton.)

Interestingly, we observed that a fraction of the deposited material cleared the lungs as class W material, while the remainder cleared as class Y. In the lungs, then, the effective half-life of class W material observed is essentially 50 d, just as in the ICRP lung model; that of class Y is much longer, appearing at this time to be about 650 d.

Figure 30 shows the ^{241}Am *in vivo* lung count data plotted against time since inhalation for employee AB. Figure 31 shows the same information for employee CD. On some days we made two counts on each employee, so we plotted two counts rather than an average. In these figures, the error

bars represent one standard deviation. The solid line connecting the data is the AERIN code prediction for the quantity of americium remaining in the lungs and the pulmonary lymph, and for 11.5% of the quantity of americium deposited in the bone. The 11.5% figure represents the activity in the bone that contributes to the lung count—the activity in the sternum, the clavicles, the scapulae, and the thoracic and cervical vertebrae. This value was determined empirically from an americium exposure that occurred over 25 years ago.

Figures 32 and 33 are plots of the urine data for both employees, and Figs. 34 and 35 are plots of the fecal data. In all these figures, the solid line represents the AERIN code prediction. In order to fit the code predictions to these data, we had to assume that americium was insoluble in the nasal-pharynx of tracheo-bronchial regions but that americium deposited in these regions could clear directly to the gastrointestinal (G.I.) tract. Thus, the urine activity equations for the two employees are

FIG. 30. Lung count data plotted against time since inhalation for employee AB.

FIG. 31. Lung count data plotted against time since inhalation for employee CD.

$U = 0.059 S_0 t^{-1.56}$ for employee AB, with a standard error of estimate of 1.262

$U = 0.10 S_0 t^{-1.56}$ for employee CD, with a standard error of estimate of 1.197.

S_0 is the systemic burden for day 1, and the standard error of estimate is defined as

$$\sigma_E =$$

$$\sqrt{\sum_i^n \frac{[(\text{AERIN code value})_i - (\text{Observed value})_i]^2}{n-2}}$$

In order to obtain the closest fit of the AERIN code predictions to the observed fecal activity, we had to assume that the particle size of the inhaled material was $0.05 \mu\text{m}$ AMAD. This is a considerably smaller particle size than we have observed in other TRU inhalation incidents.

The AERIN code predictions are made to fit the observed data through an iterative process. Once the fit is achieved, the integrated absorbed dose to the lungs, bone, and liver, for any period of time, can be read directly from the computer print-out. Generally, we are interested in the calculated absorbed dose rate during the year of maximum deposition and the absorbed dose commitment out to the age of 70. We then determine the fraction of maximum permissible organ burden resulting from the exposure.

INDUSTRIAL HYGIENE

Air- and Soil-Sampling Program at Site 300's High-Explosive Test Bunkers

Toxic materials, such as uranium, beryllium, mercury, and lead, are routinely used in the weapons-test assemblies detonated at Site 300, the high-explosives test site for Lawrence Livermore Laboratory (LLL). To ensure safe and effective

FIG. 32. Urine activity data plotted against time since inhalation for employee AB.

FIG. 33. Urine activity data plotted against time since inhalation for employee CD.

FIG. 34. Fecal activity data plotted against time since inhalation for employee AB.

FIG. 35. Fecal activity data plotted against time since inhalation for employee CD.

testing, the assemblies are detonated inside high-explosive test bunkers; to ensure that the materials remain at safe levels, a toxic material control program is followed.

The control program for beryllium, described in detail in a recent Laboratory publication,³⁸ was designed to maintain beryllium levels within the standards set by the Laboratory (Table 7) and, as such, has been successful: an 11-yr summary of beryllium monitoring for bunkers 850 and 851 (Table 8) shows that beryllium levels inside the bunkers (i.e., levels in air, on surfaces, and in firing-table soil) have remained well below the conservative Laboratory standards.

The beryllium levels in the firing-table soil, including those on surfaces, were arbitrarily set to keep the levels in air within the Laboratory standards; thus we assume a relationship between the levels in the firing-table soil and the levels in air. To better understand this relationship, if it does, in fact, exist, we have undertaken a new air- and soil-sampling program.

Figure 36 shows the equipment we use for high-volume air sampling—three high-volume samplers supported by tripods 0.5, 1.1, and 1.7 m high. The samplers are placed around typical shot setups in clusters of three each to determine if the operations in the test bunkers are producing significant levels of airborne beryllium. High-volume air sampling is also done at varying levels in firing-table soil to determine if there is a relationship between these levels and the measured airborne levels.

Personnel air sampling is carried out during test assembly setup and cleanup operations. Figure 37 shows the equipment we use—a sampling train consisting of an intrinsically safe personnel sampling pump connected to a filter cassette with a 37-mm $\times$ 0.8- μ m polycarbonate filter. The sampling pump (obtained from the U.S. Bureau of Mines) is necessary for operations carried out when high explosives are on the firing table. Sampling results are carefully examined to see if there is a correlation between beryllium levels in firing-table soil and personnel exposure and job assignments.

It is well known that certain particle sizes of toxic materials create more of a health hazard than others. Thus, to determine if the toxic materials expended at the high-explosive test bunkers are within the respirable range (i.e., less than 10 μ m in diameter), typical firing-table gravel samples are

FIG. 36. High-volume air samplers supported by tripods.

FIG. 37. Personnel air-sampling train.

TABLE 7. Lawrence Livermore Laboratory beryllium control standards.

Control standard	Air	Surfaces	Soil
Normal operating level	<0.2 $\mu\text{g}/\text{m}^3$ for an 8-h working day	<0.02 $\mu\text{g}/\text{cm}^2$ for floors and walls; <0.01 $\mu\text{g}/\text{cm}^2$ for unenclosed equipment	500 $\mu\text{g}/\text{g}$ for beryllium work areas
Warning level	0.02-2 $\mu\text{g}/\text{m}^3$ for 3 consecutive working days	-	-
Emergency action level	>2 $\mu\text{g}/\text{m}^3$ for an 8-h working day	-	-

TABLE 8. Summary of beryllium monitoring for bunkers 850 and 851.^{a,b}

Bunker, sample, and beryllium expended	Sampling period										
	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Bunker 850											
Interior air	(50) ^c	(15)	(15)	(11)	(83)	(48)	(47)	(48)	(42)	(33)	(57)
	0.000-0.001	0.000-0.001	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.002
Interior swipe	(25)	(7)	(7)	(2)	(33)	(15)	(13)	(6)	(23)	(29)	(23)
	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000
Firing-table soil	(30)	(15)	(12)	(6)	(68)	(37)	(36)	(43)	(30)	(18)	(19)
	0.000-22.50	0.000-4.00	1.75-4.00	2.50-300.00	1.75-231.25	0.000-356.25	0.000-35.00	0.250-200.00	0.250-13.25	0.250-6.75	0.600-262.50
Beryllium (kg)	0.0	0.0	0.4	1.2	1.2	2.0	46.6	0.9	0.2	0.4	0.4
Bunker 851											
Interior air	(104)	(103)	(103)	(37)	(186)	(108)	(71)	(98)	(114)	(119)	(101)
	0.000-0.022	0.000-0.003	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.010
Interior swipe	(38)	(43)	(43)	(22)	(72)	(33)	(18)	(12)	(36)	(45)	(28)
	0.000-0.003	0.000-0.004	0.000-0.005	0.000-0.007	0.000-0.001	0.000-0.005	0.000-0.000	0.000-0.001	0.000-0.002	0.000-0.002	0.000-0.002
Firing-table soil	(58)	(64)	(73)	(16)	(31)	(63)	(73)	(80)	(46)	(61)	(27)
	0.000-375.00	0.000-290.00	2.50-556.25	2.75-206.25	2.50-462.50	2.00-1250.00 ^d	0.000-990.00 ^d	5.00-1075.00 ^d	1.5-475.00	4.00-425.00	24.75-656.25
Beryllium (kg)	14.5	20.8	12.8	18.2	16.1	27.5	71.3	89.7	30.3	62.6	28.2

^aSamples were analyzed by atomic absorption spectroscopy, which has a sensitivity of 0.05 μg . Before May of 1975, analyses were done with the Morin Dye procedure, which has the same sensitivity.

^bBoth bunkers were closed from the middle of 1970 to late 1971.

^cValues in parentheses indicate the number of samples taken each year.

^dIf an unrepresentative sample is collected, the area is immediately resampled. Gravel is changed if high results are confirmed.

collected, sized with an eight-stage Anderson impactor, and analyzed for their elemental composition.

The results of this three-phase sampling program will provide a better characterization of

the workplace conditions that exist on the firing tables in the high-explosive test bunkers and will indicate whether modifications to the toxic material control program should be made.

PUBLICATIONS

J. A. Becker, R. E. Howe, K. W. Crase, and E. Farley, *Thick Target Neutron- and Gamma-Ray Yields Induced by Medium-Energy Proton and Deuteron Bombardments*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-18086 (1979).

Stopping samples of Lucite, Al, Fe, and ^{238}U (Fe and ^{238}U) were irradiated with 330-MeV deuterons (260-MeV protons). For each target, neutron energy spectra and prompt gamma-ray yields were measured using the time-of-flight technique. The detector was a right cylindrical volume of deuterated benzene, 12.5 cm in diameter by 7.5 cm long, located at 110° to the incident beam direction. The neutron yield and the prompt gamma-ray yield were found to depend upon the atomic number of the target and the incident projectile. The measured shape of the neutron energy spectrum was not strongly dependent on either the incident projectile or the atomic number of the target. A lower limit for absolute neutron yields was also obtained.

J. L. Cate, Jr., *On-Line Monitoring for Metals in the Sewer and at Points Upstream Using X-Ray Fluorescence Analysis*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-83327 (prepared for presentation at the Fall Meeting of the Institute for Packaging and Interconnecting Electronic Circuits, San Francisco, California, September 25, 1979).

X-ray fluorescence analysis (XRFA) is a promising means of monitoring effluent and process streams. This paper discusses the basic principles of XRFA, describes the XRFA system installed in the Lawrence Livermore Laboratory sewer line, and extrapolates from this base to a more sophisticated system that could be built to address the more difficult analysis problems common to the printed circuit manufacturers industry.

J. L. Cate, Jr., M. A. Matthews, and D. W. Ruepel, *A Prototype On-Line X-Ray Fluorescence Analyzer for Detection of Metals in Sewage*,

Lawrence Livermore Laboratory, Livermore, Calif., UCRL-81954 (prepared for presentation at the 34th Annual Purdue Industrial Waste Conference, Purdue University, West Lafayette, Indiana, May 6, 1979).

At Lawrence Livermore Laboratory, we have been monitoring sewage effluent for radioactivity and pH for nearly a decade. We are now in the process of installing an on-line x-ray fluorescence analyzer that will simultaneously detect high levels of metals in the effluent. The analyzer uses a ^{109}Cd source to excite the sample and a xenon-filled proportional counter to detect the fluorescent x rays. On-line sample preparation and presentation have been carefully considered, and the source detector geometry has been optimized. X-ray spectral data will be collected and analyzed in a dedicated microprocessor, and high-level readings will be routed into our existing 24-hour-a-day alarm network.

E. Farley, J. A. Becker, K. W. Crase, R. Howe, and D. Selway, *Measurements of Energy Deposited by Charged Particle Beams in Composite Targets*, Lawrence Livermore Laboratory, Livermore, Calif., D-79-5 (1979).

We measured the energy deposited in two composite targets exposed to charged particle beams—a ^{238}U -Lucite-polyethylene target exposed to beams of 0.26-GeV protons and 0.33 GeV deuterons and an Al-Lucite target exposed to 0.5-GeV electrons. In addition, we obtained data on the emission of neutrons and gamma rays from solid targets of various materials (including ^{238}U and Fe) exposed to 0.26-GeV protons and 0.33-GeV deuterons. We used passive detectors (thermoluminescent dosimeters, Lexan fission track recorders, and photographic emulsions) to measure the nonfission dose and the fission-fragment dose caused by the primary beam and its shower products at various depths and radial positions in the targets. Plots and numerical values of the measured doses are presented. The emission of neutrons and gamma rays,

was measured with a liquid-deuterated benzene detector. In general, the dose profile with depth is similar for 0.26-GeV protons and 0.33-GeV deuterons, and the return neutron-to-gamma-ray ratio increases when the target mass number increases. Deuterons, however, produce from 1.7 to 5.8 times as many neutrons and gamma rays per particle as protons.

R. V. Griffith, J. C. Fisher, D. E. Hankins, and D. E. Miller, "Personnel Neutron Monitoring Developments at LLL," in *Seventh DOE Workshop on Personnel Neutron Dosimetry*, London, England, October 23-25, 1978, PNL-2807 (Pacific Northwest Laboratory, Richland, Washington, 1978), pp. 56-66.

No abstract available.

R. V. Griffith, D. E. Hankins, R. B. Gamage, L. Tommasino, and R. V. Wheeler, "Recent Developments in Personnel Neutron Dosimeters—A Review," *Health Phys.* 36, 235-260 (1979).

Only three types of personnel neutron dosimeters are commonly used for radiation protection purposes: neutron film type A (NTA film), thermoluminescent albedo dosimeters (TLD albedo), and fission track detectors. Deficient energy response and sensitivity, fading, use of radioactive material, and other limitations prevent any of these dosimeters from being satisfactory for universal application—use in a wide variety of radiation environments. The albedo dosimeter is becoming the most widely used in terms of the number of personnel monitored. However, severe energy-response problems dictate that it be used with great care. New dosimeter concepts have been and are continuing to be studied either to replace or augment current dosimeter designs. New concepts include electrochemically etched plastics, hydrogenous thermoluminescent materials, differential glow peak formation in thermoluminescent materials, and many others. Of these, only electrochemically etched plastics have been pursued seriously by commercial dosimeter suppliers. A great deal of work remains in personnel neutron dosimetry, particularly because the current limits of neutron exposure may be reduced.

D. E. Hankins, "Albedo Neutron Dosimetry Studies at Lawrence Livermore Laboratory," in *Seventh DOE Workshop on Personnel Neutron Dosimetry*, London, England, October 23-25, 1978, PNL-2807 (Pacific Northwest Laboratory, Richland, Washington, 1978), pp. 38-45.

No abstract available.

D. E. Hankins, "Cadmium-Capture Gamma-Ray Exposure for Personnel Dosimeters," *Health Phys.* 36, 644 (1979).

No abstract available.

D. E. Hankins and R. V. Griffith, "A Survey of Neutrons Inside the Containment of a Pressurized Water Reactor," *Radiation Streaming in Power Reactors*, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/RSIC-43, ANS/SD 79/16, 114-126 (1979).

A neutron survey was made inside the containment of the Farley Nuclear Plant, Alabama Power and Light Company, Dothan, Alabama, in November 1977. The survey was made to determine the spectra of leakage neutrons and to evaluate the accuracy of albedo neutron dosimeters and a 9-in. diameter spherical remmeter. The survey also covered variations in the neutron spectra, the ratio of gamma-to-neutron dose rates, and the thermal neutron component of the neutron dose.

C. A. Harder and B. J. Held, "Self-Contained Breathing Apparatus: Equipment and Use," *The International Fire Chief* 45(5), 9-12 (1979).

In this article, the last in a series of eight, we describe the fire-fighting breathing apparatus that is available or soon to be available from U.S. manufacturers. We also present some ideas on how fire fighters can reduce the risk of inhalation hazards.

G. F. Hunt, R. C. Kaifer, D. R. Slaughter, R. E. Strout, and D. W. Rueppel, *A Microprocessor-Controlled Portable Neutron Spectrometer*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-82716 (prepared for presentation at the IEEE Nuclear Science Symposium, San Francisco, California, October 17-20, 1979).

A neutron spectrometer that acquires and unfolds data in the field has been developed for use in the energy range from 1 to 20 MeV. The system includes an NE213 organic scintillation detector, automatic gain stabilization, automatically stabilized pulse-shape discrimination, an LSI-11 microprocessor for control and data reduction, and a multichannel analyzer for data acquisition. All system components, except the multichannel analyzer, are mounted in a 47 × 23.5-cm suitcase. The whole assembly weighs 23.5 kg.

C. Laszew-Davis, *Women in the Workplace—An Industrial Hygienist's Perspective*, Lawrence Liver-

more Laboratory, Livermore, Calif., UCAR-10046 (prepared for submittal to the National Safety Congress, Chicago, Illinois, October 15-19, 1979).

Although the incidence of birth defects, spontaneous abortions, and stillbirths among the human population is quite high, the cause of the vast majority of these is unknown. Hundreds of agents capable of causing reproductive failure or of inducing germinal and/or somatic mutation have been recognized, but the actual magnitude of their effect on human reproductive health has not been quantified. In the era of protectionism that has developed in the last several years, lawmakers faced with chemical and physical hazards in the workplace have pondered the "problem" of the exposure of women of child-bearing capacity to such substances. The "solution" has taken the form of barring women of child-bearing age from jobs that could prove hazardous to the unborn child.

G. O. Nelson, *Calibration Techniques*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-82468 (prepared for presentation at the Fourth Biennial Boulder Symposium, Boulder, Colorado, August 6-9, 1979).

Preparing known concentrations of gas and vapor in air is an important function in any industrial hygiene laboratory. In this paper two systems for generating gas or vapor mixtures are compared: the simple static system and the more complex dynamic system. A completely automated dynamic system that controls the flow, temperature, humidity, and concentration of a gas or vapor mixture is also described.

G. O. Nelson, B. Y. Lum, G. J. Carlson, and J. S. Johnson, *Glove Permeation by Organic Solvents*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-81766 (prepared for presentation at the American Industrial Hygiene Conference, Chicago, Illinois, May 29, 1979).

We tested 28 protective gloves with 29 common laboratory solvents to determine the permeation characteristics of the gloves. Through gas-phase infrared spectrophotometric techniques, we identified five different breakthrough types. No one glove offered complete protection against all the solvents tested. The permeation rate was found to be indirectly proportional to glove thickness. The permeation rate of one of the two solvent mixtures tested exhibited a large, positive synergistic effect.

G. O. Nelson and R. D. Taylor, *An Automated Flow-Temperature-Humidity Control System*,

Lawrence Livermore Laboratory, Livermore, Calif. (prepared for presentation at the American Industrial Hygiene Conference, Chicago, Illinois, May 29, 1979).

The automated flow-temperature-humidity control system consists of a commercially available temperature-humidity indicator and a specially built flow-temperature-humidity control module. Parameters are set by the direct-reading dials on the control module. The air flow is maintained by a mass flow controller. Humidity and temperature are regulated by process controllers connected to the indicator. The system will run indefinitely without an operator. If the module and the indicator are properly calibrated, accurate air flows ($\pm 2\%$ of full scale), temperatures ($\pm 0.3^\circ\text{C}$), and humidities ($\pm 2\%$ RH) can be achieved.

B. N. Odell, *Environmental Impact Assessment for the Nova Projects (Building 391 Complex 391)*, Lawrence Livermore Laboratory, Livermore, Calif., UCID-18182 (1979).

The environmental impact assessment for the Nova Projects at the Lawrence Livermore Laboratory describes the proposed actions for the construction and operation of the facilities, the existing environment in and around the Livermore Valley, and the potential environmental impacts from the construction and operation of the facilities. The proposed actions do not conflict with federal, state, regional, or local plans or programs, but possible alternatives are suggested. It is concluded that the proposed actions would be more reasonable than the alternatives because they would involve relatively minor adverse environmental impacts.

H. E. Pfeifer, B. N. Odell, and V. E. Arganbright, *Noise-Abatement Method for Explosives Testing*, Lawrence Livermore Laboratory, Livermore, Calif., UCRL-81757 (prepared for presentation at the American Industrial Hygiene Conference, Chicago, Illinois, June 1, 1979).

When Lawrence Livermore Laboratory scientists began explosives testing at Site 300, the Laboratory test area located in the sparsely populated hills 15 miles east of Livermore, residents in neighboring areas complained of sudden loud noises. A combined literature and research study, coupled with an experimental test program, indicated that the combination of air temperatures and winds at various elevations was the primary

reason for blast or sound waves returning to the surface. To solve the noise problem, we had to determine the maximum amount of explosives that could be detonated above ground, under various atmospheric conditions, without excessive noise. The method devised to accomplish this predicts the weight limits of the explosives using pressure-distance-weight nomograms and the slope of a

sound-velocity curve. The sound-velocity curve is computed with temperature information from the U.S. Weather Bureau and wind data from a target-acquisition radar system. By following this method, we have been able to detonate thousands of shots without creating excessive noise in nearby communities.

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