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Foreword

This report, which covers the period October 1980-September 1981, 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 may contact the authors of the reports.

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Progress Reports

INDUSTRIAL HYGIENE

The Performance and Evaluation of Charcoal Adsorbers

P. M. Swearengen, J. S. Johnson, and C. A. Harder

Charcoal adsorbers are used extensively in air-cleaning systems for removal of toxic/carcinogenic gases and vapors. Such adsorbers are presently in use within several fume hood and glove box systems at LLNL's Chemistry and Biomedical facilities. A current project of the Safety Science Group is to establish a test procedure that will provide an in-place field test for measurement of charcoal-adsorber service life (residual adsorption capacity, RAC). The experimental design of this project is twofold. First, a parallel sampling system utilizing removable miniature charcoal cartridges has been designed and will be installed on an existing HEPA filter/charcoal adsorber unit located on an organic synthesis fume hood. Second, a series of laboratory experiments will be performed to measure charcoal-adsorber performance under controlled conditions. Laboratory tests will then be conducted on the miniature charcoal cartridges placed in service previously. It is believed that this approach will provide a realistic body of data from both simulated and real conditions to establish the basis for subsequent in-place field testing.

Theory

It has been shown previously that charcoal adsorbers can be treated as chromatographic columns, similar to the methodology of gas-solid chromatography.^{1,2} By control of the number of active sites remaining on a known mass of charcoal, a measurement can be made of the RAC of the adsorber bed. A small sample of a weakly adsorbed gas is pulsed as a square wave into the gas stream that flows across the adsorber. The effluent pulse is detected by an appropriate detector and the RAC is related to the chromatographic retention time (R.T.) of the gas. As available adsorption sites are irreversibly covered by an appropriate heavy adsorber, the retention time of the pulse gas decreases correspondingly. When the time of the pulse gas over a fresh bed of charcoal is available, a measurement can be made of the remaining effective adsorber capacity as a proportion of the original. Other parameters from chromatography can provide additional insight into the condition of the bed, including the shape of the effluent pulse peak and the nature and quantity of response shown toward the pulse gas chosen for testing.

Experiment

A schematic diagram of the in-place sampling manifold is shown in Fig. 1. An array of six removable cartridges will be installed in parallel to an existing adsorber bed. The cartridges have been designed with a capacity to vary the depth of the charcoal bed as well as to adjust the flow pattern in front of the adsorber to assure uniform presentation to the bed. A cartridge can be removed or replaced without interruption of the main system flow. Finally, the flow velocity across the cartridge beds can be controlled to ensure conditions as nearly identical to the main adsorber as possible. Upon removal of a cartridge after known sampling intervals the device is easily transported to the laboratory for subsequent experimentation. These experiments will provide an avenue to study changes in adsorber carbon without disturbing the main bed.

In-Place Field Test Procedure

It is believed that an in-place field test procedure can be devised using a pulse gas and a gas chromatographic or infrared detector system.

Figure 1. In-place sampling manifold with six removable cartridges.

Choice of gas would control the choice of detection system, but presentation of a known quantity of vapor and detection of the downstream pulse should be straightforward as in similar routine industrial hygiene field operations. Time of arrival of the detected pulse can be related to a retention time and results compared with those obtained when the bed was fresh. A schematic of this approach is shown in Fig. 2.

Laboratory Test Apparatus

A schematic diagram of the laboratory test apparatus is shown in Fig. 3. Experimentation will try to determine the most useful test gas, the results obtained with a variety of commercial carbons, and the appropriate detection system as well as its sensitivity to the test gas.

Figure 2. Field test system.

Conclusion

A plan for the systematic evaluation of charcoal adsorbers has been presented. The techniques proposed include combining methods from the scientific literature, methods from current industrial hygiene practice and some experimental approaches unique to the Safety Science Group. Preliminary laboratory results have suggested results similar to those previously^{1,2} reported. In this case, carbon equilibrated with 50% relative humidity air showed a shorter retention time for a

test gas than did fresh dry carbon. Further work as outlined here will be required to confirm conclusions similar to those obtained in other laboratories and to reduce the test format to a useful and convenient field test procedure.

References

1. W. F. Klading, A. H. Weiss, and L. A. Jonas, *Carbon* 18, 31 (1980).
2. A. H. Weiss, T. Freund, and E. Biron, *Chem. Eng.* 4, 213 (1980).

Figure 3. Laboratory test system.

Asbestos Ceiling Insulation: Evaluation of Dust Levels and Control Alternatives

C. A. Harder and G. J. Schweickert

Although the concern about asbestos-related health hazards is not new, there has been recent media attention on the possible risks from sprayed-on insulation in schools and office buildings. Previously focus had been on workers in the occupationally exposed trades—plumbers, insulators, and construction workers. The inclusion of office workers and school-age children within the category of individuals at risk has created a great deal of concern on their part.

At LLNL asbestos was used as pipe insulation in the older barracks-type buildings and is gradually being replaced whenever mechanical work is done on these systems. It is also found in one older building (Bldg. 131), where asbestos was used as a sprayed form of insulation. Over the past 10 years Hazards Control has monitored the condition of this insulation to determine if there is any risk to building occupants and, if so, what actions would be necessary to protect their health. This article summarizes the activities and conclusions of our current investigation.

Introduction

Workplace exposures in the trades and crafts can lead to asbestosis and lung cancer, given sufficiently high asbestos levels and length of exposure. Since the finding of mesothelioma (a rare cancer of the chest cavity) following somewhat lower asbestos exposures, there is now some worry that a slight or incidental exposure to low levels may initiate tumor development. Asbestosis, a noncancerous lung disease, is clearly related to high dust levels and is not believed to be a possibility when even moderate controls are used. There is currently no certainty about what concentration of asbestos fibers is not going to induce cancer; most likely, a safe threshold will be found.

Analysis of Airborne Asbestos Levels

The original installation specifications of this insulation (see Fig. 1) called for application of a tacky latex rubber primer, sprayed insulation, and an overspray of adhesive or paint to seal in loose dust or fibers. Analysis of material samples removed from the intact ceiling indicates the following composition:

chrysotile asbestos	30-40%
mineral wool	40-50%
cellulose	5-10%
binder (aliphatic acetate)	0.1%

Differential thermal analysis has shown the binder to become runny at 150°C.

Air samples are collected routinely to evaluate the concentration of asbestos fibers that may have been loosened by construction or maintenance operations, water, or physical damage (Fig. 2), or aging of the binder. Results of monitoring since 1978 are in Table 1. Except for a single instance when the entire ceiling coating in one area was scraped off, all recorded levels are just above the limits of sensitivity for the analytical methods employed.

Figure 1. Closeup of ceiling coated with asbestos-bearing insulation.

Figure 2. Section of insulation lost following water damage.

Since asbestos is naturally present in Northern California soil and becomes airborne through farming, excavating, construction, etc., and is released from brake shoes and other manufactured products, it was apparent that outdoor levels should also be monitored for comparison. On six occasions over the past 12 months, we took background samples at both indoor and outdoor locations. These results are given in Table 2. Variations in these values are not significant due to the small sample size so far, and the limitations of analytical reproducibility at these low levels.

Alternatives for Dust Control

Our investigation of approaches to control asbestos exposure from ceiling insulation has led to the following options:

1. Leave material in place.
2. Install false ceilings.
3. Encapsulate surfaces with a sealant.
4. Remove all insulation.

Table 2. Comparison of indoor and outdoor airborne asbestos concentrations (fibers/cm³) on 6 days in 1981.

Day	Indoors	Outdoors
1	0.002	0.0, 0.033
2	0.0	0.0, 0.004
3	0.005	0.003
4	0.06	0.07 ^a
5	0.045	0.004 ^a
6	0.057	0.052 ^a

^aNew analytical method. Results do not correlate exactly with other table values and are for comparison only.

The first approach presents no apparent technical difficulties. The second will not prevent dust fall, but it may contain debris and reduce potential exposure somewhat. There will be some hazard to maintenance and housekeeping staff when ceiling panels are removed. Air sampling in rooms with false ceilings shows the same amounts of airborne asbestos as in rooms with asbestos insulation and no false ceilings.

Penetrating sealants specifically designed to encapsulate this type of asbestos insulation are commercially available from several sources. The material is applied using airless spray equipment. As a trial, one room was so treated in April 1980 with an epoxy system. Observations were made during the two-step process and no advantages were found over using a good latex paint, especially since the epoxy system is much more expensive. Since then there has been no detectable change in asbestos levels in that room; it will continue to be observed.

The asbestos-containing ceiling coating of the existing building can be removed by wet or dry methods. The dry method can be accomplished in one of two ways, either by hand with putty knives, or by using a mechanical descaler or sur-

Table 1. Results of monitoring airborne asbestos, 1978-1981.

Condition	Concentration (fibers/cm ³)	No. of samples
Normal background	0.00	24
	0.01-0.04	21
Construction activity:		
1. Ceiling contact or penetration	0.00-0.04	6
	0.05-0.5	14
2. Ceiling removal	1.61-5.11	6
DOE and OSHA permissible exposure level	2.0	

face cleaning tool. The mechanical method presents three major problems. The first is weight. No matter what mechanical tool is used, someone will be holding between 10 and 30 lb overhead.

The second is exhaust air (15-50 cfm) from the operation of the pneumatic tool. This exhaust air will add to the airborne level of asbestos unless specially treated.

The third is local exhaust and HEPA filtration. Any mechanical tool will scatter or suspend asbestos-containing debris/fibers around the room unless some sort of local exhaust system is used. The collector plus exhaust hose (4 to 6 in. in diameter) will add additional weight and immobility to the removal device which must be held overhead. These problems, we feel, make the application of a mechanical removal device impractical.

The wet method of removing asbestos was tried using water hoses and hand scrapers. This method resulted in a tremendous cleanup job along with a real problem of disposing of the wet asbestos debris. Another wet method may be the use of dry steam to loosen the binder. However, the cost of equipment rental or purchase and need to train operators may make this alternative impractical.

An additional alternative is to remove the asbestos ceiling material with a hand-held scraper, allowing the loose material to drop into a hopper situated just below the ceiling (Fig. 3). The hopper would be equipped with a large tube which would end over a 55-gal drum. A plastic bag would be inserted into the drum and taped around the tube. When the bag is full it would be removed, sealed and disposed of. The hopper/drum unit can be mounted on casters so that it will be mobile. A scaffold can be set up at the proper working height to match the width or length of the room so that the worker(s) can clean a swath 14 to 18 in. by rolling the hopper/drum assembly beside the scaffold. This approach will require worker(s) to be equipped with personnel protective equipment, and some local exhaust may have to be added to the mobile collector.

Conclusion

The present intact asbestos-bearing ceiling matrix has shown no signs of gross failure due to binder aging. No one is routinely exposed to additional asbestos as a result of working in Bldg. 131. At this point the benefits of encapsulating or re-

moving the entire ceiling coating are questionable. In particular, removal operations produce bonafide exposures to the workers performing the task, and reportedly leave lingering fiber concentrations above those that existed previously. The residual contamination is attributed to dust generation during rip-out, less-than-perfect removal from the supporting substrate, and incomplete clean-up from all surfaces. Subsequent activities liberate free fibers that are no longer bound to a firm surface. In essence, it is probably far less risky to leave the material in place than to attempt its removal.

In the meantime, partial removal might be justified following extensive damage from water spills or construction and in the special case when the space above a false ceiling will be used as an air plenum.

Encapsulation is probably the best control method available at this time. In conversations

Figure 3. Hopper/collector for removal of ceiling insulation.

with representatives of Johns-Manville and the EPA, we found that they recommend this approach for installations such as ours. Repair of damaged areas would be another excellent application of this method.

If the Industrial Hygiene field air sampling program indicates a significant increase in background levels, corrective action will be initiated.

To be prepared for that event, we are continuing our investigation into appropriate control techniques. Some methods have been subjected to field evaluation, e.g., wet removal and encapsulation. Others, such as use of the hopper collection system or dry steam, will be tested in the future through a cooperative effort with the facility management.

Testing the Performance of Laminar-Flow Hoods

D. Shishido and G. J. Schweickert

Laminar-flow hoods are used extensively in the life sciences, electronics engineering, and other pursuits where cleanliness is paramount. Those used in the life sciences have established performance/safety standards; those used in the electronics manufacturing industry do not. Yet personnel and product protection are mandatory, for example, in fabricating microelectronic circuits—because of potentially hazardous chemicals and the need for absolute cleanliness. Using published methods, we tested various hoods to encourage establishment of a standard test so that users will understand the level of protection that this equipment provides.

Introduction

Laminar-flow hoods are designed to supplement or complement conventional contamination-control measures. They are available as vertical-flow hoods, horizontal-flow hoods, and containment cabinets with various modifications of either. The objectives of these hoods are to protect personnel (workers), products (work), or both.

Performance standards for the hoods used in the life sciences ("Biological Safety Cabinets") have been developed by the National Cancer Institute and the National Sanitation Foundation,* but there is no such consensus in the electronics manufacturing industry. Although they assured product protection, manufacturers of such hoods were often vague about industry standards concerning personnel protection against chemical hazards. We therefore tested eight laminar-flow hoods in place at LLNL.

Test Procedure

We tested the hoods in the "as used" condition. Hood conditions (equipment, etc.) and room ventilation were not altered, and activities in adjacent hoods were conducted at normal levels. First the hood was checked for gross malfunction with a titanium tetrachloride smoke tube, and the velocity at the hood face was measured with a velometer. If no gross malfunction was detected, the test continued as follows.

*For example, NSF Standard 49 for Class II Laminar-Flow Cabinets.

An infrared spectrophotometer calibrated for the tracer gas to be used (commercial-grade dichlorodifluoromethane) was set up along with a chart recorder. We used a gas ejector described by Caplan and Knutson;¹ the tracer gas is piped to the ejector, passes through a critical orifice, mixes with air in the ejector tube, and diffuses through a wire mesh. Flow rate through the ejector is determined by the upstream pressure and the size of the orifice. We used a 0.064-mm orifice to give a nominal flow rate of 4 liters/min.

The gas ejector was then placed in the hood at the appropriate test position. (Each hood was tested with the ejector in at least six positions, depending on its size; see Fig. 1.) A life-size mannequin was placed sitting in front of the hood to simulate a lab worker, with the sampling probe attached to its face (Figs. 2 and 3). Depending on space restrictions, the mannequin's face was 250–300 mm from the hood face and the probe was 200–250 mm from the hood face; the height of the probe was 1400–1500 mm from the floor.

We then released the tracer gas and recorded the detector readings for a minimum of 7 min, recording every 15 s after the first minute.

Test Results

We converted the absorbance values to actual concentrations of tracer gas and averaged these concentrations for each ejector position. The performance rating of the hood is the average value obtained for the test position that showed the highest concentration (leakage) of gas. We report these in the terminology proposed by Caplan and

Position A is 200 mm from front of hood
Position B is 400 mm from front of hood

Figure 1. Positions in which the gas ejector was placed for testing each hood.

Knutson,¹ xx AU yy, where xx equals the gas-release rate in liters per minute, AU means that hood conditions were tested "as used," and yy equals the concentration at the detector probe in parts per million. Table 1 summarizes the results.

Hoods 1, 2, and 3 were in the same room, from the same manufacturer, and of similar design. The room had sufficient make-up air, and

room pressure was positive relative to adjacent rooms. The performance ratings of these hoods were 4.2 AU 13.8, 4.2 AU 23, and 4.2 AU 15, respectively. The worst-performing hood, Hood 2, was also the most crowded with equipment and instruments.

Hood 4 was from the same manufacturer but of different design, and was located in another room. Its performance rating was 4.2 AU 530 at the center position (2A). Space did not permit placing the ejector at positions 1A and 3A.

Hood 5 was from a second manufacturer and was in the same room as Hood 4. Its performance rating was 4.2 AU 8.1 at position 3A.

Hood 6, in an adjoining room, was from a third manufacturer. The room pressure was negative relative to the two rooms containing Hoods 1-5. This hood was quite large, so another ejector position, position 4, was added. The section of the hood that encompassed position 4 is not normally used for chemical handling. The performance rating was 4.2 AU 11.9 at position 4B.

Hoods 7 and 8, of similar design, were from a fourth manufacturer and were located in different buildings. The preliminary check with a smoke tube indicated that these hoods had gross malfunctions (smoke spilled out of the hood). However, we included them in the tests for comparison purposes. Their performance ratings were 4.2 AU 784 and 4.2 AU 892.

Figure 2. Mannequin assuming normal work posture at hood, with gas ejector in position.

Table 1. Results of testing eight laminar-flow hoods.

Hood	Open area (m × m)	Face velocity (m/s)	Position of gas ejector	Gas concentration at probe (ppm)	Performance rating (xx AU yy)
1	1.84 × 0.34	0.20	1A	13.8	4.2 AU 13.8
			B	0.5	
			2A	0.6	
			B	0.5	
			3A	0.5	
			B	1.4	
2	1.82 × 0.50	0.20	1A	a	4.2 AU 23
			B	a	
			2A	23	
			B	3.8	
			3A	a	
			B	a	
3	1.54 × 0.34	0.20	1A	15	4.2 AU 15
			B	2.4	
			2A	3.3	
			B	1.1	
			3A	0.3	
			B	0.5	
4	1.35 × 0.42	0.30 ^c	1A	a	4.2 AU 530
			B	a	
			2A	530	
			B	361	
			3A	a	
			B	a	
5	1.70 × 0.40	0.20	1A	7.4	4.2 AU 8.1
			B	a	
			2A	4.8	
			B	4.4	
			3A	8.1	
			B	a	
6	2.35 × 0.50	0.20	1A	0.5	4.2 AU 11.9
			B	0.5	
			2A	0.5	
			B	0.5	
			3A	5.0	
			B	0.5	
			4A ^b	a	
			B ^b	11.9	
7	2.40 × 1.80	c	1A	541	4.2 AU 784
			B	a	
			2A	a	
			B	421	
			3A	784	
			B	a	
8	2.40 × 0.60	0.15	1A	61	4.2 AU 892
			B	29	
			2A	392	
			B	138	
			3A	892	
			B	587	

^aNo space for ejector.

^bThis section of hood is not normally used.

^cNo apparent face velocity.

Figure 3. The experimental setup, showing the mannequin's face in the plane of the hood and the gas analyzer on the right.

Discussion

Many variables must be considered in evaluating hood or ventilation-system performance; they include room air balance and distribution, location of equipment or fixtures inside or outside the hood, and proper installation of fans, ducts, air cleaners, etc. Evaluation of laminar-flow cabinets is more difficult than that of conventional fume hoods, because of their pattern of air flow and recirculation, internal filters, and minimal face velocity (which, in some cases, is designed to be positive to the room).

So far, we have identified four items that affect performance:

1. Hood control effectiveness is spatially variable. Almost invariably, leakage was greatest at either position 1A or 3A, the outermost sections (edges) of a hood.
2. Unlike conventional exhaust hoods, leakage does not increase with increasing open face area of laminar-flow hoods.
3. Using a hood as lab storage space or simply overloading it with equipment or instruments may hamper its air-contaminant-control characteristics. For example, the performance rating for Hood 2 may have been much worse if there had

been sufficient space in the hood to allow for testing at hood edges.

4. The face velocity of a hood did not seem to significantly affect its performance rating. However, since the face velocities of these hoods are almost imperceptible, it is difficult to measure them.

These findings are preliminary; further study is needed to understand how factors such as crossdrafts, worker activity, and downward flow velocity affect the safety of using these units for high-hazard operations.

Acknowledgment

This project is an adoption of the ideas and methods employed by Dr. Gerhart W. Knutson and Knowlton J. Caplan for a proposed performance testing standard for laboratory fume hoods. We are grateful to them for their assistance.

Reference

1. K. J. Caplan and G. W. Knutson, "Laboratory Fume Hoods: A Performance Test," *ASHRAE Transactions* 78:3, No. 1, Part 1 (1978).

Computerized Small-Scale Air Filter Test Facility

A. H. Biermann

A unique air filter test facility built at LLNL is being used for conducting filter research and development. The unique features of this facility include a fully computerized diagnostic system and filter test apparatus that can evaluate a wide range of filters ranging from small hand sheets and filter units to full-scale commercial units. Filter experiments that used to take a day, without computer interfacing and data reduction, can now be done within minutes.

Introduction

The collection efficiency of air filters depends on many variables, including particle size, air velocity, packing fraction, fiber size, and fiber and particle charge. Because of the many parameters involved, it is very advantageous in filter evaluations to have a computerized system to aid both in data acquisition and reduction and in data storage. Our system relies on an electrical aerosol analyzer and an optical particle analyzer as the major components for analyzing size distributions and concentration. We have interfaced these particle analyzers, with other diagnostic instrumentation, to an LSI-11/23 computer to determine filter efficiency as a function of particle size.

Aerosol System

The small-scale facility contains two air-flow systems which can accommodate 203-mm-diameter filters for testing. The major components of each system are an aerosol generator, a valving system, a test duct and filter assembly, diagnostic instrumentation, and a variable-speed blower. A schematic of the air-flow system and instrumentation is illustrated in Fig. 1. Typically, we atomize a 1% sodium chloride solution to produce a hetero-disperse aerosol having aerodynamic mass median diameter of $0.8\text{ }\mu\text{m}$ with a geometric standard deviation of 2.

After generation, the aerosol passes through a valving system where dilution air is introduced or part of the aerosol can be drawn away. Also, the aerosol may be passed through charge neutralizers or electrostatic precipitators if a more neutral aerosol is desired. The aerosol then enters an aluminum duct, passes through the filter undergoing

testing and is exhausted by a variable-speed blower. Flow rates of 14 to 2550 liters/min can be obtained in any test, corresponding to velocities at the filter face of 0.83 to 149 cm/s.

To measure the filter collection efficiency, we use a Climet 208 particle analyzer, a Thermo Systems Model 3030 electrical aerosol analyzer (EAA), and a Phoenix Precision Instrument Model JM-7000 aerosol photometer. The Climet particle analyzer measures particle size and concentration in the $0.3\text{-}\mu\text{m}$ to $10\text{-}\mu\text{m}$ diameter range by forward light-scattering from single particles. The EAA sizes aerosol particles according to their electric mobility in the $0.003\text{-}\mu\text{m}$ to $1.0\text{-}\mu\text{m}$ size range. These instruments are used to sample both upstream and downstream of the filter undergoing testing so that the efficiency as a function of particle size can be calculated. The photometer produces an integrated light-scattering intensity from all aerosol particles and quickly indicates an overall filter performance. In addition to particle size and concentration measurements, we measure the total volumetric flow rate through the filter with a Datametric Model 770-9628 mass flow meter and the pressure drop across the filter with a Barocel Model 1174 electronic manometer. Temperature and relative humidity are also monitored.

Computer System Hardware

The LSI-11/23 computer has 128K core and uses the Digital Equipment Corporation (DEC) RSX-11M operating system. This system has multi-user and multi-task capabilities and can accept the simultaneous operation of both air-flow systems. The LSI-11/23 is supported by many peripheral devices as shown in Fig. 2. These include two Western Dynex XL 250-10 hard disks having a

Figure 1. Schematic of the air-flow system and instrumentation.

Figure 2. LSI-11/23 computer system.

combined storage capacity of 20 megabytes and a Thinker Toy TT800R-PSC floppy disk having 500K bytes. Other peripherals include two Tektronix 4025 graphic display terminals with 32K graphic and 32K display memory, a Tektronix 4631 hard copy unit, a Silent 700 keyboard terminal, and a Versatec Model 1100AL line printer.

Also shown in Fig. 2 is one set of the diagnostic instrumentation which has been interfaced to the LSI-11. The three instruments available for aerosol measurements are interfaced to the computer in various ways depending on their type of output. The Climet output, consisting of pulses which are proportional to particle size, is sent via a Nuclear Data PSA log amplifier to a Davidson model 1056C pulse height analyzer. Processing the log of the scattered light pulses before pulse height analysis is advantageous because only 128 channels are required to store the size distribution from 0.3- μm to 10- μm diameter while still maintaining adequate size resolution. The computer is able to control the start of pulse accumulation, the stop of accumulation, and the start of data output through the use of a DRV11 parallel I/O card. Data out includes counts in each of 128 channels and is read by the computer via a DLV11 serial I/O card at a baud rate of 9600.

The EAA data output is in the form of an analog signal and a pulse indicating the appropriate time to take an electrometer current reading. The analog signal is read through an ADAC Corporation Model 1012 16-channel analog/digital converter. In addition, three control signals are provided: (1 and 2) a signal reset and start sent to the EAA by the computer when it is time to initialize the EAA cycle, and (3) a signal from the EAA to the computer indicating the time to read the analog signal. These control signals are handled through the DRV11 parallel I/O card.

The third aerosol instrument provided is the aerosol photometer. This device has an analog signal for output. The signal is amplified and sent to the computer via the A/D converter. No control signals are required for this device.

Computer System Software

A FORTRAN program code has been developed to allow the experimenter to accumulate, process, save, and plot size-distribution and filter-penetration data. Besides rapid data analysis and plotting, other key features include reduction of the EAA data by the Twomey methods, and the combination of the EAA and Climet particle-size distributions in their region of overlap (0.3-

1.0 μm). Program output includes prompts to the experimenter, status messages to the experimenter, hard copy plots, disk file data storage, and raw and reduced data listing on the line printer. Two examples of graphical output are shown. Figure 3 illustrates the nuclear concentration (number/ cm^3) and distribution for both upstream and downstream of a test filter. Figure 4 shows the resulting filter penetration as a function of particle size.

Conclusion

The principal advantages of the system are the ease, reliability, and speed of data collection, reduction, and comparison (between experiment and experiment and between experiment and theory). Also, the RSX-11M operating system allows many of these tasks to be accomplished simultaneously. The many parameters that govern filter performance, such as fiber size, packing fraction, and flow rate, can more easily be varied and studied over a wide particle-size range.

Figure 3. Upstream (solid line) and downstream (dotted line) distribution of the salt aerosol.

Figure 4. Penetration vs particle size for AF-18 filter media.

INSTRUMENT DEVELOPMENT

Neutron Spectrometry Developments: Detector Improvements and Characterization

J. H. Thorngate and D. W. Rueppel

For the past ten years there has been an active program in the Hazards Control Department to develop neutron spectrometry techniques for application to radiation protection problems.¹⁻¹⁰ The duration of this program indicates two things: (1) the difficulty of the problem and (2) a continuing recognition of the need for neutron spectrometry. Since our last report on the progress in this program we have spent considerable effort on (1) optimizing the design of existing detectors and (2) carefully measuring their response to gamma rays and neutrons of known energies.

Spectra have several uses in radiation protection. Doses can be calculated directly from measured spectra, but the data obtained from spectrometers are probably more useful for evaluating the data obtained from other dosimeters. Shielding calculations also rely on a knowledge of the neutron spectra.

A program such as this usually begins with the assumption that sufficient data exist in the literature to set up a system and to reduce the data. The problems with existing data and the limits of applying it to a specific application become apparent later. We are now in a phase of the program that requires us to reexamine the basic parameters of our detectors.

Detector Optimization

The organic liquid scintillator NE213 (manufactured by Nuclear Enterprises, Inc.) is widely used to measure the spectrum of neutrons with energies between 1 and 20 MeV. Both less and more energetic neutrons can be measured with these detectors but only if considerable care is taken with the measurements and the data reduction. A parameter important at any energy is detector resolution. The ultimate limiting factor in how well adjacent neutron responses can be separated is the amount of light the scintillator produces. This cannot be changed, so the light that is produced must be detected as efficiently as possible. The uniformity of light collection from the scintillator has a major effect on the resolution of

the detector. A paper describing a sophisticated light pipe used to improve resolution¹¹ spurred us to consider this problem in our detectors. Light pipes are seldom mentioned in papers describing neutron spectrum measurements with liquid organic scintillators, although the use of a light pipe is mentioned in passing in the widely quoted paper of Verbinski et al.¹²

Basically, the problem arises because NE213 is not highly transparent to its own light. This factor, coupled with the geometrical problems of collecting the light produced in the scintillator, results in the light produced near the photocathode being more efficiently collected than that produced at the opposite end of the scintillator. A clear example of this problem is illustrated in Fig. 1 which shows the response of a scintillator mounted directly on the photomultiplier to ²²Na gamma rays. The gamma rays were heavily collimated into a plane perpendicular to the cylindrical axis of the scintillator. The variations in pulse height from irradiating the detector near the photocathode, halfway up the scintillator, or at the end of the scintillator away from the photocathode are quite pronounced.

We made similar gamma-ray measurements using successively longer light pipes between the scintillator and the photomultiplier. For these tests, 2-in.-diam polymethyl methacrylate light pipes varying in 1/8-in. increments in length were used. An optical coupling grease was used between the light pipe and the scintillator and the photomultiplier tube. The improvement produced by a 1-in. light pipe is shown in Fig. 2. These data

Figure 1. Response of 2-by-2-in. NE213 scintillator with no light pipe to a collimated ^{22}Na source irradiating the detector near the photocathode ("bottom"), away from the photocathode ("top"), and midway between those extremes ("middle").

Figure 2. Response to ^{22}Na with a 1-in. light pipe between the scintillator and photocathode.

were evaluated in two ways by plotting, as a function of light pipe length, (1) the pulse height of the Compton edges produced by the collimated ^{22}Na source when nearest and farthest from the photocathode (normalized to the response midway along the detector), and (2) a function (that is related to resolution) calculated from the peak and half-heights of the Compton spectra. These spectra were obtained when the scintillator was irradiated from the side with an uncollimated ^{22}Na source. These results are shown in Fig. 3 and clearly show the need for a light pipe. The length of the light pipe chosen depends on the degree of loss in resolution that is considered acceptable.

On the basis of these results we built a new detector that uses a 2-by-2-in. cell of NE213 cou-

pled to an RCA 8850 photomultiplier tube via a 2-in.-diam, 1-in.-long glass light pipe. The scintillator cell is coated with reflecting paint but the light pipe is not, since part of the improvement in response is because the uncoated light pipe allows the loss of some of the light produced at the end of the scintillator. Coupling between the scintillator cell, light pipe and photomultiplier is provided by a thin layer of clear silicon rubber cement. A glass light pipe was chosen to minimize the amount of hydrogen surrounding the detector.

Additional proof of the effectiveness of the light pipe is shown in Fig. 4. The response to Compton scattered electrons in this new detector is more symmetrical than that of an older detector having no light pipe.

Figure 3. Effects of light pipe length on (a) pulse height and (b) resolution.

Figure 4. Pulse height distributions for scattered electrons in a detector with no light pipe and in one with a 1-in.-long light pipe.

Detector Response to Electrons

The Compton scattered electrons were produced during a set of measurements made to provide accurate data on the light produced in NE213 detectors by electrons. Gain settings and calibrations of these detectors often depend on gamma ray measurements. The light produced by neutron interactions with the detectors is frequently related to the gamma-ray response. We made measurements using gamma rays with energies from 22 keV to 6.14 MeV. Below 120 keV there is a high probability for total energy absorption in the detector. Therefore, peaks are produced that can be used for energy calibrations. In this range we used ^{109}Cd , ^{241}Am , and ^{57}Co . Above 120 keV a Compton scattering experiment was used. Two detectors were placed on a line 25 cm apart and the source was placed perpendicular to that line 16 cm from the center of one of the detectors. A 4-in.-thick lead shield was placed between the source and the nearest detector (see Fig. 5). By requiring a coincidence between the detectors, Compton electrons scattered in the detector farthest from the source for which the scattered photon was detected in the other detector were recorded. For this geometry the photons had to be scattered through an angle of 147.4° . Chance coincidences were minimized by using a 10-ns resolving time for the

coincidence circuit. Coincidence timing was tested by observing the annihilation photons from a ^{22}Na source placed midway between the detectors. Electrons from ^{22}Na , ^{207}Bi and ^{137}Co photons scattered in the detector were measured, giving six points ranging from 0.33 to 1.53 MeV. An additional low-energy point (38 keV) was obtained from ^{57}Co .

The results of these measurements are shown in Figs. 6 and 7. At low energies the light produced by the scintillator is not linearly related to the photon or electron energy but is well described by a power function. At higher energies a linear fit, with a nonzero intercept, is appropriate.

To determine the response at even higher energies, the 4.43-MeV carbon gamma ray from a PuBe source [$^9\text{Be}(\alpha,n)^{12}\text{C}^*$] and the 6.14-MeV oxygen gamma ray from a Pu ^{13}C source [$^{13}\text{C}(\alpha,n)^{16}\text{O}^*$] were used. In these cases, a small peak corresponding to pair production followed by escape of both of the annihilation quanta proved useful. These high-energy data fell 3 to 4% below the pulse height predicted by the linear fit to the scattered electron data. This nonlinearity was traced to limitations in the dynode bias circuits for the photomultiplier.

Since gamma rays, most commonly from ^{22}Na , are used to provide pulse height calibrations for subsequent neutron measurements, some

Figure 5. Diagram of the Compton scattering experiments.

means of relating specific features of the measured gamma-ray pulse height response to electron energies is needed. This source produces only Compton interactions with the detector so there is no convenient total energy peak to use. Furthermore, measurable characteristics of the Compton interactions such as peak location or half height are related to the maximum-energy scattered electrons in a manner that depends largely on the resolution of the detector. One approach to this problem has been discussed by Dietze¹³ but related parameters we obtained from our gamma/electron calibrations were not consistent with his results. A weak correlation between the Compton edge and the measured half height and resolution

was obtained but we concluded it was more useful to get the energies of the Compton edge half heights directly from a series of calibrations such as those we conducted. Others have used Compton scattering for calibration purposes (recently, for example, Diehl and Graser¹⁴) but care must be exercised if sources emitting more than one gamma ray are used since it is possible to get true coincidences between cascade gamma rays in some geometries. The geometry we chose suffers from this problem only if one of the gamma rays penetrates the shielding between the source and the detector used to detect the Compton scattered photon.

Figure 6. Relative light output as a function of electron energy at low energies. $L(0.34067) = 1$.

Figure 7. Relative light output as a function of electron energy at high energies. $L(0.34067) = 1$.

Detector Response to Neutrons

Since it is neutron spectra that we are attempting to measure, the pulse height response of the scintillator as a function of neutron energy is important. A large number of response data have been published but the agreement between them is poor. The previously cited paper of Verbinski et al.¹² is widely used as a source for these data and does have the advantage that its data tend to fall in the middle of the other published data. There has been some question about this data, particularly at lower energies.¹⁵ Another problem is that their gamma calibrations depend on only one point from ^{22}Na , and assume a zero intercept, which our measurements show is not the case.

We measured the pulse height response of three NE213 detectors to monoenergetic neutrons at 37 energies from 155 keV to 16.7 MeV. Using three detectors allowed us to compare our new and our old detectors to see if aging was a significant problem. The older detectors were obtained

in late 1975 and the new one in mid-1980. No significant differences were found in the response of the detectors. The results obtained for the new detector are compared with the Verbinski et al. results in Fig. 8. As we had suspected, the low-energy results are different even if an adjustment is made to add a nonzero intercept to the gamma calibrations for the data of Verbinski et al. The agreement above a few MeV is quite good, also as expected.

To reduce measured pulse height responses to neutron spectra requires a thorough knowledge of scintillator light output as a function of neutron energy. The data reduction technique we currently use also requires the first and second derivatives of these data.¹⁶ We have found that fitting the data with a fifth-degree log polynomial is useful. The fit is usually within 3% over its range. Extrapolations would be questionable so we have used the Verbinski et al. data above 20 MeV.

Figure 8. Relation between neutron energies and electron energies that produce the same amount of light in a new NE213 scintillator.

References

1. W. L. Pickles and J. H. Elliott, "Neutron Spectrometer," *Hazards Control Progress Report No. 44, September through December 1972*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-72-3 (1973).
2. J. H. Elliott, W. L. Pickles, and D. R. Slaughter, "Neutron Spectrometry," *Hazards Control Progress Report No. 46, January through April 1973*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-73-2 (1974).
3. D. R. Slaughter and J. H. Elliott, "Neutron Spectrometer," *Hazards Control Progress Report No. 47, September through December 1973*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-73-3 (1974).
4. J. H. Elliott and D. R. Slaughter, "Neutron Spectrometer Development," *Hazards Control Progress Report No. 48, January through June 1974*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-74-1 (1974).

5. D. R. Slaughter and J. H. Elliott, "Neutron Spectrometer Development," *Hazards Control Progress Report No. 49, July through December 1974*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-74-2 (1975).
6. D. R. Slaughter and D. W. Rueppel, "Neutron Spectrometer System," *Hazards Control Progress Report No. 50, January through June 1975*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-75-1 (1975).
7. D. R. Slaughter and D. W. Rueppel, "Development of a High-Resolution Neutron Spectrometer for Field Use," *Hazards Control Progress Report No. 50, January through June 1975*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-75-1 (1975).
8. D. R. Slaughter and D. W. Rueppel, "Calibration of Proportional Counters for Neutron Spectrometer," *Hazards Control Progress Report No. 50, January through June 1975*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-75-1 (1975).
9. D. R. Slaughter, R. C. Kaifer, D. Fuess, and D. W. Rueppel, "Neutron Spectroscopy in the Energy Range 0.5-20 MeV Using a NE213 Scintillator," *Hazards control Progress Report No. 53, July through December 1976*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-75-2 (1977).
10. J. H. Thorngate and D. W. Rueppel, "Developments in Neutron Spectrometry," *Hazards Control Progress Report No. 57, October through March 1979*, Lawrence Livermore National Laboratory, Livermore CA, UCRL-50007-79-1 (1979).
11. H. Scholerman and H. Klein, "Optimizing the Energy Resolution of Scintillation Counters at High Energies," *Nucl. Instr. and Meth.* **169**, 25-31 (1980).
12. V. V. Verbinski, W. R. Burrus, T. A. Love, W. Zobel, and N. W. Hill, "Calibration of an Organic Scintillator for Neutron Spectrometry," *Nucl. Instr. and Meth.* **65**, 8-25 (1963).
13. G. Dietze, "Energy Calibration of NE213 Scintillation Counters by γ -Rays," *IEEE Transaction on Nuclear Science NS-26*(1), 398-402 (Feb. 1979).
14. R. Diehl and U. Graser, "Energy Calibration of Organic Scintillation Detectors for Gamma Rays," *Nucl. Instr. and Meth.* **186**, 665-668 (1981).
15. P. G. Kirmser and Kuo-Kuang Hu, "A Continuous Functional Representation of the Response Surface for a NE213 Neutron Spectrometer," *Nucl. Instr. and Meth.* **154**, 169-174 (1979).
16. D. R. Slaughter, D. W. Rueppel, and D. A. Fuess, "Neutron Spectrum Measurements for Radiation Protection Purposes," Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52415 (1978).

RADIATION PROTECTION

Six-Inch-Square Phoswich Detector Array for Plutonium Lung Counting

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Two 6-in.- (15.2-cm-) square phoswich detectors obtained from the Harshaw Chemical Company have been evaluated for possible application as plutonium lung counters. Although our evaluation is still preliminary, the data collected to date suggest that the use of these detectors for routine lung counting would reduce the minimum detectable activity for isotopically pure ^{239}Pu by about 40%, such that a maximum permissible lung burden of pure ^{239}Pu (16 nCi) could be detected in a plutonium worker of average stature with 2.6-cm chest-wall thickness in a 4000-s count. At present, using two 11.4-cm-diam phoswich detectors, one lung burden of ^{239}Pu is not detectable in the same counting time. Our preliminary data also suggest a reduction in the Minimum Detectable Activity for ^{241}Am , even though the background count-rate for these detectors is much higher in the 60-keV band used for spectral analysis.

Introduction

At LLNL, the detection and measurement of plutonium in the lung is generally done using two 11.4-cm-diam phoswich detectors^{1,2} placed high on the chest and tangent to the sternum and clavicle. The counts are made in a well-shielded environment using pulse-shape-discrimination electronics to reject Compton-scattered events and photomultiplier tube noise, thus achieving a detector background of approximately 4 cpm in the 17-keV band used for plutonium analysis. Adding this background to the subject's own background due to ^{40}K scatter in the body, etc., allows the calculation of Minimum Detectable Activity (MDA) values which can then be derived for people of differing body types.

One series of MDA calculations at the 95% confidence level is shown plotted in Fig. 1 for three common isotopically pure actinide elements. These cover a wide range of values depending upon the composition and chest-wall thickness of the subject and the detection efficiency of the counter for the particular radionuclide of interest.

All of the MDAs were calculated using a modified formula of Altshuler and Pasternak,³ shown in Eq. (1), where the subject and detector background count-rates are not well known:

$$\text{MDA} = 2K \frac{\left(2 \frac{B}{T}\right)^{1/2} + \frac{K^2}{T}}{S} \quad (1)$$

where K is the constant determined by the confidence level (1.645 for 95%), B is the background count-rate, T is the counting time (min), and S is the sensitivity (cpm/ μCi), assuming a mean value of 22% fat and 78% muscle for all chest-wall thicknesses.⁴

Figure 1. MDA calculations for ^{239}Pu , ^{238}Pu , and ^{241}Am , based on counts taken with the 11.4-cm-diam detector.

A more rigorous statistical analysis using actual observed human background variability, etc., incorporating the methods proposed by Faulk and Coop,^{5,6} might be more appropriate in describing these MDA values; however, for the present we are using the plotted values as a relative basis for comparing the MDAs calculated for a second detection system which will be discussed later.

For ²⁴¹Am, the MDA is comparatively low, less than 0.3 nCi for all of the subjects, compared with a maximum permissible lung burden of 15 nCi. For ²³⁸Pu, with a maximum permissible lung burden of 16 nCi, the MDA varies from about 6 to 30 nCi over a range in chest-wall thickness from 2 to 3.5 cm, accommodating most individual body types. For ²³⁹Pu, the MDA varies from about 12 to 60 nCi over the same range, showing that one maximum permissible lung burden of 16 nCi is not detectable in a person of average stature with a 2.6-cm chest-wall thickness.

However, if it is known that the plutonium mixture is weapons-grade material, with say 1200 ppm ²⁴¹Am content, and americium can be used as a tag in the measurement, then the MDA values for plutonium range from about 1 to 3 nCi.

Large-Area Square Phoswich Detectors

In October 1980, two 6-in.- (15.2-cm-) square phoswich detectors became available to our laboratory for possible application as plutonium lung counters. Each detector consists of a 0.5-in.-thick

sodium iodide crystal, backed by a 1.5-in.-thick cesium iodide crystal (NaI activated), both of which are coupled to the same 5-in.-diam photomultiplier tube. The entrance window is 10-mil beryllium, with associated electronics similar to that used for the 11.4-cm-diam phoswich detectors.

Background Count-Rate and Energy Resolution

The detectors have a remarkably low background count-rate for their size. There are only about 5–6 cpm in the plutonium x-ray band summed from 13 to 24 keV, compared with 4 cpm for the two 11.4-cm-diam detectors, even though the square phoswich surface area is 2.3 times greater. From 50 to 70 keV, the background count-rate is approximately 17 cpm compared with about 10 cpm for the 11.4-cm-diam detectors. The square phoswich also has a better energy resolution. Figure 2 shows a ²⁴¹Am spectrum taken with both systems. The superior resolution reflects the good light-collection capability of the 15.2-cm-square detector compared with the 11.4-cm-diam detectors. However, this may not be a fair comparison, since the 11.4-cm-diam detectors are old and are probably in need of re-work at the factory. Some of the newer 5-in.- (12.7-cm-) diam detectors exhibit good resolution characteristics when compared with the square phoswich.

Figure 2. ²⁴¹Am spectrum taken with the 15.2-cm-square and 11.4-cm-diam detectors.

Measurement Comparisons

Calibration data taken using the LLNL Realistic Phantom^{7,8} and compared in Figs. 3 and 4 for ^{239}Pu and ^{241}Am in lungs show that counting efficiencies are about a factor of two greater for the 15.2-cm-square detector.

MDA calculations similar to those derived for the smaller detector are compared in Fig. 5 for the square detector. They suggest that the use of these detectors for routine lung counting would reduce the MDA for isotopically pure ^{239}Pu by about 40% relative to the 11.4-cm-diam detector, such that a maximum permissible lung burden of pure ^{239}Pu (16 nCi) could be detected in a plutonium worker of average stature with a 2.6-cm chest-wall thickness in a 4000-s count. The data also suggest a theoretical reduction of about 30% in the MDA for ^{241}Am .

To test the validity of these calculations, phantom measurements were made using mock lungs containing 16.4 nCi of uniformly distributed ^{239}Pu or about one lung burden of activity. Measurements of an inactive phantom with 2.63-cm chest-wall thickness and 18% fat content were subtracted from the measurements of the active phantom. A total of three measurements were made and in each case the residual counts were positive in the 17-keV band. Two additional

Figure 3. Counting efficiencies of the two detectors for ^{239}Pu .

Figure 4. Counting efficiencies of the two detectors for ^{241}Am .

Figure 5. MDA calculations for ^{239}Pu and ^{241}Am , based on counts taken with the two detectors.

counts, made for 6000 s, were also positive. One phantom count made with a 2.08-cm chest-wall thickness and 0% equivalent fat content was detectable, while a second count made using a 3.16-cm chest-wall thickness equivalent to a 17% fat content was not detectable.

Lungs loaded with a mixture of 2 nCi ^{241}Am and 32 nCi ^{239}Pu to simulate weapons-grade material with 1200 ppm ^{241}Am weight fraction were also measured, but not under the same conditions as for the 16-nCi lungs. In general, plutonium will be more difficult to detect in this situation, since the x rays from both plutonium and americium will be riding on top of a continuum from the scattered 60-keV gamma rays from ^{241}Am . However, after stripping out the x-ray contribution from americium, 32 nCi of ^{239}Pu activity was still detectable in the phantom for chest-wall thicknesses of 2.08 cm and 2.64 cm and 0% fat content, but not at the next thickest phantom chest overlay, 3.16 cm. One detector became damaged and had to be returned to the factory before additional measurements using chest plates and torso equivalent to a 22% fat content could be made.

No low-level ^{241}Am measurements were made on the phantom before the detector became damaged. However, several measurements using similar counting geometries had been made on people with small amounts of ^{241}Am present. The results of some of these counts are shown in Fig. 6. The upper curve shows a small subject (A) with 0.3 nCi ^{241}Am in the lung, compared with a large subject (B) of 3.6-cm chest-wall thickness with about 0.2 nCi. A normal (no ^{241}Am) subject (C) of equivalent size to the large subject is shown in the third curve. The bottom curve is subject (B) counted with the 11.4-cm-diam phoswich array. All of these counts were made for 3000 s, with the 60-keV gamma ray used for analysis.

References

1. G. R. Laurer, *In-Vivo Measurements of Radionuclides Emitting Soft, Penetrating Radiations*, Ph.D. dissertation, New York University (1968).
2. G. R. Laurer and M. Eisenbud, "In-Vivo Measurements of Nuclides Emitting Soft Penetrating Radiations," *Proc. Symposium on Diagnosis and Treatment of Deposited Radionuclides*, May 1967, Richland, Washington (Excerpta Medica Foundation, 1968), pp. 1189-1207.
3. B. Altshuler and B. Pasternack, "Statistical Measures of the Lower Limit of Detection of a

Figure 6. ^{241}Am spectra taken with the 15.2-cm-square detector.

- Radioactivity Counter," *Health Phys.* 9, 293 (1963).
4. E. Dolgirev, G. N. Kaidanovsky, N. V. Porozov, and V. P. Shamov, "The Methods of Absolute Calibration of Equipment for Measurements of Pu-210, Pu-239, and Am-241 in the Human Body," *Proc. 3rd IRPA International Congress, Washington, DC* (1973).
5. R. B. Faulk, "A Review of Various Measures of Detectability," presented at the Instrumentation Workshop for Low Level Transuranic Measurements Applied to In-Vivo and Environmental Monitoring, Los Alamos National Laboratory, Los Alamos, NM, March 1980.
6. K. Coop, I. Aiken, and M. Marshall, "Detection Limits for Chest Counting at the Los Alamos Scientific Laboratory," presented at the Instrumentation Workshop for Low Level Transuranic Measurements applied to In-Vivo and Environmental Monitoring, Los Alamos National Laboratory, Los Alamos, NM, March 1980.
7. P. N. Dean, R. V. Griffith, and A. L. Anderson, "Design Criteria for Phantoms for Calibration of External Detectors for the In-Vivo Assay of Plutonium," *IAEA International Symposium on Diagnosis and Treatment of Incorporated Radionuclides*, December 1975, Vienna (1976), p. 265.
8. R. V. Griffith, P. N. Dean, A. L. Anderson, and J. C. Fisher, "Fabrication of a Tissue-Equivalent Torso Phantom for Intercalibration of In-Vivo Transuranic Nuclide Counting Facilities," *IAEA International Symposium on Advances in Radiation Protection Monitoring* (1978).

FIRE SAFETY

Suppressing Fires Involving Tapes and Tape Reels with Portable Fire Extinguishers and Room Sprinklers

H. K. Hasegawa, D. G. Benson, S. G. Leeds, and K. L. Foote

Because the Magnetic Fusion Energy (MFE) and main computer centers at LLNL have become increasingly concerned about the fire hazard of magnetic tape reels, we initiated a research program to evaluate this fire potential and the effectiveness of appropriate countermeasures. Our objectives were to test and evaluate the effects of using (1) a 17-lb Halon 1211 fire extinguisher, (2) a 15-lb carbon dioxide (CO_2) fire extinguisher, and (3) standard "wet pipe" sprinklers on a fire in a simulated tape-storage rack. We found little published information related to this topic, which is surprising since tape storage normally shares the same space with computers or occupies spaces which communicate with computer rooms; a fire in tape-storage must be rapidly extinguished before it damages sensitive electronics.

Test Procedure

Following a survey of various types of tape-storage racks at LLNL, we fabricated the three-shelf unit (nine tapes per shelf) shown in Fig. 1.

Figure 1. Tape-storage rack (nine tapes per shelf) fabricated for experiment.

We felt that this configuration would enhance the growth rate and severity of the fire because it is a free-standing open rack that allows maximum air entrainment to all tape reel surfaces and because it holds the tapes upright throughout the burn with uniform spaces between them, ensuring that they remain in place and burn with maximum surface-to-volume ratios.

The first experiment in the series was to determine the time-dependent processes occurring during the development of a deep-seated, fully involved fire and to monitor the following:

- The time at which a 165°F fusible link sprinkler mounted directly above the fire would activate, and its effectiveness in knocking down the fire.
- The length of time necessary for an ionization-type smoke detector located in a remote corner of the test-cell ceiling to activate.
- Temperatures at different levels on the rack.
- Fire-development diagnostics.

The first experiment also served as a baseline fire exposure which enabled us to define intensity levels of fires to be used in the tests: (1) a low-intensity fire, defined as fire involvement of the tapes on the lowest shelf and partial involvement of those on the second shelf; or (2) a high-intensity fire, defined as the full involvement of all three shelves.

Reproducibility of the two fire intensities was imperative to properly compare the two types of portable extinguishers; we supplemented our visual judgment of fire size by monitoring the temperature at each level on the rack.

After reviewing videotapes of magnetic tape burns we had performed previously, we decided that the bunsen burner was an appropriate ignition source for this application. The low intensity of the burner produced a very slow initial fire development, which enabled us to pick a number of points in time to apply extinguishant for the low-intensity fire.

Results

The following is a brief summary of the experiments performed to date.

Baseline Fire

Figures 2 and 3 show the fully developed fire and the resultant damage to the tape array. Pertinent observations were:

- The gas to the burner was shut off at $t_0 + 210$ s.
- The smoke detector sounded at 223 s.
- The sprinkler head fused and discharged water at 402 s.

As may be seen in one of the temperature profiles (Fig. 4), the fire was deep-seated by the time the sprinkler discharged. The resulting water spray *did not* extinguish the fire. Although the sprinkler's response time was optimized by positioning it directly over the fire, its effectiveness was reduced due to the sparseness of droplets in the center of the spray pattern. (The fire was terminated by hose stream.)

15-lb CO₂ Extinguisher on Low-Intensity Fire

The burner was turned off at $t_0 + 120$ s, and CO₂ was applied at 263 s. The extinguisher had no problem knocking down the fire in about 2 s.

15-lb CO₂ on Medium-Intensity Fire

The burner was turned off at approximately 150 s, and CO₂ was applied at 280 s. The extinguisher nozzle had to be positioned very close to the flames (approximately 6 in.) and CO₂ discharged for about 10 s before the fire was put out. The CO₂ was nearly depleted at extinguishment.

Figure 2. Fully developed fire.

Figure 3. Damage after baseline fire.

Figure 4. Mid-rack temperature during baseline fire (sprinkler discharged at 402 s).

17-lb Halon 1211 on High-Intensity Fire

The burner was shut off at approximately $t_0 + 90$ s, and the fire was fully involved and deep-seated at 315 s (see temperature in Fig. 5). Halon 1211 was applied at 375 s at an approximate distance of 6 ft. The 17-lb Halon 1211 extinguisher knocked the fire down completely in approximately 4 s, using only 6 lb of Halon.

Conclusions

This experimental series dramatically illustrated that the 17-lb Halon 1211 extinguisher was far superior to CO_2 and possibly sprinkler water

spray for this application. The fact that 1211 starts out in liquid form, then vaporizes when it hits the fire, allows the user to effectively apply Halon from a safe distance. To determine the effect of extinguisher size, we also tried a 5-lb 1211 unit on a fully involved fire—it did not terminate the fire. Even though the 17-lb unit only used 6 lb of Halon, it was successful. Apparently, the rate of application due to residual Halon and pressure was the margin that affected extinguishment. Consequently, the 5-lb unit didn't have sufficient backup "punch" to tackle a fire of this magnitude.

Future tests will evaluate several aspects of the effectiveness of a Halon 1301 total-flooding system on magnetic tape reel fires.

Figure 5. Mid-rack temperature during high-intensity fire (Halon 1211 applied at 375 s).

ENVIRONMENTAL PROTECTION

Particle Size for Greatest Penetration of HEPA Filters

R. A. da Roza

High-efficiency particulate air (HEPA) filters used in the nuclear industry are pre-tested for efficiency using a monodispersed DOP aerosol of $0.3\text{-}\mu\text{m}$ diam. This testing is based on the assumption that $0.3\text{-}\mu\text{m}$ -diam particles are the most penetrating size for HEPA filters. However, if this is not the size of maximum penetration (SOMP), then "what is" and "how much greater is the penetration" are questions that need to be answered for an accurate evaluation of environmental releases of hazardous materials. To answer these questions, I reviewed the literature and compared published experimental data with theory.

Introduction

It is very difficult to measure the efficiency of a HEPA filter as a function of particle size. Typically, the aerosol concentration upstream from a HEPA filter is a few times 10^5 greater than that downstream. If the upstream concentration is too high, then filter loading is a problem. If it is too low, then the aerosol downstream cannot be detected with sufficient accuracy. Another approach is to measure the efficiency as a function of particle size on filters that are similar to HEPA filters but are of less efficiency. A theory is then developed that can be used to predict the efficiency function of a HEPA filter. The first two papers reviewed measured the efficiency function directly on HEPA filters. The remaining papers were reviewed to show that a theory has been developed that adequately predicts the efficiency and, in particular, the size of maximum penetration.

Theory Review

The most modern theories of filtration of fine particles on fibrous filters have been published by Liu and Associates at the University of Minnesota¹⁻³ and by Fuchs and Associates at Karpov Institute of Physical Chemistry in Moscow.⁴⁻⁶ Older theories have been discussed in books^{7,8} and several of the experimental papers reviewed. These modern theories show that filtration efficiency is a function of the filter media properties, the aerosol

properties, and the properties of air. I followed the theory of Lee and Liu¹ in this study and used their complex equations¹ to calculate the theoretical curves of fiber efficiency vs particle diameter, and the SOMP. However, I did not make their simplifying assumptions for the diffusion coefficient or that the ratio of particle diameter to fiber diameter is much less than unity.

Experimental Review

From an extensive literature search, nine reports on the subject were chosen for comparison of their data with the theory. Factors used in making the choices were: similarity to HEPA filter conditions, completeness of information, and apparent accuracy. To compare the theory with the experimental data, the complete theoretical equation was plotted using the appropriate values of fiber diameter, solidity (fiber volume fraction), and velocity. The matching experimental values were also plotted. Two comparisons will now be discussed.

Figure 1 shows the data from Schuster and Osetek⁹ for DOP through a 25-cfm HEPA filter. They did not give any filtration parameters, only that their system was a scaled-down version of a typical industrial HEPA filter system with the same flow volume per unit filter surface area. The solidity was obtained from measurements on a disassembled HEPA filter made by American Air Filter Company. A glass density of 2.61 g/cm^3 was used. This was obtained from Johns-Manville

Figure 1. Schuster and Osetek's data.⁹

Company in Denver, as was the mean surface diameter of $0.7 \mu\text{m}$, although a filter is made from a broad range of fiber diameters. The points plotted were obtained from a smooth curve drawn through their data. The conversion was made from protection factor (P.F.) to single-fiber efficiency using Lee and Liu's¹ equations:

$$\text{Penetration} = 1 - E = 1/\text{P.F.} \quad (1)$$

and

$$E = 1 - \exp\left(\frac{-4\eta\alpha L}{\pi D_f(1 - \alpha)}\right) \quad (2)$$

where

- E = overall efficiency of filter,
- L = thickness of filter,
- η = single fiber efficiency,
- α = fiber volume fraction of filter (solidity),
- D_f = fiber diameter.

The calculated SOMP, $0.21 \mu\text{m}$, agrees well with the experimental data. The calculated single-fiber efficiency is high, but the shape of the curve agrees well. One would expect the experimental data to give a flatter curve since the real HEPA filter is composed of a range of fiber diameters.

Figure 2 shows the data of Chen.¹⁰ His values for η_0 , the collection efficiency for an isolated fiber, were changed to η_α , collection efficiency for a fiber in a mat of solidity, α , by his equation $\eta_\alpha = \eta_0(1 + 4.5\alpha)$ using an α of 0.05. His η_α is the same as the η in this report. As can be seen by the scatter in the points, actual data points are plotted, not smoothed values. The agreement between theory and Chen's data is very good in both SOMP and magnitude of the single-fiber efficiency.

Summary

A total of 39 sets of data giving fiber efficiency as a function of particle diameter were obtained from the nine reports studied. There was very good agreement between the experimental data and the shapes of the theoretical curves. The absolute magnitude of the theoretical efficiency did not always correlate very well with that of the experimental efficiency. This value is very sensitive to the uncertainties in the conversion between single-fiber efficiency and total filter efficiency, Eq. (2).

The agreement with the shapes of the theoretical curves is adequate verification that the theoretical calculations for HEPA filters can be used to get the best value for the SOMP and to estimate

Figure 2. Chen's data.¹⁰

the penetration at $0.3\ \mu\text{m}$ as compared to that at the SOMP. These values were obtained from Fig. 1 and Eq. (2), respectively. Table 1 summarizes the results. The ratio of 7.1 for penetration at the SOMP ($0.21\ \mu\text{m}$) to that at $0.3\ \mu\text{m}$ compares well with the experimental ratio of 5.5 reported by Schuster and Osetek.⁹

References

1. K. W. Lee and B. Y. H. Liu, "On the Minimum Efficiency and the Most Penetrating Particle Size for Fibrous Filters," *J. Air Pollution Control Assoc.* 30(4), 377 (1980).
2. H. C. Yeh and B. Y. H. Liu, "Aerosol Filtration by Fibrous Filters—I. Theoretical," *J. Aerosol Sci.* 5, 191 (1974).
3. H. C. Yeh and B. Y. H. Liu, "Aerosol Filtration by Fibrous Filters—II. Experimental," *J. Aerosol Sci.* 5, 205 (1974).
4. A. A. Kirsh, I. B. Stechkina, and N. A. Fuchs, "Efficiency of Aerosol Filters Made of Ultrafine Polydispersed Fibres," *J. Aerosol Sci.* 6, 119 (1975).
5. A. A. Kirsch and I. B. Stechkina, "The Theory of Aerosol Filtration with Fibrous Filters," in *Fundamentals of Aerosol Science*, D. T. Shaw, Ed. (John Wiley and Sons, New York, 1978), pp. 165-256.

Table 1. Comparison of estimated penetration and fiber efficiency values^a for $0.21\text{-}\mu\text{m}$ particles (the calculated SOMP) and $0.3\text{-}\mu\text{m}$ particles.

	0.21 μm	0.3 μm
Penetration, P	1.65×10^{-7}	2.32×10^{-8}
$P_{0.21}/P_{0.3}$	7.1	
Fiber efficiency	0.263	0.296

^aAssuming filtration velocity is $1.9\ \text{cm/s}$.

6. A. A. Kirsch and I. B. Stechkina, "Inertial Deposition of Aerosol Particles in Model Filters at Low Reynolds Numbers," *J. Aerosol Sci.* 8, 301 (1977).
7. P. A. F. White and S. E. Smith, Eds., *High Efficiency Air Filtration* (Butterworths, London, 1964).
8. C. N. Davies, *Air Filtration* (Academic Press, London, 1973).
9. B. G. Schuster and D. J. Osetek, "Tandem HEPA Filter Tests," *Am. Ind. Hyg. Assoc. J.* 39, 144 (1978).
10. C. Y. Chen, "Filtration of Aerosols by Fibrous Media," *Chem. Rev.* 55, 595 (1955).

INSTRUMENT DEVELOPMENT

Remmeters for Pulsed Sources of Neutrons

J. H. Thorngate, G. F. Hunt, and D. W. Rueppel

Measurements of neutron dose equivalents around fusion experiments are complicated by the pulsed nature of the sources. Common remmeters, using proportional counter detectors, may have detector signals whose lengths are comparable to the length of the source pulse. When this occurs, significant underestimates of the dose equivalent may be recorded. We were asked by the health physicists to consider this problem with a particular emphasis on the needs of the MFTF Program; this is an experiment in magnetically confined fusion technology that expects to produce one or two pulses per hour at most, with lengths as short as 50 ms or as long as seconds. The low pulse-repetition rate ruled out the use of silver activation detectors such as the Los Alamos Albatross.¹ Although a modification of this technique that followed the decay of the silver might have been useful, the relatively long length of the minimum-width pulse led us to consider using a detector with a fast response time. The result was essentially a simple remmeter with extremely high count-rate capabilities.

A thermal neutron detector centered in a 9- or 10-in.-diam sphere of polyethylene gives a reasonable approximation to a rem response.² The sphere can be modified if a somewhat better response is desired.^{3,4} We chose a ⁶Li-loaded cerium-activated glass scintillator for the thermal neutron detector. A boron-loaded organic scintillator might also have worked but would not have been as rugged. The light produced by the glass scintillator decays with a 70-ns decay constant. A pulse this short can easily be shaped to pulses as short as 10 or 20 ns, allowing counting rates up to 5×10^5 per second before 1% losses are encountered.

Prototype

The prototype of this instrument, shown in Fig. 1, was described in a previous report.⁵ It used a 1-in.-diam 1/8-in.-thick glass scintillator in a polyethylene sphere equivalent to a 9-in. sphere. The large scintillator made this unit quite sensitive, 84,000 counts per millirem, which was a mixed benefit. It allowed measuring very low fields but was limited to dose equivalent rates of about 12 mrem per second, so that it could only record 0.5 mrem from a pulse 50 ms long. Another

feature of this unit was a gate circuit designed to activate data storage only when a preset count rate was encountered. This allowed measuring consecutive source pulses without accumulating background between them. It also provided a means of recording how many source pulses had occurred during the integrating period. This circuit used analog count rate techniques that limited its sensitivity to 3 mrem per second. Thus, the usable dynamic range was only four when the unit was used in this mode.

The conversion from detector counts to millirem was made in a way that provided a dose readout only after the source pulse had ended. That was perceived as a problem for long source pulses or if steady-state sources were to be measured with the instrument. The energy response of this system compared favorably with other remmeters,⁵ but its shortcomings led to the development of a second model.

Second-Generation Model

Significant electronic changes were made in the second model that is shown in Fig. 2. A smaller (1-cm-diam, 1-mm-thick) scintillator was used

Figure 1. Prototype remmeter for pulsed sources.

to reduce the sensitivity to 8500 counts per millirem, more like commercial remmeters. The smaller scintillator allowed a smaller photomultiplier to be used so the polyethylene ball could be equivalent to a 10-in. sphere which improved the low-energy response somewhat. A direct conversion, using a "divide-by-n" scaler, was included so that a continuous readout of dose equivalent in 0.1-mrem units was available. The second register used in the prototype to display the number of

source pulses had a switch added in the second model so that this display could show either the number of source pulses or the detector counts or time in 0.001-hour increments. Being able to record detector counts is a convenience for calibration. By recording the pulses produced by a given dose equivalent, the factor to convert detector pulses to mrem can be calculated. This factor is then entered on a set of switches to calibrate the instrument.

A further improvement for this model was to change the source-pulse detection circuit to a digital circuit. Now if two counts occur more than 80 ns apart but within 1 s of each other, the unit will be gated on and a source pulse recorded. The minimum time is set by the 20-ns pulse-shaping time chosen coupled with a fast divide-by-four circuit needed to isolate the detector signals from the slower subsequent circuits. The 1-s interval was chosen to be consistent with the normal background rate of this detector. This time can be easily adjusted for other background rates. The relative response of this unit is compared to other remmeters in Table 1. Actual sensitivities of these units are about 10^4 counts/mrem for the Andersson-Braun design, 3200 counts/mrem for the modified 9-in. unit, 8.4×10^4 counts/mrem for the prototype pulsed-source remmeter, and 8400 counts/mrem for the second-generation pulsed-source remmeter.

Conclusions

The circuit modifications adopted in the second unit were so successful that they are being retrofitted into the original unit. The sensitivity and physical configuration of the original unit have given it special applications. A cart is being contemplated for the second unit to increase its mobility.

So far neither unit has been used around a magnetic confinement fusion experiment, but the prototype was used successfully to measure the photoneutrons from a high-energy pulsed x-ray system. These source pulses were considerably shorter than the design limit of this device but any pulse width can be accommodated as long as the dose equivalent rate does not exceed 12 mrem per second for the prototype or 30 mrem per second for the new unit. For comparison, these values convert to 43 rem per hour and 108 rem per hour, respectively. Increased activity in the fusion experiments at LLNL is expected to provide considerable opportunity for use of these instruments.

Figure 2. Second-generation remmeter for pulsed sources.

Table 1. Comparison of relative responses of the prototype and the second-generation pulsed-source remmeters with standard remmeters.

Source	Prototype pulsed-source remmeter		Second-generation pulsed-source remmeter	
	Relative to Andersson-Braun	Relative To modified 9-in. sphere (PNR-4)	Relative to Andersson-Braun	Relative to modified 9-in. sphere (PNR-4)
$^{252}\text{Cf} + 25 \text{ cm D}_2\text{O}$	1.36	1.11	1.09	0.99
$^{252}\text{Cf} + 10 \text{ cm D}_2\text{O}$	1.04	0.98	1.00	1.00
Bare ^{252}Cf	0.95	0.95	0.96	0.92
$^{238}\text{PuBe}$	1.06	1.01	1.12	1.10

References

1. D. Brown, R. J. Buchanan, and A. R. Koelle, A Microcomputer-Based Portable Radiation Survey Instrument for Measuring Pulsed Neutron Dose Rates, *Health Phys.* **38**, 507-521 (1980).
2. R. L. Bramblett, R. I. Ewing, and T. W. Bonner, A New Type of Neutron Spectrometer, *Nucl. Instr. and Meth.* **9**, 1-12 (1960).
3. I. O. Andersson and J. Braun, A Neutron Rem Counter, Aktiebolaget Atomenergi, Studsvik, Sweden, AE-132 (1964).
4. D. E. Hankins, A Modified-Sphere Neutron Detector, Los Alamos National Laboratory, Los Alamos, NM, LA-3595 (1967).
5. J. H. Thorngate, G. F. Hunt, and D. W. Rueppel, Rem Meter for Pulsed Sources of Neutrons, Lawrence Livermore National Laboratory, Livermore, CA, UCID-18792 (1980).

FIRE SAFETY

Fault-Tree Analysis of a Smoke Detector System at LLNL

H. K. Hasegawa, G. P. Naanep,* and M. W. Magee

We have completed an analysis of a products-of-combustion (POC) smoke detector system, typical of those installed at LLNL, to aid the Fire Safety Division. The program objective was to identify probable fault modes in a representative LLNL smoke-detector circuit. Results of this study will help in designing future systems, modifying existing systems, and selecting critical circuit components. Furthermore, recommendations can be made for optimizing inspection and maintenance schedules.

Introduction

Through failure modes and effects analysis, we examined credible modes of hardware failure and determined their effects on the system. Then, through qualitative and quantitative fault-tree analysis, we assessed system design, system hardware, and maintenance policies. The qualitative analysis required generating system-failure scenarios and identifying single-point failures and common-cause events. The quantitative analysis entailed collecting and estimating data for component failure, identifying maintenance policies for components, computing system unavailability, and calculating the importance of system faults (basic events) and system failure modes that contributed to the occurrence of the top event in the fault tree.

Description of System

We analyzed a Pyrotronics PYR-A-LARM¹ Model FIU-6 Fire Indicating Unit, a Model ZIU-6 Zone Indicating Unit, and a detector circuit with two smoke detectors.

The fire-detection system is part of a general protective-signalling system consisting principally of a hardwired circuit with detection devices on one end and an emergency control console on the other end at the LLNL firehouse. The leads from the zoned smoke detectors are connected to the dispatcher's console through the fire indicating/zone indicating unit (FIU/ZIU) that serves to power the detectors and to indicate zone

alarm. The smoke detectors in a zone are wired in parallel. If a detector in any zone sets off an alarm, the dispatcher receives a signal from the FIU. The signal received at the firehouse is either supervisory or alarm, with no description of zone. Zone designation is provided at the building by either the FIU/ZIU or an annunciator panel located near the main entrance(s).

All other protective signals pass through the fire-indicating unit. These include tamper switch signals, pull-box alarm signals, etc. If there is an incomplete circuit to the firehouse or a tamper switch signal, a supervisory signal (yellow light) is sent. For a smoke detector signal, an alarm is sent (red light).

In addition to the basic circuit, we evaluated the sprinkler system supervisory circuit and the emergency power supply, both of which are integral parts of the system. (To make the analysis more tractable, we reduced the number of ionization detectors to two and retained all the other necessary components in the system.) This is a reasonable representation since we are looking at local response of detectors from a fire in its incipient stage. It should be noted that detector placement in the model was representative of an existing system in a high-bay experimental enclosure. Therefore, detector response times were maximized.

Primarily, the FIU is the power distribution and signal transmission center for the system. It operates on 120-V, three-wire, 60-cycle, single-phase power under normal operating conditions. However, in the event of a power failure a gas-powered generator or a battery emergency power supply (EPS) will switch on.

*Econ, Inc., 4020 Moorpark Ave., San Jose, CA.

In addition to supplying power and monitoring detection devices, the FIU can control additional local equipment such as door closers or fan shutdown relays through supplementary relay contacts.

The ZIU, on the other hand, is necessary to identify the area or zone (in a multi-area building) from which the trouble or alarm signal is coming

Basic Theory of Operation

Both the FIU and ZIU contain relays which are normally energized or de-energized. Operational modes are normal supervisory current, no current (trouble), and overcurrent (alarm). To transmit a trouble signal, the appropriate relay(s) will de-energize, closing a set of trouble contacts. To transmit an alarm signal, the appropriate relay(s) will energize, closing a set of alarm contacts. In either case, both local and remote signals will be triggered.

System Analysis

This analysis was performed with the following assumptions:

- Components, subsystems, and similar items can have only two conditional modes: they can either operate successfully or they can fail. No operation is partially successful.

- Basic failures are independent of each other.

- Smoke detectors were not analyzed as specific models nor were they looked at in terms of detailed internal components.

- A component in the fire detection system can fail in four ways when there is a demand—

- (1) It can fail to change state; e.g., relay contacts fuse closed.

- (2) It can fail and failure can go undetected (no repair); e.g., failure of an unsupervised component in the FIU. (Failure probability, P , = cyclic failure rate. $P = 1 - e^{-\lambda t}$, where λ = failure rate.)

- (3) It can fail and failure can be detected; i.e., the component is under repair (announced failure). For example, a supervised component fails and is detected by the supervisory circuit. ($P = \lambda \tau$, where τ = repair time and λ = failure rate.)

- (4) It can fail and failure can be detected at the end of scheduled inspection; i.e., the component is under repair (unannounced failure).

Results

The undesired event or top event for this analysis is "FIU/ZIU unit does not transmit alarm when there is a fire in zone X." The fault tree is shown in Fig. 1. Notice that the first gate is an "and" gate* which requires the failure of both local and remote alarms. However, for our evaluation, we considered only the right side of the tree which covers automatic remote alarm. We felt that this was the worst-case situation for the system, because of the absence of occupants to respond to local alarm. The tree is composed of 54 basic events. The qualitative analysis, which was supported by the FTAP² computer code, requires no numerical or probabilistic data input. Results of this analysis provide insight into the logical structure, design, and maintenance of the fire protection system in relation to scenarios for system failure. The FTAP run produced 61 minimal cutsets[†] (failure scenarios) having 1 or 2 events. Table 1 illustrates the breakdown of these qualitative results. They indicate that:

- Almost half (26) of the minimal cutsets were single-event failures primarily associated with the FIU, which indicates insufficient circuit redundancy in the system.

- The success of the system is keyed to a significant number of components in the FIU/ZIU circuit. It is also the common-mode failure point for all supervisory and alarm systems.

- Random failures of relays, rectifiers, and resistors may compromise the system. Because

Table 1. Breakdown of minimal cutsets.

No. of events	No. of different cutsets	Components involved
1	16	FIU
1	5	ZIU
1	3	Supervisory circuit
1	1	Emergency power supply
1	1	Smoke detectors
2	13	Supervisory circuit
2	11	Emergency power supply
2	9	FIU
2	1	Smoke detectors

*The output event above an "and" gate results from the co-existence of all input events. The output event above an "or" gate results from one or more of the input events.

[†]Critical paths whose failure causes system failure. They designate unique modes by which the top event can occur, and represent the causes of system failure.

Figure 1. Fault tree: FIU/ZIU does not transmit alarm when there is a fire in zone X.

these are typically unannounced failures, they are correctable only through competent inspection and service.

- The series design of the FIU/ZIU circuit precludes its operation during repair. Announced failures (single event) can be more readily controlled by timely, short repair schedules.

- Over half (34) of the minimal cutsets were two-event failures involving the supervisory circuit, FIU, off-site power, and the smoke detectors.

The quantitative analysis, aided by the computer code IMPORTANCE,³ calculated a top event probability of 1.0×10^{-3} per demand or a probability of success of approximately 99% per demand (there is uncertainty in the last significant digit). The computer code ranked the elements of the fault tree with respect to their individual contributions to the top event in addition to ranking the importance of the various cutsets. Important contributors to system failure were insufficient smoke to detectors and single-point failures associated with the reliability of individual relays in the FIU/ZIU circuit.

Conclusions

1. Our results show a high reliability figure of 99% per demand for this particular fire detection system. However, this figure is really not relevant unless it is compared to similar analysis of other systems. This study should be continued to include the analysis of at least two additional and dissimilar detector systems and/or components.

2. The qualitative analysis is the most meaningful part of the study. The identified components and failure paths provide a great deal of insight into design modifications, system specification, and inspection and maintenance schedules.

3. The primary common-mode failure point in the system is the FIU. The fact that all potential failures in the FIU/ZIU are 1- and 2-event failures make these units very susceptible to malfunction. The primary cause for these potential 1- and 2-point failures is lack of circuit redundancy

which is inherent to this particular design. And because the FIU is the heart of the circuit, great care should be taken to check circuit redundancy and/or reliability of relays and rectifiers when specifying equipment.

4. The supervisory circuit and battery emergency power supply produced the majority of the 2-event failures. In this case, reliability of relays, switches, and trouble lights should be looked at.

5. Maintenance and inspection procedures should be tailored to monitor those components which can fail unannounced.

6. It should be remembered that success in predicting the probability of a specific occurrence depends on how accurately the system is represented in a fault tree, how detailed the tree is, and how valid are one's mathematical expression and probabilities. A continuous effort should be made to obtain current and accurate component failure probability data. In addition, a comparison to historical statistics should be carried out to verify the analytically derived reliability figures.

7. Although this study did not look at the performance of the detector system under seismic conditions, the following will be generally true:

- (a) The mechanical response of the components will be highly dependent on mounting details.

- (b) The above is also true for wiring and solder joints.

- (c) The only quantitative way to evaluate this performance is to place the system on a large-scale shaking table and monitor continuity.

References

1. *Multi-Zone Fire and Smoke Detection Systems Description Brochure*, PYR-A-LARM Fire and Smoke Detection Systems and Components, Pyrotronics, Cedar Knolls, NJ (1980).
2. R. Willie, *FTAP: Computer-Aided Fault-Tree Analysis*, University of California, Berkeley, CA, ORC 78-14 (1978).
3. H. L. Lambert, *IMPORTANCE: The IMPORTANCE Computer Code*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-79269 (1977).

Publication Abstracts

N. Alvares, D. Beason, W. Bergman, H. Ford, and A. Lipska, *Fire Protection Countermeasures for Containment Ventilation Systems*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-84979. Presented at 16th Nuclear Air Cleaning Conference, San Diego, CA, October 20-23, 1980.

The goal of this project is to find countermeasures to protect HEPA filters, in exit ventilation ducts, from the Heat and Smoke generated by unwanted fire.

Methods developed to cool fire-heated air by fine water spray upstream of the filters are available and are currently installed in some new facilities where containment is an issue. Since exposure of HEPA filters to smoke aerosols could also cause disruption of the containment system definition of the problems, and modes of mitigation were sought.

Several potential faults could occur, including plugging of the HEPA filter which would cause overpressurization of the ventilated space, filter breakdown due to extreme pressure differential across the filter media, and penetration of the filter by condensable gas-phase pyrolyzates which could carry chemically combined toxicants with them.

We have identified, through testing and analysis, several methods to partially mitigate the smoke exposure to the HEPA filters. These independently involve controlling the fuel, controlling the fire, and intercepting the smoke aerosol prior to its sorption on the HEPA filter. Fuel and fire control involve standard fire protection practice (with some modifications for new materials and nontraditional geometries). Exit duct treatment of aerosols is not unusual in industrial applications and involves the use of scrubbers, prefilters, and inertial impaction depending on the size distribution and concentration of the subject aerosol. However, when these unmodified techniques were applied to smoke aerosols from fires on Laboratory materials, common to experimental laboratories of LLNL, we found they offered minimal protection to the HEPA filters. Ultimately, we designed a continuous, movable, high-efficiency prefilter using modified commercial equipment. Our technique is capable of protecting HEPA filters over the total time duration of the test fires. The reason for success involved the modification of the prefiltration media. Commercially available filter media has particle sorption efficiency that is inversely proportional to media strength. To achieve properties of both efficiency and strength, we laminated rolling filter media with the desired

properties. Our approach was Edisonian, but we truncated in short order to a combination of prefilters that were effective for our purposes. We do not believe that the use of rolling prefilters solely to protect HEPA filters from fire-generated smoke aerosols is cost effective in every type of containment system, especially if standard fire-protection systems are available in the space. But in areas of high fire risk, where the potential fuel load is large and ignition sources are plentiful, the complication of a rolling prefilter in exit ventilation ducts to protect HEPA filters from smoke aerosols is definitely justified.

N. J. Alvares, P. R. Hammond, K. L. Foote, and H. W. Ford, *Flammability of Fuel/Fluorocarbon Azeotropes*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85463. Presented at the First International Specialists Meeting of the Combustion Institute, Bordeaux, France, July 20-25, 1981.

When large quantities of flammable fluids are used in high pressure flow systems, the chance of accidental release of the fluids requires consideration of measures to alleviate the fire risk. If these operations are introduced into an existing facility where the original fire risk was low, retrofitting additional fire-protection equipment and control systems may be costly and can complicate other aspects of the operation. An alternative procedure would be to seek substitute liquids for the process, or to reduce the flammability of the desirable fluid by additives (in small concentrations) that do not interfere with the mechanism of the process.

We have specific use for methyl and ethyl alcohol (MeOH and EtOH) in systems of high volume and pressure. Where the risk of accidental release is small, but finite, increased fire protection is required. However, the cost and time delays caused by upgrading the existing fire-management system are extensive; therefore we have initiated a modest program to assess how effectively various noninterfering additives reduce the flammability of our solvents.

A. Biermann, A. Bogdanoff, W. Kuhl, and W. Bergman, *The LLNL Air Filter Test Facility*, Lawrence Livermore National Laboratory, Livermore, CA. Presented at the AIHA Conference, Portland, OR, May 25-29, 1981.

This paper describes the unique air filter test facility built at the Lawrence Livermore National Laboratory for conducting filtration R&D for the

Department of Energy. The facility consists of a large-scale test apparatus for evaluating standard size ventilation filters (610 mm $\times$ 610 mm) and two small-scale test apparatus for evaluating smaller filters (203 mm $\times$ 203 mm). The unique features of this facility include a fully computerized diagnostic system and filter test apparatus that can evaluate a wide range of filters ranging from small hand sheets and filter units to full-scale commercial units.

A Digital Equipment Corporation laboratory computer (LSI-11/23) has been interfaced to control and accept data from the above instrumentation. The computer uses the RSX-11M multi-user time sharing operating system and is supported by both hard and floppy disks, a graphics terminal with hard copy output, teletype terminals, and a line printer. The computer can handle both experimental test facilities simultaneously, calculate the necessary size distributions and filter efficiencies, and save the experimental results for comparison to theoretical models at a later time. Because of the time sharing operating system, the computer is still available for other problems while experiments are in progress.

With this computer data acquisition system, the total efficiency for a filter profile over the particle size range 0.005 to 10.0 μ m diameter can be seen in less than two minutes. The same operation without computer interfacing had previously taken over one day.

Illustrations will be given of typical filter evaluations. In air filtration R&D it is important to measure pressure drop across the filter, flow rate, particle mass loading, and the filter collection efficiency as a function of particle size and charge. Each filter test apparatus consists of an aerosol generator, an air duct for containment, drying and dilution, a filter housing, air blowers, and the analytical instrumentation for measuring temperature and relative humidity and the filter pressure drop, face velocity and efficiency. Aerosol concentration, size distribution, relative humidity, and flow rate can be maintained constant for each filter evaluations.

Usually polydisperse aerosols of sodium chloride or dioctylphthalate having number median diameters of 0.2 - 0.3 μ m are produced by nebulization. Monodispersed aerosols can also be generated, but are used primarily for instrumentation calibration. The major analyzers used for filter efficiency measurements are a Climet optical particle analyzer and a Thermo Systems electrical aerosol analyzer. The optical analyzer measures the number of aerosol particles as a function of

size in the range of 0.3 μ m to 10 μ m diameter. The mobility analyzer measures the number concentration in the smaller aerodynamic size range of 0.005 μ m to 1.0 μ m diameter. In combination, these two instruments give the total aerosol distribution of interest, 0.005 to 10 μ m diameter, and, by measuring the number concentration upstream and downstream of the filter undergoing testing, the filter collection efficiency as a function of particle size can be calculated.

In addition to these measurements, a Sinclair-Phoenix light scattering photometer is used to measure the size integrated filter efficiency. Along with the particle concentrations, the pressure drop across the filter and the mass flow rate are monitored. The flow rate can be varied from 0.5 to 50 cfm (0.7 to 78 cm/s) in the small-scale test apparatus and from 50 to 1500 cfm (6.4 to 191 cm/s) in the large-scale test apparatus.

A. Biermann, B. Lum, W. Kuhl and W. Bergman, *Studies on Clogging in Fibrous Filters*, Lawrence Livermore National Laboratory, Livermore, CA. Presented at the ACS/IES Winter Symposium, Tucson, AZ, Jan. 26-28, 1981.

This paper presents the recent findings of a comprehensive theoretical and experimental program to study filter clogging in fibrous filters. Two theoretical models have been developed which can qualitatively predict the increase in pressure drop and efficiency during filter clogging. The models represent limiting cases of the early and late stages of clogging. Each model is based on adding particle deposits with one of two limiting geometries to the single fiber representation of collection by clean filters. The first model, which represents the early stages of filter clogging, treats the particle deposits on the fibers as part of the originally clean fibers. Thus, during filter clogging, the fiber diameter is increased to include both fiber and new particle deposits. The second model, which represents the late stages of filter clogging, assumes that clogging occurs as a build-up of chain-like deposits outward from the fibers. These particle chains are treated as a new group of fibers having a different diameter and volume fraction than the original fibers. Using these models, expressions for pressure drop, collection efficiency, and mass loading are developed.

Theoretical predictions from these models were compared to filtration experiments using sodium chloride aerosols. Collection efficiencies as a function of particle size were determined at various stages of filter loading. Filter resistance and

mass loading are also monitored. In general, the theoretical predictions are in good qualitative agreement with the experimental results. Comparisons of theory and experiment are made showing the effect of face velocity and particle size on the filter efficiency and pressure drop. Experimental results have also shown that a fibrous filter at advanced stages of clogging has the same efficiency and pressure drop as a clean filter with comparable fiber volume fraction and fiber size.

C. A. Cadena, R. A. da Roza, J. S. Johnson, and R. D. Szidon, *Increasing the Life of Cutting Fluids Used in the LLNL Machine Shop*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19246 (1981).

Cutting fluids used in the main machine shop at LLNL are disposed of as contaminated liquid waste. The uranium and beryllium occasionally machined there cause the contamination. We studied methods of extending the useful life of the fluid and thus reduce the volume of waste produced. We considered fluid dilution, acidity, cleanliness, tramp oil and solids. A list of detailed recommendations has been provided to the machine shop superintendent. If implemented, these should significantly extend the effective life of the cutting fluid. We were not able to remove sufficient beryllium or uranium from contaminated fluids to reclassify them as uncontaminated.

R. L. Dobson and T. Straume, *Radiobiological Implications of New Dose Estimates for Hiroshima and Nagasaki*, Lawrence Livermore National Laboratory, Livermore, CA. Prepared for the Twenty-Ninth Annual Meeting of the Radiation Research Society, Minneapolis, MN, May 31-June 4, 1981.

Radiation doses from the Hiroshima and Nagasaki A-bombs have recently been recalculated by W. E. Loewe and E. Mendelsohn at Lawrence Livermore National Laboratory. These new estimates which differ substantially from the widely accepted T65 doses, indicate that the gamma-ray component and total dose were higher in Hiroshima than previously thought and lower in Nagasaki and that the neutron components were substantially lower in both cities.

When the new doses are used in reanalyzing dose-response relations from A-bomb survivor data, leukemia curves for both cities are sigmoidal and no longer significantly different from each other; they now suggest neutron RBEs near unity and risk coefficients at low doses compatible with

those of ICRP for low-LET radiation. Results are similar for breast cancer. However, the more extensive data for total malignancies and for chromosome aberrations show significant inter-city differences. If these differences are due to RBE effects, they suggest that neutron RBEs at low doses were quite high. This dependence on endpoint of inter-city differences, found also with T65 doses, needs explanation. Otherwise, the new doses fit well with epidemiological observations in Japan, and they improve consistency between A-bomb and other radiobiological data.

R. L. Dobson and T. Straume, Letter to the Editor, *Science* **213**, 8.

G. Espinosa and R. V. Griffith, *Evaluation of a Commercial, Semi-Automatic System for Counting Tracks in Solid State Nuclear Detectors Used for Personnel Dosimetry*, Eighth DOE Workshop on Personnel Neutron Dosimetry Report, PNL-SA-9950, pp. 88-96 (1981).

Abstract not available.

T. A. Gibson, Jr., C. B. Ozaki, and J. F. Becker, "The Health Physics Aspects of X-Rays Produced by Evacuated Microwave Wave Guides." *Health Physics* **40**, 893-894 (June 1981).

Abstract not available.

R. V. Griffith, *Personnel Neutron Dosimeters*, Lawrence Livermore National Laboratory, Livermore, CA. Prepared for presentation at the Measurement Science Conference, Anaheim, CA, January 30-31, 1981.

Abstract not available.

R. V. Griffith, K. J. Davidson, D. E. Miller and K. E. Vindelov, *Developments in Solid State Detectors for Personnel Neutron Dosimetry*, Eighth DOE Workshop on Personnel Neutron Dosimetry Report, PNL-SA-9950, pp. 77-87 (1981).

Abstract not available.

D. E. Hankins, *Albedo Neutron Dosimeters Used as Area Monitors on Concrete Walls*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85050. *Health Physics* **41**, 543-546 (Sept. 1981).

Abstract not available.

D. E. Hankins, *Design of Phantoms for Calibration of Albedo Neutron Dosimeters and the Use of Albedo Dosimeters as Area Monitors*, Lawrence Livermore National Laboratory, Livermore, CA. Presented at the Health Physics Society Annual Meeting, Louisville, KY (June 1981).

We determined the response of albedo dosimeters placed on 15 phantoms of different size, shape and composition which could be used for calibration of albedo dosimeters. Our results indicate that the size of the phantom required to give a response similar to that of a person can be relatively small. The most important feature of a phantom which affects the albedo dosimeters response is its shape. The highest albedo response is obtained from a flat surface and the lowest response from a doubly-curved phantom such as a sphere. Albedo neutron dosimeters require a body or other backscattering material to provide the low energy albedo neutrons. We have found that albedo dosimeters can be used as area monitors when placed on a block of polyethylene 4 by 4 by 2 inches thick. The response of albedo dosimeters on this block of polyethylene is similar to that obtained from the chest region of a phantom except when the block is placed on concrete walls. The walls reduce the response by 30% which can easily be corrected. The albedo dosimeter calibration procedure using the 9/3-in. sphere technique has been modified for use with wall-mounted dosimeters.

K. E. Hardis, C. A. Cadena, G. J. Carlson, R. A. da Roza, and B. J. Held, *Correlation of Qualitative and Quantitative Results from Testing Respirator Fit*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-83381 (1980).

Although qualitative methods have been used extensively to determine respirator fit, there was a question whether these approaches adequately tested for respiratory protection. Three qualitative methods were evaluated, i.e., tests for negative pressure and for penetration of isoamyl acetate and irritant smoke. These three were each performed concurrently with a single quantitative fit test, the dioctylphthalate (DOP) test, during 274 half-mask and 274 full-facepiece wearings. The values for DOP penetration after each qualitative test were lognormally distributed. The data collected were statistically unique for each mask type, and relatively large penetration values always corresponded to a failing qualitative test. The percentage of adequately fitting respirators,

based on a passing qualitative test, ranged from 96.3 to 100%. Based on each penetration value, the probability of passing or failing a given qualitative test can be calculated.

H. K. Hasegawa, N. J. Alvares, A. E. Lipska, H. Ford, and D. G. Beason, *Fire Protection Research for Energy Technology Projects: FY 1979 Year-End Report*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-18902 (1981).

This report describes work performed in fiscal year 1979, on a DOE funded study entitled "Fire Protection Research For Energy Technology Projects." The primary goal of this program is to ensure that fire protection measures for Fusion Energy Experiments (FEE) evolve concurrently with the complexity of FEE. Ultimately, it is planned that the detailed study of fusion experiments will provide an analytical methodology which can be applied to the full range of energy technology projects.

We attempt to achieve this objective by coordinately advancing three (3) major task areas; (a) determine the fire hazards of current FEE facilities (b) assess the ability of accepted fire management strategies to meet and negate the hazard, (c) perform unique research into problem areas we have identified to provide input into analytical fire growth and damage assessment models.

Through detailed study of the 2XIIB magnetic fusion facility and the Shiva laser fusion facility at LLNL, we have obtained a good engineering description of the state of the art of fusion fire protection. We applied fault-tree analysis to assess fault modes in the fire protection systems. Concurrently, we continue to develop analytical techniques for assessing the fire hazards of these facilities.

Furthermore, we have conducted general surveys, outside of LLNL, of several European and two domestic fusion facilities.

To support our fire growth and hazard analyses, preliminary techniques for physical and chemical aerosol analyses have been developed and implemented. In addition, preliminary measurements of the dynamics of cable fires in our small scale apparatus have been completed.

Finally, with the aid of Econ, Inc., we have drafted a loss assessment protocol which is the ultimate output of this study.

H. K. Hasegawa, N. J. Alvares, A. E. Lipska, H. Ford, S. Priante, D. G. Beason, *Fire Protection*

Research for Energy Technology: FY 80 Year-End Report, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53179 (1981).

This report describes work performed in fiscal year 1980, on a DOE funded study entitled, "Fire Protection Research for Energy Technology Projects." It is a continuing research program, initiated in 1977, chartered to advance fire protection strategies for Fusion Energy Experiments (FEE) in order to keep in stride with the complexity of fusion technology. Our charter has since been expanded to encompass other forms of energy research using the analytical methodology we are developing through the detailed study of two Lawrence Livermore National Laboratory (LLNL) FEE's.

We pursued this primary goal by concurrently advancing three major task areas; (a) determination of unique fire hazards of current FEE facilities; (b) evaluation of the ability of accepted fire management measures to meet and negate the hazards; and (c) performance of unique research into problem areas we have identified to provide input into analytical fire growth and damage assessment models.

Our accomplishments for fiscal year 1980, were as follows:

- Finalization of the fault-tree analysis of the Shiva fire management system;
- Development of a second-generation, fire-growth analysis using an alternate model and new LLNL combustion dynamics data;
- Improvements of techniques for chemical smoke aerosol analysis;
- Development and test of a simple method to assess corrosive potential of smoke aerosol;
- Development of an initial aerosol dilution system;
- Completion of primary small-scale tests for measurements of the dynamics of cable fires;
- Finalization of primary survey format for non-LLNL energy technology facilities; and
- Studies of fire dynamics and aerosol production from electrical insulation and computer tape cassettes.

B. J. Held, "Facial Hair and Breathing Protection," *International Fire Chief*, 46(12), Dec. 1980.

Because of its research in respiratory protective devices used by the fire service and industry, LLNL receives numerous requests for information about breathing protection. By far, the greatest number of letters and phone calls from the fire

service concern the use of breathing apparatus by fire fighters with beards, long sideburns, or extra-long moustaches. Periodically, there are grievances filed and hearings held for reprimands and dismissals issued by both industry and fire service because a user of a respiratory protective device refused to shave excess facial hair, claiming a violation of personal rights. These are complicated occasionally by a condition, found usually in black males, in which shaving causes mild to severe irritation to the skin.

Since the problem of facial hair and breathing apparatus is of such widespread interest and concern, this article will discuss the situation and try to put it into perspective. While this article may not provide the answers to specific problems, which may involve emotional factors, it will give some specific information known about facial hair and breathing protection.

B. J. Held, N. J. Alvares, D. G. Beason, C. A. Harder, and J. W. Stengel, "Fire Tests on Closed-Circuit Oxygen Breathing Apparatus," *International Fire Chief* 46(11), Nov. 1980.

At the public hearings into the proposed Occupational Safety and Health Administration Fire Brigade Standard, held in August/September 1979, much of the testimony debated whether closed-circuit oxygen breathing apparatus, particularly of the positive pressure type, was safe for fire fighting use. Since closed-circuit, oxygen, self-contained breathing apparatus (SCBA) is the only type available with a rated use greater than 30 minutes, it may be needed for fire fighting in high-rise buildings, mines, tunnels, and below decks on large ships.

However, it may impose an increased hazard to the fire fighters in the event of a poor facepiece fit or other inadvertent oxygen leak that could result in high oxygen concentrations on the exterior of the mask.

LLNL has a 40-person fire department which has the responsibility for fire combat and fire protection on site, at a nearby field test station and in mutual aid to surrounding communities. The fire fighters occasionally face situations where they need to have breathing protection for durations longer than the capacity of normal SCBA. Because of this need, the fire department has surveyed critically closed-circuit SCBA, including positive pressure types. The department has elected not to include them in its breathing protective equipment until they have been proven non-hazardous to the personnel.

B. J. Held, C. A. Harder, and D. G. Beason, "Operation of Self-Contained Breathing Apparatus Exposed to Ultra High Temperatures," *International Fire Chief* 47(3), March 1981.

In order to ensure that the fire fighters at LLNL are provided with self-contained breathing apparatus (SCBA) that would protect them best in the fire conditions they might encounter, the laboratory conducted a series of tests to determine which environmental factors might affect their SCBA operation adversely. Knowing these factors enables the selection of the most appropriate make of SCBA for their use and the training to minimize any SCBA problems which could occur under certain conditions.

This magazine has reported, in previous articles, the results of tests conducted on SCBA while operating under various environmental conditions. This article covers test results when open-circuit SCBA were operated for three minutes at 250°C (485°F) and when facepieces from these units were exposed to open flames for a total of 10 seconds.

S. S. Hoots, 1963 Revisited—Should we Set a Precedent of Recalculating Old Exposures?, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85457. Prepared for presentation at 26th Annual Health Physics Society Meeting, Louisville, KY, June 22-25, 1981.

In 1963, some Lawrence Livermore National Laboratory (LLNL) employees participated in fission burst reactor experiments based at a remote site. In those days, beta exposures were not routinely monitored at this site, although film badges were worn and analyzed for penetrating dose. Today's emphasis on skin cancer and radiation encouraged one LLNL employee to seek assessment of the skin and hand dose from beta radiation he acquired while working many hours on enriched uranium reactor parts. These parts had undergone fast fission bursts within days and/or weeks prior to his work. Recalculation included research into the low nonexistent reactor assembly—the knowledge of the specifications as well as the actual condition of the parts was needed. Although there was a final report on the system, most useful information came from the facility logbook and from the health and safety logbook.

Presented here are the calculations. We expended much time and effort on these results. Included also are comments and afterthoughts which consider the possible consequences from

reevaluations. The final question is: How do we deal with dose reevaluations in the future?

J. S. Johnson, Lawrence Livermore Laboratory's Beryllium Control Program for High-Explosive Test Firing Bunkers and Tables, Lawrence Livermore National Laboratory, Livermore, CA, UCID-18006 (1980).

This detailed report on Lawrence Livermore Laboratory's control program to minimize beryllium levels in Laboratory workplaces includes an outline of beryllium surface, soil, and air levels and an 11-y summary of sampling results from two high-use, high-explosive test firing bunkers. These sampling data and other studies demonstrate that the beryllium control program is functioning effectively.

R. C. Kaifer, T. E. Jenkins, and T. Straume, Wide-Range Monitor for Pulsed X-Ray Sources, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85937 (1981). Presented at the 1981 Nuclear Science Symposium, San Francisco, CA, October 21-23, 1981.

A monitoring instrument based on a high-pressure ionization chamber has been developed that measures average dose rates as low as 0.1 R/h and responds linearly to short pulses at dose rates up to 1.2×10^{10} R/h. Its sensitivity can be remotely changed by a factor of 10^4 , to enable accurate measurement of both background radiation and very high intensities such as can be expected from accelerator beam-spills. The instrument's detector-electrometer pulse response was measured using a dose-calibrated field-emission accelerator having a 30-ns pulse width.

C. L. Lindeken, Radiological Considerations of Phosphogypsum Utilization in Agriculture, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-84927. Prepared for presentation at International Symposium on Phosphogypsum, Lake Buena Vista, FL, November 5-7, 1980.

There are three areas of radiological concern associated with phosphogypsum utilization in agriculture and all of these are related to its radium content. First, there is concern over the buildup of radium in soil as a consequence of long term use, which may result in possible radiation exposure to agricultural workers. Second, and also related to this buildup, is the uncertainty regarding radium transfer to man via uptake of radium by agricul-

tural crops. The third concern presupposes that land use will ultimately change from agricultural to residential and that the radium in the soil might then constitute a hazard to occupants of residences built on the land.

These concerns can be placed in perspective by considering a hypothetical case involving extended heavy applications of phosphogypsum. In California, initial gypsum application of 10 tons/acre may be made for reclamation purposes followed by alternate year applications of 5 tons/acre for soil quality maintenance. This initial application is about ten times the application rate typically employed in the southeastern states. If the radium content of the phosphogypsum were 15 pCi/g and the till depth 6 inches, this schedule could be maintained for more than 100 years before the radium buildup in the soil would reach a proposed federal concentration limit of 5 pCi/g.

A uniform concentration of 5 pCi/g of radium distributed through the top 6 inches of soil results in an estimated terrestrial exposure rate of 7 μ R/hr and an estimated average airborne radon daughter concentration of 0.012 working levels (WL). The estimated terrestrial exposure rate is within the range of natural background from naturally occurring radionuclides in the soil. The radon daughter WL estimate is comparable to the 0.015 WL guidance set for indoor (residential) exposure, but should not be applied to agricultural workers.

Radium uptake expressed as the ratio of radium in dry weight foodstuff to the radium in the soil is typically in the range of 0.01. Assuming a consumption of 80 g/day (dry weight) of vegetation grown on soil containing 5 pCi/g of radium, this uptake would result in a daily radium intake of 4 pCi/day. However, the radium uptake ratio of 0.01 may be too high. In a matrix containing calcium in excess, gypsum may actually inhibit plant uptake of radium through the common ion effect. The mean daily intake of ^{226}Ra in the standard U.S. diet is about 1.4 pCi, but varies at least from 0.7 to 2.1 pCi.

Land use conversion from agricultural to residential has the greatest potential for concern, since soil with 5 pCi/g of radium can generate airborne radon daughter concentrations in the range of the guidance limit for residential exposure.

C. L. Lindeken, W. J. Silver, and M. A. Auyong,
Use of $^{234}\text{U}/^{238}\text{U}$ Measurements in Determining the Source of Uranium in Groundwater, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-84505. Prepared for presentation at the 26th An-

nual Bioassay, Analytical and Environmental Conference, Ottawa, Canada, October 14-15, 1980.

A water well at the Lawrence Livermore National Laboratory's (LLNL) Site 300 contains about 40 pCi/l of uranium. Because depleted uranium (the tailing in the gaseous diffusion separation of ^{235}U from ^{238}U) is used in high explosive tests at the Site, it was important to determine if the uranium observed in the water was due to Laboratory operations. Naturally occurring uranium is usually differentiated from depleted uranium by differences in the $^{235}\text{U}/^{238}\text{U}$ ratio. An alternate method of differentiation is based on $^{234}\text{U}/^{238}\text{U}$ measurements. Measurements of ^{234}U , ^{235}U , and ^{238}U using both mass spectrometry and alpha pulse spectrometry demonstrated that the uranium in the well water was naturally occurring. This paper discusses uranium source determinations based on isotopic distribution and the problems associated with the use of $^{234}\text{U}/^{238}\text{U}$ ratios.

A. Lipska, S. Priante, D. Beason, H. Ford, and S. Stover, *The Combustion of Reels of Magnetic Tapes*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-18976 (1981).

Thermal degradation of magnetic tape assemblies used at the National Fusion Energy Computer Center was subjected to thermogravimetric analysis (TGA) and differential scanning calorimetric analysis (DSC) as well as to two large-scale flammability tests. The TG measurements were done in nitrogen and in air at heating rates of 2.5, 10, and 20°C/min from ambient to 600°C. The DSC measurements were performed in nitrogen at 10°C/min. This part of the experimental endeavor was designed to learn as much as possible about formulations used in preparing the plastic composites. In addition, we had also monitored the production of corrosive ions generated in the TG apparatus as well as in the test cell.

One of the large-scale tests used a diffusion flame to ignite the tape reels, the other used a very low Bunsen flame. The tests measured the rate of oxygen depletion temperature rise in several locations of the test cell, total hydrocarbon production, CO and CO₂ formation and the rate of corrosive products as well as flammable and toxic products formation.

Results show that the magnetic computer tapes, reels, and cases: 1) decompose at fairly low temperatures; 2) do not release detectable amounts of corrosive products at low heating

rates; 3) release small amounts of detectable corrosive products at high heating rates; 4) form a variety of chemicals upon thermal degradation. The physical and chemical properties of these products are not readily available and therefore should be further investigated from both the possible health and flammability hazards; and 5) ignite readily, produce copious amounts of smoke and are extremely hard to extinguish with water once the assemblies are fully involved.

M. L. Mendelsohn, T. Straume, and R. L. Dobson, *Sensitivity of Hiroshima and Nagasaki Epidemiological Inferences to Dosimetric Parameters*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86621 (1981). Prepared for Proceedings of Symposium, DOE Series Reevaluations of Dosimetric Factors, Hiroshima and Nagasaki, September 15-16, 1981.

An analysis is made here of the influence that various possible values of physical dosimetric parameters can have on radiobiological interpretations of Hiroshima and Nagasaki epidemiologic data. The physical parameters studied, which include yields of the weapon devices, neutron and gamma-ray outputs, and slopes of the dose-versus-distance functions, are allowed to vary over reasonable ranges and the resulting effects on a representative biological endpoint are evaluated. The endpoint used is radiation-induced chromosome aberrations in blood cells of A-bomb survivors. While this is statistically perhaps the strongest set of biomedical observations available for the purpose, it is used here simply as an indicator endpoint for exploring the biological consequences of varying the physical parameters.

G. O. Nelson and G. J. Carlson, *Prediction of Service Life of Organic Vapor Respirator Cartridges*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85005 (1980).

We find the two most commonly used cartridge service-life models exhibit anomalous results at low concentrations. The Statistical Moment equation, for example, produces negative breakthrough times for many solvent-vapor concentrations less than 10 ppm. The Wheeler equation yields decreasing breakthrough times as the challenge concentration is lowered. This decrease is especially evident with relatively volatile vapors such as methanol, formaldehyde, and vinyl chloride.

G. O. Nelson, G. J. Carlson, and J. S. Johnson, *Service Life of Respirator Cartridges for Formaldehyde*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19155 (1981).

Formaldehyde is widely used, both as a preservative and as a disinfectant. Because of recent evidence indicating a carcinogenic potential for this compound, studies were performed on the service life of respirator cartridges for formaldehyde. An experimental system was designed to produce relatively high concentrations (20 ppm) of formaldehyde and challenge the cartridges with the vapor stream. A NIOSH-approved wet chemical technique utilizing chromotropic acid was used to verify the formaldehyde concentrations in the study. Twenty-five cartridges were tested for the service life of a concentration of formaldehyde gas from 7.1 to 14.8 ppm. Acid gas cartridges and those containing Pittsburgh FCA or ASC carbon showed superior service life.

M. S. Singh and M. A. Summers, *Residual Radioactivity and Energy Deposition in KDP Crystals From 14.7 MeV Neutron Activation*, Lawrence Livermore National Laboratory, Livermore, CA. Presented at the Health Physics Society Annual Meeting, Louisville, KY, June 1981.

Potassium dihydrogen phosphate (KDP) crystals were irradiated at the Livermore Rotating Target Neutron Source Facility (RTNS-II) with 14.7 MeV neutron fluences up to 1.8×10^{15} n/cm². We calculated the energy deposition in the crystal from the elastic and non-elastic nuclear interactions and decay of neutron induced residual nuclei. Measurements of emission from nuclei with half-lives of several hours agreed closely with the neutron transport calculations. Our theoretical analysis and experimental measurements showed that most of the residual radioactivity is comprised of short-lived beta emitters. This activity can be easily shielded against using a few millimeters of glass or aluminum. Our analysis showed that the exposure level from the gamma ray component is negligible. Safety precautions required during handling of the irradiated KDP samples are also discussed in this paper.

T. Straume and R. L. Dobson, "Implications of New Hiroshima and Nagasaki Dose Estimates: Cancer Risks and Neutron RBE," *Health Physics* 41, 666-671 (Oct. 1981).

Abstract not available.

T. Straume and R. L. Dobson, *Leukemia and Cancer Risk Estimates from Recalculated Hiroshima and Nagasaki Doses*, Lawrence Livermore National Laboratory, Livermore, CA. Presentation made at Health Physics Society Annual Meeting, Louisville, KY, June 1981.

A recalculation of radiation doses delivered by the A-bombs at Hiroshima and Nagasaki has recently been done by E. Mendelsohn and W. Loewe at Lawrence Livermore National Laboratory. These new estimates, significantly different from presently accepted T65 doses, indicate that the gamma-ray component and total dose were higher in Hiroshima than previously thought and lower in Nagasaki, while the neutron components were substantially lower in both cities.

Using these new dose values together with existing data from cancer in A-bomb survivors, we have reanalyzed dose-response relations. In contrast to earlier conclusions from T65 doses, the leukemia response curve for Hiroshima becomes nonlinear, similar to that for Nagasaki, rising more steeply at higher doses. The curves for the two cities now appear not significantly different from each other. This makes it difficult to draw conclusions about RBE from these particular data, but values for the leukemia mortality risk coefficient (deaths per person · rad) can be derived. At low doses the value is consistent with that given in ICRP 27, 20×10^{-6} deaths per person · rem. However, at large doses (e.g., 100 rad) the coefficient appears to be several fold higher. Using the new dose estimates, risk coefficients are also derived for breast cancer and for other malignancies.

T. Straume and K. Raschke, *Underground Storage of Spent Reactor Fuel: Emplacement in Granite at the Nevada Test Site*, Lawrence Livermore National Laboratory, Livermore, CA. Presentation made at Health Physics Society Annual Meeting, Louisville, KY, June 1981.

Eleven spent fuel assemblies from an operating commercial nuclear power reactor were emplaced in a granite formation at NTS 420 m below surface ground level. Electrical heaters were added in two separate drifts to simulate the temperature, stress and displacement fields of a large fuel repository. This poster session describes the project in general and how radiation safety was designed into the facility and fuel handling operations.

A. J. Toy, C. L. Lindeken, K. S. Griggs, and R. W. Buddemeier, *Environmental Monitoring at the Lawrence Livermore National Laboratory: 1980 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50027-80 (1981).

Abstract not available.

C. L. Wanç, R. Kalibjian, and M. S. Singh, *Design of Neutron Streak Camera for Fusion Diagnostics*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86162 (1981). Prepared for the Tenth European Conference of Controlled Fusion and Plasma Physics, Moscow, USSR, Sept. 14-19, 1981.

In laser fusion, such as with the NOVA under construction at the Lawrence Livermore National Laboratory, the D-T reaction is expected to be complete within 100 ps. It is important to measure the time-dependence of the neutron flux from the fusion target. We describe the design of a new neutron detector of 20 ps resolving time that can be used to study the "history of fusion burn."

C. K. Westbrook, D. G. Beason, and N. J. Alvares, *An Experimental and Theoretical Study of Flame Inhibition by Bromine-Containing Compounds*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-85409. Presented at the First International Specialists Meeting of the Combustion Institute, Bordeaux, France, July 20-25, 1981.

Flame inhibition by halogenated compounds is an important problem having great practical and theoretical interest. Experimentally, inhibition and retardance of flames has been observed for many years, and the properties of many different inhibitors have been catalogued. With halogenated species, it is well known that bromine and iodine are substantially more effective inhibitors than are chlorine or fluorine. In addition, the rate of inhibition is roughly proportional to the number of halogen atoms present, so that CHBr_3 , CH_2Br_2 , and CH_3Br reduce the flame speed in methane-air approximately in the ratio 3:2:1. Relatively little detailed kinetic modeling work on flame inhibition has been carried out. Dixon-Lewis and co-workers studied H_2 -air flames inhibited by HBr , and Westbrook has examined methane-air and methanol-air flames inhibited by HBr and by CH_3Br . The present paper represents the first effort to date in which a combined experimental and theoretical approach has been used to study the effects of several inhibitors on hydrocar-

bon-air flames. This work is part of an attempt to build a consistent picture of chemical kinetic flame inhibition, beginning with a simple halogen

molecule such as HBr and progressing sequentially towards more complex and more practical inhibitors such as CF_3Br .