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NOTICE

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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 who are listed in the Contents.

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PROGRESS REPORTS

RADIATION PROTECTION

Environmental Radiation Dose Rate Measurements with $\text{CaF}_2:\text{Dy}$ TLD's

In our previous progress report¹ we described two radiation background studies using thermoluminescent dosimetry which were underway at that time. One study was of variations in natural terrestrial backgrounds measured in residences. The other study was of geographical variations in natural environmental gamma radiation in the 50 United States, using techniques developed for the residential study. Both of these studies are now complete.

Study of Natural Terrestrial Background Variations Between Residences. As a part of personnel dosimetry, the Laboratory is interested in residential radiation backgrounds because the employees take their dosimeters home with them and these dosimeters thus are in residences about three times as long as they are at the Laboratory. For those whose assignments do not expose them to work-related radiation, it can then be assumed that the accumulated dose registered by their dosimeters is from natural background, most of which probably reflects a home exposure. For increased accuracy of dose assignment we were interested in the magnitude of the variations between natural terrestrial background levels and the effect these would have on dose reporting when an average background exposure rate is assigned.

To carry out these measurements, 110 members of the Hazards Control Department were issued $\text{CaF}_2:\text{Dy}$ dosimeters to keep in their homes for three-month periods. At the end of each period the dosimeters were recalled and read out on our automatic hot gas reader. The study was completed when one year, ending in Spring 1971, had been covered. The results are summarized in Table 1.

Exposure rates observed in individual homes are compared season-by-season in Fig. 1. This comparison is shown in Table 2 as an average ratio between the summer, winter, or spring values to the fall period. These data indicate little change in exposure rates; the accompanying mean standard deviations demonstrate the high precision of the measurements.

During the spring period a dosimeter was placed in the area of the Hazards Control Building (Building 253) which we normally use to estimate the average Laboratory background. This dosimeter indicated an exposure of 9.2 mR for the three-month period, which is in good agreement with median exposure rates seen in the residential study.

Geographical Variations in Environmental Radiation Background in the United States. From March 1 to June 1, 1971, we conducted a radiation background survey using thermoluminescent dosimeters (TLD's) at

Table 1. Natural terrestrial background variations between residences in the Livermore area

Period	Median exposure (mR/3-mo)	Range (mR/3-mo)
Summer	9.6	8 - 19
Fall 1970	9.6	8 - 17
Winter 1970-71	8.5	7 - 20
Spring 1971	8.8	7 - 19

Table 2. Comparison of exposure rates observed in individual homes

Period	Exposure ratio (Season/Fall)	Mean standard deviations
Summer	.991	0.014
Fall	-	-
Winter	.889	0.012
Spring	.929	0.011

Fig. 1. Comparison of exposure rates in individual homes by season.

120 weather stations spread throughout the United States. Through the cooperation of the National Oceanic and Atmospheric Administration, we were able to select stations which provided a reasonably uniform geographical distribution.

Freshly annealed $\text{CaF}_2:\text{Dy}$ (TLD 200) dosimeters were mailed to cooperating stations with instructions for conducting the tests. The dosimeters were placed in the station's instrument shelter for three-month exposure periods, then recalled and read out in our automatic hot gas reader. The cosmic-ray component of the total environmental radiation exposure rate was calculated from the relationship between cosmic radiation and elevation reported by Lowder and Beck.² Their data applies to 50°N geomagnetic latitude; accordingly, corrections were made for departures from this reference latitude at each station.³

Recent TLD measurements made in lead-shielded containers at three different elevations (Mt. Hamilton - 4202 ft, Mt. Diablo - 3849 ft, and Livermore - 600 ft) show that $\text{CaF}_2:\text{Dy}$ gives essentially a proper theoretical response to the hard component of cosmic radiation. Thus it is clear that the TLD data obtained at the surveyed weather stations reflect both terrestrial and cosmic radiation. Therefore, the terrestrial exposure rate is obtained by subtracting the cosmic contribution from the gross CaF_2 mrad dose.

$\text{CaF}_2:\text{Dy}$ response to cosmic radiation also affects the exposure rates reported in the residential survey. But the *relative magnitudes* of the background variation remain, and the comparison of seasonal effects (Fig. 1) will remain unaffected because they are expressed as ratios.

Low Dose Area Neutron Monitor

In late August we installed eight low-dose neutron monitoring stations around the Laboratory perimeter. Each station consists of an Anderson-Braun remeter with a ^{235}U foil and a piece of polycarbonate film as a detector (see Ref. 1, p. 2). The polycarbonate film registers damage tracks caused by fission fragments from neutron interactions. These films will be recovered in six months and etched with a caustic solution which enlarges the damage tracks, then the tracks will be counted with a spark counter.

The ^{235}U foils, obtained from Oak Ridge National Laboratory, contain approximately 5 mg of 97% ^{235}U plated on a stainless steel disk with a diameter of 0.95 in. The 6-micron thick polycarbonate film is mounted on a 0.050-in. thick plastic ring and held in place by a 0.020-in. thick stainless steel ring in a manner similar to an embroidery hoop. The detector is assembled with the ^{235}U foil placed behind the plastic ring and centered by the steel ring. Thus the polycarbonate film and the ^{235}U radiator are kept separated by 0.050 in. The detector combination is then placed in the center

of the remeter cavity to make measurements.

We calibrated each of the remeters at 50 mrem from an unmoderated ^{252}Cf source in a 30-cm diameter D_2O sphere, and in a 50-cm diameter D_2O sphere. The calibrations were made by comparison with an active remeter connected to a scaler. The average calibration factor for the eight remeter units exposed to three different spectra was 38.7 counts/mrem with a standard deviation of 4.7%.

There remains the question of detector background. The expected background for unexposed polycarbonate film is less than one count for a 3-cm² film. However, the ^{235}U foil contains about 3% ^{238}U , which has a spontaneous fission half life of 7×10^{15} years.⁴ We are not sure how much this will contribute to the background, but calculations indicate that we may expect as many as 25 counts over a six-month period. We will try to measure the spontaneous contribution by exposing the radiator-plastic combination in a ^{10}B carbide sphere for six months. The sphere should prevent neutron fission in the ^{235}U foil so that any counts would be attributable to spontaneous fission background.

Using source calibrations and assuming a background of 25 counts/six months, we should be able to detect as little as 0.5 mrem in that period at the Laboratory perimeter. If the background is less than 25 counts in six months, the limit of detection will be correspondingly less. However, even at 25 counts, this system should provide a very sensitive measure of the neutron background at the Laboratory perimeter.

Alpha Track Registration for Neutron Dosimetry

In our search for an accurate, sensitive personnel neutron dosimeter, track registration remains an attractive possibility. This is primarily because of its insensitivity to gamma radiation and its ability to detect individual neutron interactions. Unfortunately, the utility of fission foils as particle radiators is diminished by the radiation hazard associated with most fissionable materials. In addition, the preparation of large numbers of good quality foils is expensive, usually in excess of \$75 each.

As an alternative to fission fragment detection, we have been investigating the use of alpha radiators such as ^6Li and ^{10}B . The most promising registration material is cellulose nitrate.

Because of the difficulty we have experienced in trying to count tracks from the weak neutron-induced ^6Li or ^{10}B alphas in conventional cellulose nitrate, we have been working with the experimental Kodak film

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

LR 115.⁵ The red dye used in this film makes damage tracks stand out nicely as white holes when observed under a microscope. The film is etched with a solution consisting of 60 g potassium hydroxide, 400 g potassium thiocyanate plus water to make 1 liter. Etching is done at 60°C for 45 minutes. When the film is exposed to a ^{252}Cf fission spectrum using 0.025-in. thick TLD 600 chips or 1/16-in. ^{10}B -loaded plastic as radiators, we observe a continuous range of track sizes with a maximum diameter of about 20 μ .

Track densities per unit fluence are highly spectrum-dependent of course, with as many as 1000 tracks/cm²/mrem for a thermal spectrum using either lithium or boron radiators. However, since our primary concern is the measurement of fast neutron doses, we have made exposures with the radiator-plastic enclosed in 1/16-in. borated plastic to eliminate low energy neutrons. Under these conditions, we observe approximately 100-200 tracks/cm²/rem for ^{252}Cf spectrum neutrons, as compared with a background of 200 tracks/cm². Without radiators, we see about 1 to 10 tracks/cm²/rem for direct neutron interactions in the bare LR 115 film. For 14-MeV neutrons the LR 115 sensitivity is about 100 tracks/cm²/rem with little increase when a radiator is used. We have noticed an increase by as much as a factor of 2 in track density when the plastic is placed behind the radiator exposed to fission neutrons rather than in front. This is due to the higher energy of the alpha particles in the forward direction which causes alphas to escape the radiator with sufficient energy to be detected.

High background in the LR 115 plastic film is a major limitation to the detection sensitivity. This background is caused by flaws in the film together with alphas from the air and materials near the film. It appears that of the two, alpha background buildup is the more important problem. Normal cellulose nitrate can be annealed overnight at 80°C to eliminate alpha background. However, when we tried annealing LR 115 in the same way, the material would no longer register neutron induced alphas. We find that a 65-hr annealing at 65°C did allow subsequent registration, but with a lower track sensitivity and smaller tracks than unannealed material. The background tracks were still present although much smaller than without annealing. It may be that a longer annealing period at yet lower temperatures will give satisfactory discrimination.

A major problem with LR 115, particularly for routine use, is a rapid means of track counting. Though the larger tracks stand out nicely, there is a range of sizes which are difficult to count reproducibly with a microscope. Also it is possible that some information about the relative spectral distribution could be obtained from track size distribution. We are therefore

investigating the possibility of automatic counting and sizing either by modifying our television system⁶ or by use of a commercial particle sizing system.

Our experiments to date indicate that if we can reduce the background by a factor of 10 and achieve automatic counting, then we may be able to use cellulose nitrate track-registration as a gamma-insensitive neutron dosimetry system.

TLD Albedo Personnel Dosimeter

We have completed a design for a personnel neutron dosimeter. The dosimeter, which is shown in Fig. 2, contains three TLD 600's and one TLD 700 in a plastic container which is shielded on the wearer's bodyside by 0.02 in. of cadmium and on the front by 0.062 in. of borated plastic enriched in ^{10}B . Two holes are punched in the borated plastic, but one of these is plugged by a 0.02-in. cadmium disk. This plastic is oriented over the detector in such a way that one TLD 600 is unshielded from the front and a second TLD 600 is shielded by 0.02 in. of cadmium from the front. The remaining TLD 600 and the TLD 700 are both shielded on the front by the borated plastic and all of the detectors are shielded on the body side by 0.02 in. of cadmium. This

Fig. 2. Exploded view of personnel neutron dosimeter.

shielding arrangement results in different energy responses, thus enabling rough spectrum discrimination.

We are testing a prototype of this dosimeter with many different neutron spectra which are representative of those normally encountered. Preliminary indications are that this dosimeter overresponds by only a factor of 2 with heavy hydrogenous moderators when compared to a bare ^{252}Cf spectrum calibration, and that it should be able to detect a neutron dose of 30 mrem in the presence of a 100 mR gamma exposure.

Five hundred of these dosimeters are to be made for use in routine dosimetry, and a final report will be issued early in 1972.

An Investigation of the Mechanism of Thermoluminescence in LiF

The standard LLL personnel dosimeter contains an LiF thermoluminescent dosimeter (TLD). Although this TLD responds to radiation in a reproducible, well-documented manner, a detailed description of the reactions which make up the overall response of the

TLD is lacking. We are beginning a project to provide information about the details of the response mechanism.

Commercial LiF TLD's contain trace quantities of Mg and Ti as necessary impurities. Both impurities improve the sensitivity of LiF as a TLD. The Mg creates defects in the crystal structure which trap the electrons produced by ionizing radiation in an excited, metastable state.^{7,8} The Ti creates defects in the crystal structure which act indirectly as luminescence sites for the electrons which are released from the Mg-related traps during heating of the dosimeter.⁹

Investigators who have attempted oxygen analysis on LiF crystals have found oxygen concentrations comparable to or greater than the concentrations of the intentionally introduced Mg and Ti. It is our working hypothesis that oxygen affects the response of LiF TLD's to ionizing radiation.

In order to test this hypothesis, we are trying to grow crystals with different, known concentrations of oxygen. These crystals will be used in various experiments to seek correlations between oxygen concentration, radiation induced TL, and other physical parameters.

INSTRUMENTATION DEVELOPMENT

Background-Compensated FIDLER

Thin NaI (Ti) detectors are often used in plutonium surface contamination surveys, measuring either the 17-keV x-ray band or the 60-keV gamma from ^{241}Am (a beta decay product of ^{241}Pu). The FIDLER (an acronym for Field Instrument for the Detection of Low Energy Radiation) is a 5-in. diameter, 1/16-in.-thick NaI (Ti) detector developed at LLL for these field surveys. Measurements are by necessity made in the presence of natural terrestrial background, which varies with the condition of the soil and geographical location. As a result, plutonium detection sensitivity will vary inversely with background. Background interference poses no problem in locating highly contaminated areas, but peripheral zones between low-level contamination and natural background cannot be established unless we know the contribution of background to the observed counting rates.

A one-year study of natural terrestrial gamma background in the energy region of 10-100 keV showed that, whereas counting rates varied with geographical location, the percentage of the total activity within any given 10-keV interval was reproducible within about 5%.¹⁰ As a result, the 10-100 keV natural background gamma spectrum can be calculated from a counting rate measurement within

this energy range. Through the use of a pulse rate meter having three switch-selected outputs from a high voltage power supply, we can detect counting rates in narrow energy bands centered at 17, 60, and 80 keV. Field tests showed that natural background in the 17- and 60-keV energy bands could be estimated to within $\pm 10\%$ from a determination of the counting rate in the 80-keV band.¹¹

We have recently completed a prototype background-compensation circuit, which automatically subtracts the natural background component from the 17- and 60-keV response of the FIDLER. Background compensation is achieved by normalizing the 80-keV counting rate to an equivalent background in the 17- or 60-keV channel, then digitally subtracting this rate from the output of the 17- or 60-keV channel. Basis for normalization was the result of the one-year study, which showed that the FIDLER's response to natural background in the 17- and 60-keV bands was 6% and 60% respectively of the response in the 80-keV band. Figure 3 shows the physical arrangement of the FIDLER and pulse rate meter with the additional circuitry.

The operating principles may be explained as follows. Referring to the block diagram in Fig. 4 and using the 60-keV channel as the sample, the 80-keV channel output is gated on only 60% of the time by

an internally generated square wave. After gating, the output of the 80-keV channel is statistically equal to the background in the 60-keV channel. An up-down counter is used to subtract the normalized 80-keV output from the 60-keV channel. The 60-keV pulses count up while the 80-keV pulses count down. When the number of 60 keV-pulses overflow the counter, an output pulse is transmitted to the count rate meter circuit in the pulse rate meter. After overflow, the counter is reset to 9 and a following 60-keV pulse will again overflow. Thus the number of overflows is equal to the number of 60-keV pulses above background. Basic Eberline PRM-5 electronics are used along with two additional PRM-5 amplifier/analyzer boards and LLL circuitry to normalize and subtract background. For simplicity, only one readout meter, which is switch selectable to the 80-keV, 60-keV or 17-keV channels is provided. The additional circuitry adds 1.2 mA drain to the PRM-5 power supply for a total current drain of 32 mA.

Field tests of this instrument will be reported in a later progress report.

Calibration of the LLL Drum Scanner for ^{239}Pu -Contaminated Waste

The drum scanner being developed at LLL for assaying ^{239}Pu in 55-gal waste drums has been in

Fig. 3. FIDLER with pulse rate meter and chassis for add-on circuitry.

operational use for eight months. During this time, some minor mechanical modifications have been made and the electronics package has been enlarged to include a 128-channel pulse height analyzer. This report describes an extensive calibration of the unit

Fig. 4. Block diagram of background-compensated FIDLER.

in its present configuration and some limitations of the scanner design.

Calibration was accomplished with seven plutonium-oxide sources packaged in 1, 2, 4, 8, and three 16-g quantities. Each source was contained in a sealed aluminum right cylinder with a maximum wall thickness of 0.062 in. By counting various combinations of the seven standard sources, calibration curves have been established to cover the range from 1 to 60 g. Scans were made with the sources located at the center and at the bottom of the drum, on the central axis. The resulting calibration curves, shown in Fig. 5, represent the best least squares fit of a straight line to the data points.

During preliminary calibration,¹² we found that the turntable and turntable drive assembly presented considerable attenuation for 385-keV (complex)

gamma rays when sources were located near the bottom of the drum. Only extensive modifications to the turntable would reduce this shielding effect, and since other methods for correcting the data are available, these modifications have not been made.

The results of six measurements with a 16-g source located at various positions in an empty 55-gal drum are shown in Fig. 6. These results illustrate the error introduced by turntable shielding near the bottom of the linear scan. To correct for attenuation by the turntable assembly, two calibration curves are used, one for sources located in the upper two thirds of the drum, and a second for sources in the lower third. The source location in the drum is determined from a strip chart recording of detector count rate versus position.

Operating experience for the past eight months has been that drum weights have been extremely constant

Fig. 5. Calibration curves for standard 55-gallon waste drum.

Fig. 6. Sensitivity in counts/min/g of ²³⁹Pu at various positions inside a standard 55-gal drum.

with 95% of all drums containing 50 ± 10 lb of waste materials. This should minimize to some degree the problems associated with source shielding. Pulse height spectra are obtained with a 128-channel analyzer for each drum to ensure that there is no appreciable interference from other radioisotopes.

Beryllium Monitor

Following the restarting of the Livermore Pool Type Reactor (LPTR) in July, we reactivated the ^{124}Sb source used in the previously described beryllium monitor.¹³ By the time the short-lived activity had decayed away (in one month) the ^{124}Sb source strength was about 2 Ci. To determine the sensitivity with this source, we used the cylindrical lead storage pig as an internal shield and placed the whole monitor assembly inside a large concrete waste contaminant block with 16-in. thick walls for personnel shielding.

Unfortunately, the added concrete shielding increased the epithermal neutron background, presumably from cosmic-induced spallation reactions on the elements in the concrete. We can, however, report an overall increase in sensitivity. Figure 7 is a plot of the minimum detectable amount of beryllium on a filter paper as a function of counting time with the relatively high background rate of 51 counts/min and a sensitivity of 0.7 net counts/min/ μg . Also shown in Fig. 7 is a plot of our previous best sensitivity of 0.2 net counts/min/ μg with a background of 30 counts/min.

We will next investigate several methods for reducing the background associated with the additional shielding and reactivate the ^{124}Sb source to 5 Ci. The third curve in Fig. 7 shows what one can then expect for a sensitivity as a function of counting time.* Improvement beyond this will require use of the smaller butterfly lead shield and burial in the ground or construction of a borated water shield for personnel protection and neutron background reduction. In all probability the use of a butterfly internal lead shield¹³ will not improve the sensitivity of the beryllium monitor. The reduced lead shield would allow intense gamma fields to be present in the moderator material. The moderator contains enough deuterium to produce an additional neutron background which would increase linearly with the source strength. The neutron background produced in the lead shield is independent of source strength. Thus, removing some lead from the shield would only reduce this background if the source were weak (in this case less than 1 Ci). By increasing

the number of BF_3 detectors to 25, we can reasonably expect to double the signal and the background. This would lower the minimum detectable amount of beryllium by 40%.

The total background rate for the 13 BF_3 detectors inside a 6-in. borated paraffin shield is 1.2 counts/min. The internal lead shield produces a background (without the source inside) of about 0.7 counts/min/lb of lead which cannot be reduced further electronically. Thus, even if we could achieve a background rate of 1.2 counts/min without the internal lead shield in place, we cannot expect a background less than 20 or 25 counts/min when the system is operating. In addition, if the source strength is greater than 5 Ci, gamma pileup pulses will begin to increase the background rate.

Therefore, it is reasonable to expect a minimum detectable amount of beryllium on filter papers of about 1 μg in one hour at the 67% confidence level, or about 3 μg in one hour at the 95% confidence level with these improvements.

Evaluation of Computer-Based Pulse-Height Analyzer

A combined instrument for both collection and primary manipulation of pulse height data would have many advantages, but instruments of this kind are relatively new to the smaller spectroscopy laboratory. There were many unanswered questions about the capabilities and limitations of such computer-based systems. We, therefore, leased one complete system in order to evaluate its application. During the last five months we have evaluated the following capabilities and application problems.

- The maximum number of simultaneous users that can efficiently operate the system,
- The selection of appropriate peripheral equipment for our specific applications,
- The capabilities of the system hardware,
- The capabilities of the software supplied by the manufacturer, and
- The question as to whether we should generate additional software of our own to increase the system's usefulness.

The principal advantage of a combined analyzer-computer system over an analyzer system is that the typical analyzer is capable of recording spectra and outputting the acquired data in spectral form, or integrated regions only, while the computer-based analyzer system can output essential information such as peak areas, energies, widths, and background as well as raw spectra.

A realistic maximum number of users who can use the system at one time is two; in fact, this maximum is reasonable only when data is being manipulated by

* It is interesting to note here that we have seen microgram quantities of Be in other substances such as Al, Cu, glass, Fe, etc. The only requirement is that the substance be thin enough for the gamma field to penetrate effectively.

Fig. 7. Minimum detectable amount of Be on filter paper as a function of counting time.

one of the users at a time. Two-user operation is most satisfactory when at least one person has long counting time requirements, so that competition for output units, particularly the CRT and teletype, is not

excessive. Another requirement is primarily a social one — users must be careful not to disturb either the stored data of the other user or the program under which both are currently running.

In regard to peripheral equipment, we have found that the teletype low speed paper punch and reader, magnetic tape cassette, and x-y plotter are the most useful for our work. Since all of our primary computations are completed before output is necessary, high speed paper tape punch and reader are not required for communication with another computer. The slow paper-tape reader on the teletype is sufficient. Long programs on paper tape can be transferred to magnetic tape. Also there are very few spectra which we have reason to store on paper tapes in addition to storing on cassette tape. The cassette tapes are a highly compact form of data and program storage and have been extremely reliable so far.

A number of software programs and options are available, and the number of functions and computations is considerable. As is to be expected, a general program cannot supply all the requirements of a number of individual users. A higher order and simpler programming language, which is to become available will enable users to change their programs more easily. The use of this language will, however, require an additional 8K words of memory core, increasing the total system memory size to 16K words.

A more efficient program in terms of use of memory locations is written in assembly language. This language is available now, and we have used it to write our own simple programs such as a cassette tag-word list routine. We are beginning to make the system more useful by writing assembly language programs to extend the data storage area and to calculate accurate centroids of peaks (in terms of energy) and computer calculated backgrounds. The manufacturer of our system has supplied programs to perform these functions, but so far we have not been able to get them to operate correctly.

We currently feel that calculation of areas, energies, and backgrounds of well resolved peaks is all that should be attempted in an analyzer-computer system costing less than \$30,000. To do more in automatic peak search, unresolved peak extraction using fitting routines and automatic analysis based on the apparent list of peak energies and areas should probably be left to larger computers. We find that our group seldom needs this type of full scale automatic processing, but preliminary data reduction capability is always required in order to quantitatively use any pulse height spectrum.

ENVIRONMENTAL PROTECTION

Applicability of an Atmospheric Model to Effluent From the Livermore Pool Type Reactor (LPTR)

In mid-1970, the Radiation Safety Section began a re-evaluation of concentration levels of ^{41}Ar effluent at the Laboratory boundary which would result from operation of the LPTR (Building 281). The calculations, which were based on a standard Gaussian plume model, made use of the following equation:

$$x(x, y, z, H) = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp - \left[\frac{1}{2} \left(\frac{H}{\sigma_y} \right)^2 + \frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right]$$

where

x, y , and z are the usual coordinate axis,

Q is the quantity emitted per unit time in Ci/sec,

$\bar{u}$ is the average wind speed in m/sec,

σ_y, σ_z are the standard deviations of the plume distribution in meters obtained from the Pasquill Stability Categories, and

H is the emission height in meters.

These calculations showed that the maximum average off-site concentration is about a factor-of-five lower than the maximum permissible off-site

concentration established by the AEC. Because the LPTR was shut down in late 1970 and was not started again until June 1971, measurements of the ^{41}Ar concentration could not be made to verify these calculations.

During the third week of May 1971, tests were begun to determine if the diffusion model described the actual conditions at the LPTR. Of particular concern were the shortness of the stack and the effect of atmospheric turbulence resulting from the curvature of the building dome near the stack.

Smoke released from the stack was observed to be carried downward along the contour of the building when wind speeds exceeded 15 mph as shown in Fig. 8. During the first smoke release it was also seen that a strong wind (over 20 mph) from the northeast caused stack exhaust to be drawn into the building through an air conditioning system intake which is located on the southwest corner of the facility. The odor of the test smoke inside the building, which became very noticeable during and immediately after the test, indicated that air and ^{41}Ar could be recirculated under these conditions.

The downdraft along the building contour indicated that the diffusion model might not represent the actual

Fig. 8. Flow pattern of test smoke released from LPTR building stack with wind speed <15 mph. Arrows show generalized direction of flow.

situation. Dispersion measurements would have to be made to determine how accurately the model represented the situation and, if not, how the model could be altered to accommodate the downdraft.

The Environmental Evaluation Section suggested the use of the fluorescent particle dispersion technique to study dispersion from the LPTR dome and volunteered their assistance and equipment. On June 28, 1971, 225 g of ZnS particles (1.5μ in diameter) were dispersed into the exhaust stream with a Metronics Fluorescent Particle Aerosol generator. These particles were collected by Rotorod samplers located in a downwind pattern as shown in Fig. 9. By counting the scintillations of the ZnS impacted on the samplers when exposed to alpha radiation, the collected mass of ZnS in each sampler could be determined. Since the ZnS particles were uniformly dispersed over a 10-min period, and assuming that they passed the samplers for 10 min, a concentration (in $\mu\text{g}/\text{m}^3$ of air) at each sampling station could be computed. Figure 10 shows the computed concentrations at each sampling station resulting from the experiment and the theoretical concentrations predicted for Type B

Fig. 9. Arrangement of Rotorod samplers in relation to LPTR Building.

atmospheric stability conditions, which, at a wind speed of 4.8 m/sec, were most closely matched during the experiment. The stack height was 13 m.

Based on the results of this experiment, it appears that the diffusion model provides acceptable results at 400 m from the stack for Type B atmospheric conditions. These findings also suggest that the model may be used with confidence for computing average dispersion characteristics because the averaged atmospheric conditions are similar to the test conditions.

Because of the peculiar geometry of the LPTR building, it can be assumed that there will be a point between the stack and the 400-m arc where the model no longer holds due to the turbulent air flow around and over the curved walls and roof. It is hoped that another experiment with higher wind speed can be completed to determine how observed values deviate from the model.

TECHNICAL NOTES

RADIATION PROTECTION

Hydrogen Gas Pressure Dosimeter

We have completed a study of the feasibility of using a gas-evolution dosimeter for measuring high intensity radiation fields. Previous work¹⁴ indicated that both passive and active systems could be used. The passive dosimeter built for testing consisted of about 1.5 g of thin polyethylene film sealed inside an evacuated glass vial, as shown in Fig. 10. Under intense irradiation, the film will release hydrogen gas, with the pressure buildup being approximately proportional to absorbed dose. A dangerous handling problem could arise if the pressures become large, so our first test involved irradiating a dosimeter to destruction in the ⁶⁰Co irradiation facility. A metal sheath (see Fig. 11) surrounded the dosimeter for protection. The dosimeter was removed from the field at intervals to check for damage. Failure occurred at about 2×10^9 rad. Subsequent exposures were kept below this value.

The dosimeters were read by crushing them inside a small sealed cylinder of aluminum (shown in Fig. 11) and observing the resulting pressure. An absorbed dose of 10^7 rad yields a pressure of about 2.5 psi.

Drop tests made on units exposed to about 3×10^7 rad resulted in an explosion which severely shattered the glass and scattered small pieces over a wide area. Because we felt that this handling problem was too severe and outweighed the potential usefulness of the dosimeter, the study was terminated. Further work should be directed toward the active system to alleviate this handling problem.

TLD Multiple Annealing and Background Radiation Study

Thermoluminescence dosimeters (TLD) have been used for personnel dosimetry at LLL since June 1969. The TLD crystals in use are $\text{CaF}_2:\text{Dy}$ (Harshaw TLD 200); natural isotopic abundance LiF (EGG TLD 100); and LiF enriched in ⁷Li (EGG TLD 700).¹⁵ To evaluate the work-related dose to a TLD that has been worn in the field for a given period, the contribution from normal background radiation must be eliminated from the total dose. The method we use is to withhold a number of TLD's of the same type and annealing as those being mailed to personnel in the field to be used as controls. These control TLD's are stored in an area that has been determined to have an average LLL radiation background, and several are irradiated to various known doses. The control and personnel TLD's are then read out at the same time. The control

TLD's therefore acquire approximately the same amount of background radiation as the TLD's worn by personnel, so that the difference in the amount of thermoluminescence (TL) between these two groups of TLD's is the amount of radiation received above background.

Approximately 30 control dosimeters from each group were retained in control status to be used for additional studies. These included an evaluation of radiation over an extended period of time and the effects of multiple annealings on sensitivity. To resolve these two problems five TLD crystals were taken from each type and each month's controls from September 1969 thru June 1971 to read out on the automated gas reader.¹⁶ The thermoluminescence of the three crystal types were plotted as a function of time (months) with the results shown in Table 3.

The ability to measure the rate of thermoluminescence increase per month increases the feasibility of exchanging TLD's annually instead of quarterly, as we are now doing.

A possible change in the sensitivity of TLD crystals after many annealings was investigated as follows. A group of crystals were annealed twice at 400°C for 1-1/2 hr, followed each time by a 40-min cooling period, then given a final annealing at 75°C for 24 hr. (The double annealing at 400°C tends to restore the memory of a TLD crystal to its original state.) After annealing, the TLD crystals were irradiated to 1 R ⁶⁰Co, allowed to decay for several hours, and then read out. The data, which showed all of these TLD crystals to be within $\pm 7\%$ of the average, would indicate that there is no appreciable change in the sensitivity of a thermoluminescent crystal caused by multiple annealings.

These studies were done in collaboration with Professor Ruth I. Yaffe of San Jose State College, who was a participating guest at LLL under the sponsorship of the Associated Western Universities.

Calibration of Tritium Stack Monitor

The accuracy of the tritium stack monitor for the Building 212 Insulated Core Transformer (ICT) target area has been determined as follows. Tritiated water (34 mCi/ml) was introduced into a glove box adjacent to the target area by a variable speed reciprocal syringe pump (see Fig. 12) and vaporized at the rate of 2.05 mCi/min.¹⁷ The gasses were then passed through a high efficiency filter and further diluted to produce a total stack flow of 8.35 m³/min. The gas sample

Fig. 10. Comparison of theoretical concentrations of ZnS particles along arc of sampling stations shown in Fig. 9 for Type B atmospheric stability conditions with experimentally derived values. The deviations in the range below 10^{-7} g/m^3 are in the sensitivity threshold region.

Fig. 11. Hydrogen gas pressure dosimeter test apparatus. Polyethylene film is sealed in vials on right. Bridged shield is shown below, and pressure-measuring chamber with plug is shown on left.

Table 3. Comparison of TLD's^a

TLD type	Units/mo	Gamma exposure (mR/mo)
100	18	3.5
200	830	2.8
700	9.4	3.6

^a TLD 100 data for the months of September 1969 thru February 1970, TLD 700 data for September 1969 thru March 1970, and TLD 200 data for September 1969 were not used due to problems associated with the annealing of TLD's during that time period.

was continuously drawn from the stack through an ion chamber and the ionization current was displayed on a picoammeter.

The results from a 13-min injection period are shown in Fig. 13. Although a steady state was not achieved as desired, the area under the curve could be integrated and compared to the actual amount injected. Assuming a response constant of $1.71 \times 10^{-14} \mu\text{Ci}/\text{m}^3/\text{amp}$ for the ion chamber, the integrated curve yields a total of 24.8 mCi. The actual amount injected was 26.7 mCi. Part of the discrepancy between the two values resulted from tritium absorption in the hood, ductwork and high efficiency filter.

Fig. 12. Block diagram of stack monitor calibration system.

Fig. 13. Response of picoammeter as a function of time for an input of 2.95 mCi/min lasting 13 min.

INSTRUMENTATION DEVELOPMENT

Calculation of NaI(Tl) Detector Efficiency for Point and Disk Radiation Sources

Vegors, Marsden, and Heath¹⁸ have published efficiency calculations for certain NaI(Tl) detector and source sizes. However, because such data is unavailable for other detector and source sizes, we have written a computer program to handle any disk source diameter which is less than or equal to the detector diameter.

For our purposes, detector efficiency is defined as the fraction of gamma rays emitted by the source which interact with the detector. The equations for the point source (Eq. 1) and disk source (Eq. 2) have been developed by Heath¹⁹ and are given here and illustrated in Figs. 14 and 15.

Efficiency calculations have been made for 11-1/2 x 4 in., 8 x 4 in., 2-1/2 x 1/16 in., 2-1/4 x 1/16 in. NaI(Tl) detectors for source-to-detector distances of

$$T(E) = \frac{1}{2} \left\{ \int_0^{\tan^{-1} \left(\frac{r_0}{h_0 + t_0} \right)} \left[1 - e^{-\tau(E) \frac{t_0}{\cos \theta}} \right] \sin \theta \, d\theta \right. \\ \left. + \int_{\tan^{-1} \left(\frac{r_0}{h_0 + t_0} \right)}^{\tan^{-1} \left(\frac{r_0}{h_0} \right)} \left[1 - e^{-\tau(E) \left(\frac{r_0}{\sin \theta} - \frac{h_0}{\cos \theta} \right)} \right] \sin \theta \, d\theta \right\} (1)$$

Fig. 14. Geometry for point source.

from 0.001 to 300 cm. Since the disk source equation is not valid for disk radii less than or equal to the detector radius, only disk radii less than or equal to

$$T(E) = \frac{1}{\pi R^2} \int_0^R x dx \int_{-\pi/2}^{\pi/2} d\phi \left\{ \tan^{-1} \left(\frac{-x \sin \phi + \sqrt{x^2 \sin^2 \phi - (x^2 - r_0^2)}}{h_0 + t_0} \right) \left[1 - e^{-\tau(E) \left(\frac{t_0}{\cos \theta} \right)} \right] \sin \theta d\theta \right. \\ \left. + \int \tan^{-1} \left(\frac{-x \sin \phi + \sqrt{x^2 \sin^2 \phi - (x^2 - r_0^2)}}{h_0} \right) \left[1 - e^{-\tau(E) \left(\frac{-x \sin \phi + \sqrt{x^2 \sin^2 \phi - x^2 - r_0^2}}{\sin \theta} - \frac{h_0}{\cos \theta} \right)} \right] \sin \theta d\theta \right\} \quad (2)$$

Fig. 15. Geometry for extended (disk) source.

the detector radius were considered. Table 4 shows the detector-disk source combinations considered. McMaster²⁰ cross section data was used to calculate cross sections for NaI.

Locating Gas-Block Plugs in Cannon Event Cables

On some previous underground nuclear events, signal cables have apparently provided a path for radioactive gas to reach the surface. To ensure containment during

Table 4. Detector/disk combinations considered

Detector size (in.)	Disk diameters considered (in.)
11 x 4	1,2,5,8
8 x 4	1,2,5,8
2 1/2 x 1/16	1,2
2 1/4 x 1/16	1,2
1/2 x 1/16	1

future events, nondestructive methods must be developed to verify that the cables have effective gas blocks.

We have developed a gamma ray transmission scanning method to locate the rubber gas-block plugs in the foam HELIAX cables to be used for the Cannikin Event. The scanning apparatus consists of a radioactive source, lead shielding with collimation slits, a NaI(Tl) detector, a photomultiplier tube, and

Fig. 16. Cable scanning assembly.

Fig. 17. Block diagram of cable scanning system.

counting electronics. Cable is passed through the collimator at about a 20 ft/min, where the presence of a gas-block plug gives a detectable attenuation of 59.6 keV gammas from ^{241}Am of about 10 to 15%. The scanning assembly is shown in Fig. 16 and a block diagram of the electronics is given in Fig. 17. This scanning system successfully located one plug in each of 47 cables.

Fig. 18. Simplified schematic of battery-powered smoke detector.

FIRE SAFETY

A Multipurpose Battery-Powered Smoke Detector

We have made a simple adaptation of a commercially available ionization-type smoke detector so that it can be operated by battery power. With very low standby battery drain, the unit is adaptable to many uses where ac power is unavailable. Examples are monitoring construction sites, making tests to determine where permanent systems should be installed, or permanent installation in mobile equipment.

Figure 18 shows the essentials of the system, which operates as follows. When smoke or combustion products enter the open chamber, its effective resistance rises, which triggers the gas discharge tube, causing current drawn from the 220-V battery to energize the relay. The relay contacts are used for the desired external load switching. The ionization chamber sensitivity can be varied by changing the diameter of the center electrode in the outer chamber.

The complete unit is packaged in a 4 X 5 X 6-in. chassis with the detector mounted on the side.

The Pressure/Time Profile for a Fire in an Enclosure with an Exhaust Fan

In buildings containing toxic or radioactive materials, it is important to prevent release of such material to the outside environment. Design criteria for these buildings must ensure that there can be no release of hazardous materials during a "maximum credible fire". One of the means of accomplishing this is to maintain a negative pressure inside the building with respect to the outside pressure.

As an aid to designing such systems, we have derived an equation expressing the building pressure as a function of the pressure/time profile in a "maximum credible fire", and have written a computer program to compute the pressure/time profile for various exhaust fan removal rates.

Publications

C. L. Lindeken, D.E. Jones, R.E. McMillen, *Natural Terrestrial Background Variations Between Residences*, Lawrence Livermore Laboratory Rept. UCRL 72964 (1971). Submitted to *Health Physics*.

Approximately 100 $\text{CaF}_2:\text{Dy}$ (TLD-200) dosimeters were placed in the homes of LLL employees as part of a program to determine the magnitude of natural terrestrial background variation. Dwellings were typically wood-frame structures with stucco exteriors. Measurements were made over two 3-month periods during the summer and fall of 1970. Essentially no difference was observed between the two sets of measurements. In both cases, the median dose rates were 9.6 mR per 3-month period; the ranges were from 8 to 19 mR and from 8 to 17 mR for the summer and fall months, respectively. Interior dose rates were, on the average, about 25% lower than those out of doors. Comparison of dose rates within individual homes showed an average summer-to-fall ratio of 0.973. Each dosimeter contained two chips. Average deviation in readings between chip pairs was about 2%.

Dosimeters were used without energy filters. To account for the phosphor's energy dependence below 100 keV, an energy weighted millirad/milliroentgen response factor was calculated. Such a calculation is practicable because the energy distribution within gamma spectra from natural terrestrial sources, particularly in the region of 100 keV and below, has been found to be relatively constant. Using the calculated response factor, dose rates made with unfiltered CaF_2 agree within about 15% with those determined with a 3-in. by 3-in. NaI(Tl) counter. Elimination of the energy filter provides additional sensitivity, as advantage can be taken of the enhanced response of CaF_2 below 100 keV, and simplifies packaging and handling requirements of these measurements.

D.E. Jones, C.L. Lindeken, R.E. McMillen, *Natural Radiation Background Dose Measurements with $\text{CaF}_2:\text{Dy}$ TLD*, Lawrence Livermore Laboratory Rept. UCRL-73432 (1971). This paper was presented at the Third International Conference on Luminescence Dosimetry held at Risø, Denmark, October 11-14, 1971.

Four quarterly and one monthly integrated environmental dose measurements were made with $\text{CaF}_2:\text{Dy}$ TLD's in approximately 100 homes of LLL employees and at selected out-of-doors locations. Another project is a nearly uniform geographic sampling of background dose in the 50 United States.

These data are particularly interesting since they represent simultaneous integrated measurements with uniform geometry. The quarterly data also represent the average seasonal dose rates for specific locations in the Livermore Area. At the median exposure (9.6 mR) from the quarterly home data, the individual values have a standard deviation of $\pm 5\%$. This report summarizes these data and emphasizes the technique and methods for overcoming phosphor limitations.

This technique for natural background dose measurement is reliable and relatively inexpensive. The major accuracy limitation is proper recognition and handling of potential nonrandom errors. These include factors such as fading and energy dependence. The phosphor response to cosmic radiation is under study as a potential source of error in TLD environmental measurements. This study was started when our results were compared with the data from other techniques. The comparison was inconclusive in elucidating the response. Preliminary results are shown for response to cosmic radiation and high energy protons and alpha particles.

P.H. Gudiksen, *The Activity of Tungsten-181 as a Function of Time Within a Nuclear Cratering Cloud*, Lawrence Livermore Laboratory Rept. UCRL-72965 (1971). Submitted to *Health Physics*.

Project Schooner was a nuclear experiment conducted at the U.S. Atomic Energy Commission's Nevada Test Site during December 1968 as part of the Plowshare Program for development of nuclear excavation. The large dust cloud generated by the detonation contained numerous radionuclides, including ^{181}W . Filter samples were collected at elevated levels within the cloud as early as 12 min after cloud formation. Surface air and deposition samples were also obtained, to a distance of 500 km downwind from the detonation point. A numerical model was developed to account for the observed rate of change of ^{181}W concentrations during the first 12 hr after the detonation. The model, for which the 12-min concentrations and particle size distributions are input data, incorporates the effects of atmospheric diffusion in the three spatial dimensions, of gravitational settling of particles within discrete size groups, of distortion of the cloud due to the vertical profile of the horizontal winds, and of the deposition of the particles on the earth's surface. The calculation indicates that the ^{181}W concentration profile of the cloud at 70 min has features similar to those measured, although some of the inhomogeneities are

not accurately reproduced by the model. Calculated concentrations generally agree within a factor of 2 with measured concentrations. The calculation also agrees within a factor of 3 with the ^{181}W activities shown by the samples collected at various elevations between 1 and 4 hr after cloud formation. Likewise, the activities measured by the surface air samplers during cloud passage are with a factor of 3 of those calculated. The surface deposition levels are reproduced to within about a factor of 5 of those measured; this disparity may be due to incomplete knowledge of the fall velocities of the particles. The rate of change of the measured cloud burden of ^{181}W can be reproduced to within 30% by the model.

G.O. Nelson and E.G. Shapiro, *A Field Instrument for Detecting Airborne Halogen Compounds*, Lawrence Livermore Laboratory, Rept. UCRL-73032 (1971). Presented at the American Industrial Hygiene Conference, May 27, 1971, in Toronto, Canada.

A field instrument for continuously measuring the concentration of halogenated compounds has been developed. The principle of operation is based on the spark spectral increase which occurs in the presence of a halogen. The degree of spectral enhancement depends on the concentration of halogenated material present. The instrument can be zeroed in a contaminated atmosphere and has a detection limit of several parts per million for most chlorinated materials. This lightweight (13 lb) ac powered instrument has a 50 millivolt recorder output, a choice of four ranges, and a full scale response time of 3 to 5 sec.

D.S. Myers, J.F. Tinney, P.H. Gudiksen, *Health Physics Aspects of LLL Tritium Release*, Lawrence Livermore Laboratory Rept. UCRL-73098 (1971). Presented at the Tritium Symposium, August 30-September 2, in Las Vegas, Nevada.

On August 6, 1970, 189,000 Ci of tritium gas was accidentally released through an exhaust stack at the Lawrence Livermore Laboratory in Livermore, California. Soon after the release, emergency-response personnel surveyed the site with portable tritium air monitors and an extensive environmental sampling program was initiated. The results of this sampling program indicate that no significant exposure to on- or off-site individuals resulted from the release. All environmental samples of water, milk and urine contained normal background levels of tritium. Although detectable levels of activity were found in some vegetation and atmospheric water vapor samples, the highest measured concentrations as well as the calculated maximum credible ground level air concentrations during cloud passage, were well below the off-site maximum permissible concentrations for

continuous exposure. Since tritium was not present in urine samples above detectable levels, the maximum undetectable dose which could have been received from exposure to the cloud would have been about 0.025 mrem. Based on vegetation sampling results, the maximum dose to a child exposed via the forage-cow-milk pathway would be about 70 mrem.

W.J. Silver, E.G. Shapiro, N.A. Greenhouse, K.M. Scown, *A Tritium Stack Monitor with a Wide Digital Range*, Lawrence Livermore Laboratory Rept. UCRL-73295 (1971).

A stack monitoring system has been developed that gives an immediate indication of the total tritium released during any time period over the range of 1 Ci to 10^7 Ci. The system consists of an air mover, a one-liter ion chamber, a MOSFET current-to-frequency converter, a 7-decade accumulator, a 6-decade scaler-timer, and a printer. The scaler is designed to activate an alarm when activity is released at any time during a 10-min period that exceeds certain preset levels. Each 10 min the scaler prints out and resets, thus providing a continuous record of the release. The accumulator operates in parallel with the scaler and sums activity released until manually reset. The scaler, printer and accumulator are visually displayed at a central control panel. The total system has been calibrated at the lower end by releasing small known quantities of tritium to the stack. The upper range has been checked by exposing the ion chamber to a large radiation source.

W.J. Silver, *Effects of Rain on a Tritium Release*, Lawrence Livermore Laboratory Rept. UCRL-72967 (1971).

The potential effects of rain on tritium released from a high level tritium facility were studied. The specific activity of raindrops falling through an HTO release cloud was calculated for a hypothetical 10,000 Ci release from a 30-meter stack. From this the total activity deposited per unit area was determined and plotted for several distances downwind. The dose received by an individual due to skin wetting was found to be most significant within a few stack heights of the release point. Beyond that, the most significant dose results from direct exposure to the HTO cloud. By far the most important consideration was found to be the potential exposure to individuals living near the site boundary who might be exposed to tritium through the grass-to-cow-to-milk-to-person route. Releases of less than 100 Ci were found to be significant if the release occurred during a rainstorm and dairy cows were grazing as far as 10,000 m downwind from the release. On the basis of this, the potential hazard due to

washout is now analyzed for all operations involving more than certain preset quantities of tritium.

N.A. Greenhouse, R.E. McMillen, G.C. Peterson, *An Evaluation of Radiation Hazards from High Voltage Vacuum Interrupters*, Lawrence Livermore Laboratory Rept. UCRL-72981 (1971).

High voltage vacuum interrupters are electro-mechanical relays frequently used to control dc, ac, and rf currents at potentials up to about 100 kV. With high potential differences impressed across the open electrodes, these devices can become potent x-ray generators. The principal source of x-rays is apparently field-emission of electrons from the cathode. Additional electrons may be produced by ionization of residual gas, and subsequent ion bombardment of the cathode. X-ray fields of the order of tens of R/hr at one meter were produced from interrupters operated within their maximum voltage rating. The production of x-rays is correlated with electrode condition and alignment, gap distance, and envelope pressure.

D.S. Myers, *A Plea for Consistent Lung Burden Criteria for Insoluble Alpha Emitting Isotopes*, Lawrence Livermore Laboratory Rept. UCRL-73354 (1971). Presented at the 11th Hanford Biology Symposium on The Biological Implications of the Transuranium Elements, September 27 to 30, 1971, Battelle-Northwest, Richland, Washington.

There appear to be certain inconsistencies in establishing appropriate lung burdens for certain insoluble alpha emitting isotopes. These inconsistencies are discussed and a plea is made for guidance in establishing consistent lung burden criteria.

The maximum permissible dose to the lungs as defined by existing radiation standards is 15 rem/yr. The figure of 16 nCi is quoted widely in the literature as being the lung burden for insoluble ^{239}Pu . However, the new lung model specifies that 15% of the insoluble ^{239}Pu , which is cleared from the pulmonary region of the lung with a 500-day half-life, is deposited in the pulmonary lymph nodes. The new lung model further specifies that 90% of the insoluble plutonium deposited in the pulmonary lymph nodes remain there permanently.

If one were to consider the pulmonary lymph nodes as the critical organ with a maximum permissible dose rate of 15 rem/yr, then the amount of insoluble ^{239}Pu deposited in the pulmonary region of the lungs during a single inhalation event which will lead to a maximum permissible respiratory lymph node burden is 1.1 nCi. For chronic inhalation situations, the permissible accumulated lung burden after 50 yr which will produce a maximum permissible respiratory lymph

node burden is 0.07 nCi. Thus, unless it is decided that the lymph nodes should not be considered as the critical organ for exposure to insoluble ^{239}Pu because of their apparent relative insensitivity to radiation dose, perhaps the maximum permissible amount of insoluble ^{239}Pu deposited in the lungs should be significantly reduced.

W.E. Ruch, G.O. Nelson, C.L. Lindeken, R.G. Johnson, D.J. Hodgkins, *Respirator Cartridge Efficiency Studies: I. Experimental Design*, Lawrence Livermore Laboratory Rept. UCRL-73166 (1971).

This is the first in a series of papers dealing with the determination of the service life of respirator cartridges in atmospheres containing organic vapors. A testing facility to produce test atmospheres of known composition has been built. The cartridges are placed in a specially designed and constructed holder; and breakthrough times are determined by measuring the upstream and downstream concentrations, using dual flame ionization detectors. The breakthrough characteristics can be ascertained by using either a steady-state condition or a cycling flow produced by a breath simulator. A standard cartridge has been designed to evaluate system performance and to periodically check the system for reproducibility. Parameters to be studied include the effects of organic compounds, concentration, work rate, temperature, and relative humidity on cartridge efficiency.

R.E. Johnsen, C.L. Lindeken, R.D. Taylor, *Respirator Cartridge Efficiency Studies: III. Development of a Mechanical Breathing Machine to Simulate Human Respiration*, Lawrence Livermore Laboratory Rept. UCRL-51072 (1971).

A mechanical breathing machine has been developed to simulate the human breathing cycle. This machine has a variable speed and torque control that can simulate five human breathing patterns: sedentary, 208, 415, 622, and 830 kg-m/min. These patterns are produced by the stroke action of twin pistons controlled by replaceable cams, each machined for one of the five work rates. Calibration was performed using a 1-psi pressure transducer for the amplitude (maximum flow rate during the inspiration phase) and period (length in seconds of this phase) and a 5-ft³ spirometer for the minute volume. Values obtained for amplitude, period, and minute volume correspond closely to those outlined in the Respiratory Protective Devices Manual. Data obtained with this machine can provide the reciprocating flow patterns required for the testing of respirator cartridges.

D.E. Jones, K.F. Petrock, B.G. Samardzich, E.G. Shapiro, *The LLL Badge for Personnel Monitoring*,

Lawrence Livermore Laboratory Rept UCRL-73084 (1971). This paper was submitted to *Nuclear Instruments and Methods*.

A complete system for personnel dosimetry with thermoluminescent dosimeters (TLD) is described. Unique hardware, badge exchange, computerized record system, self-checking features, TLD specifications, dynamic operating range, and a fitted nuclear accident dosimeter (NAD) package are discussed. The personnel dosimetry badge contains either two or three 1/8-in.-square TLD chips, depending upon the exposure probability of the wearer. LiF (natural isotopic abundance lithium) and CaF:Dy phosphors are used in all badges, with ^7Li -enriched LiF phosphor added for the high-exposure-probability employees. The badge is small (1-3/8 in. in diameter X 1/8 in. thick) and extremely rugged, and it contains a permanent identification number that can currently accommodate 1.6 million badges. Unique items designed for the system include an automatic badge reader and a semiautomatic encoding punch. The automatic hot-nitrogen-gas reader cycles three badges per minute, with all data output on computer cards. The badge encoding punch is automatically set for punching by typing the identification onto the plastic badge.

B.L. Rich and B.G. Samardzich, *Organizational Aspects of a Personnel Dosimetry Service*, Lawrence Livermore Laboratory Rept. UCRL-73254 (1971). This paper was presented at the 16th Annual Health Physics Society Meeting in New York, N.Y., July 11 to 15, 1971.

This paper discusses some practical application aspects of personnel dosimetry. Points made are: (1) The ultimate dosimeter does not exist. TLD appears to be the current best choice for most applications. (2) It is improbable that any one dosimeter will serve all needs equally well. Several dosimeter systems throughout the industry seem unavoidable. (3) An intercalibration organization should be established to foster improved accuracy in calibration and processing. Participation should be voluntary. (4) Commercial services are valuable to smaller contractors but larger services benefit economically and from a convenience standpoint by providing the service "in house." (5) Certain low risk groups should be placed on an annual or semi-annual frequency for convenience, sensitivity and economy. Certain difficulties in background determination, fading, etc., should be evaluated for each application. (6) Results from any current personnel dosimeter should be treated as a piece of data rather than the final answer, particularly in significant exposures. Professional investigation and evaluations must be made. (7) Automation reaches an

equilibrium point. At some point further automation is not justified from an economy standpoint. (8) Personnel dosimeter change by in-plant mail is recommended. (9) Much improvement is necessary in record keeping to provide ready access to details required in statistical studies and various types of required reports. Treatment of internal dosimetry data should also be improved and standardized where feasible.

J.V. Boggs, *Personnel Neutron Dosimetry LLL Effort*, Lawrence Livermore Laboratory Rept. UCRL-73331, Summary. This paper was presented at the 2nd Workshop on Personnel Neutron Dosimetry, July 8-9, 1971, at Richland, Washington, and is included in the workshop proceedings.

This paper is an overall description of LLL personnel dosimetry.

J. F. Tinney, *In-Vivo X-Ray Fluorescence Analysis-Concepts and Equipment*, Lawrence Livermore Laboratory Rept. UCRL-72962 (1971). This paper was presented at the Symposium on The Role of Semi-Conductor Detectors in the Future of Nuclear Medicine conducted by the Argonne Cancer Research Hospital and the Society of Nuclear Medicine at Chicago, Illinois, February 12, 13, 1971. It has been included in the proceedings of this meeting.

R. Gunnink and J.F. Tinney, *Analysis of Fuel Rods by Gamma-Ray Spectroscopy*, Lawrence Livermore Laboratory Rept. UCRL-51086 (1971).

We have studied the effectiveness of gamma-ray spectrometry in measuring the fissile content and isotopic abundances of nuclear fuel rods, using Ge(Li) and NaI(Tl) detectors. The Ge(Li) results showed that analyses accurate to within a few percent can be achieved for ^{239}Pu , ^{241}Pu , and ^{241}Am , and to within $\pm 5\%$ for ^{240}Pu . Simulation studies involving the analysis of NaI(Tl) spectra indicate that under proper conditions, precisions of 1-2% for ^{235}U , ^{239}Pu , ^{241}Pu , and ^{241}Am are possible.

We gave particular attention to the study of gamma-ray interferences and their influence on the precision of the analyses.

J.L. Cate and T.O. Hoeger, *A Monitoring System for Sewage Effluent*, Lawrence Livermore Laboratory Rept. UCRL-73299 (1971). This paper was submitted to American Industrial Hygiene Association Journal.

An automatic, on-line monitoring system for the sanitary sewage effluent from the Lawrence Livermore Laboratory has been constructed. It can detect, at levels lower than AEC guidelines, all radioisotopes in

use at the Laboratory and it monitors pH continuously. It is wired into a central alarm system that alerts personnel on a 24-hr basis. A year's operating experience is summarized, and plans for an improved system are discussed.

J.L. Cate, Jr., *Determination of Lead in Air Sample Filters for X-Ray Fluorescence Analysis*, Lawrence Livermore Laboratory Rept. UCRL-51038 (1971).

In recent months, great interest has been shown in the measurement of lead and lead compounds in the environment. One area of particular interest is the measurement of lead in the atmosphere; it is present in the exhaust from internal combustion engines burning leaded fuel, and hence is ubiquitous in urban areas. The determination, by conventional means, of particulate lead in air samples collected on filter media is tedious and expensive. Our experience in the use of isotope-excited, energy-dispersive, x-ray fluorescence analysis suggested that this technique might provide a quicker, less expensive and non-destructive determination of lead on filter media.

J.R. Gaskill, C.A. Harder, G.O. Nelson, *Engineering Fire Suppression Systems for Large Volumes Using Halon 1301*, Lawrence Livermore Laboratory Rept. UCRL-73083. This paper was presented at the

Symposium on Safety in Plutonium Handling Facilities, Dow Chemical Co., Rocky Flats Division, Golden, Colorado, April 13-16, 1971.

Engineering studies of Halon 1301 fire-suppression systems for large volumes (up to 10,000 cu ft) are summarized and the results are presented. Guidelines are given for designing such a system, with particular attention paid to fire detectors, alarms and controls, and the Halon distribution arrangement.

J.R. Gaskill, C.A. Harder, G.O. Nelson, *Engineering Tests of Halon 1301 Fire Extinguishing Systems for Field Assembly Buildings*, Lawrence Livermore Laboratory Rept. UCRL-51021 (1971).

Field tests were conducted on the response time of ionization and heat sensors to smoky and flaming fires as a function of detection location. Other tests were made on the spatial distribution of a mock halogenated extinguishing agent as a function of discharge location and orientation. Information derived from these tests was combined in fire extinguishing tests using trifluorobromomethane (Halon 1301) to yield useful data in the design of real total flooding systems.

By-products of this work include the successful use of an effective, less expensive agent discharge valve and a rapid, accurate means of measuring agent concentration.

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