AN AUTOMATED TLD SYSTEM FOR GAMMA RADIATION MONITORING

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Summary

A gamma radiation monitoring system utilizing a commercially available TLD reader and unique microcomputer control has been built to assess the external radiation exposure to the resident population near a nuclear weapons testing facility. *Maximum use of the microcomputer was made to increase the* efficiency of data acquisition, transmission, and presentation, and to reduce operational costs. The system was tested for conformance with an applicable national standard for TLD's used in environmental measurements.

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Introduction

While the measurement of radiation exposure to personnel working in nuclear facilities is not new, it is only in relatively recent times that sufficiently sensitive systems have been developed to measure the external radiation exposure in the environment outside. The increasing interest of scientists and laymen alike in the possible health effects of low level ionizing radiation has created strong pressure for more precise measurement of ever lower radiation levels which, in turn, has required more sophisticated data handling and analysis techniques. Fortunately, developments in electronic instrumentation have advanced to the point where equipment is now available which can perform such tasks with speed and ease. The use of microcomputers has revolutionized the instrumentation field, and radiation measurement instruments have just begun to be affected.

For many years thermoluminescent dosimeters (TLD's) deployed in a large network, have been used to measure the background radiation exposure in the area surrounding the U.S. Department of Energy's Nevada Test Site. Located in south-central Nevada, the Test Site and its exclusion area form a rough rectangle 150 km north-to-south and 125 km east-to-west that is primarily used for the underground testing of nuclear weapons. Under a memorandum of understanding, the U.S. Environmental Protection Agency and previously the U.S. Public Health Service have conducted the offsite radiological monitoring program. This consists of continuous and systematic efforts to assess the radiological impact of the nuclear testing program on the nearby offsite environment and its residents, many of whom live in the small communities and far-flung ranches which dot this vast area. Portions of western Utah, Nevada, and eastern California are routinely monitored by the TLD network for external gamma radiation.

Although TLD's had been used for this monitoring since 1965, the original system was labor intensive and lacked the desired sensitivity for background level measurements.[1] In order to minimize the manpower required for the routine handling of the TLD's and the processing of the data, some type of automatic system seemed appropriate. The Harshaw* Model 2271 Automated TLD System was purchased in 1973. Since the background radiation levels in much of the area are generally lower than the nationwide average, the highly sensitive phosphor, dysprosium-activated calcium fluoride (CaF_2:Dy), designated TLD-200 by Harshaw, was selected as the thermoluminescent (TL) material. Handling and processing techniques were then developed and tested, and the first field data was obtained in late 1974. The system was accepted for routine use in July 1975.

As confidence and experience in the use of this TLD system was gained, it was felt that more attention should be paid to the data handling activity, which still required considerable manual effort. Therefore, in 1978 an improved reader control system and data handling scheme based on a micro-computer was designed, and the necessary additional equipment was purchased. The new system has been in routine use since mid-1979 and performs the TLD readout, quality control checks, and preliminary report preparation locally. Data are then formatted for transmission to a larger host computer for more sophisticated analysis.

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* Use of brand name does not imply endorsement by the U.S. Environmental Protection Agency.

TLD System

The reader is a Harshaw Model 2271 Automated TLD System, shown in Figure 1, which has been described in detail elsewhere.[2] It is unique in that the solid thermoluminescent material, in the form of a 3.2- by 3.2- by 0.89-mm "chip", is permanently mounted to a 43- by 31-mm aluminum card onto which is glued a Mylar mask covering a punched hole array which makes up the individual card identification number. This code is optically scanned for each card during readout. Furthermore, the card contains two chips, each of which is sandwiched between thin sheets of Teflon plastic and suspended in two 9.5-mm holes punched in the card as shown in Figure 2. Up to 250 of these cards may be loaded into a tray from which they are sequentially fed into the reader. At the operator's discretion it can be programmed to read one or both chips at a selectable temperature for a selectable time. A typical readout time is 10 seconds per chip to a maximum temperature of 300°C. Each chip is sequentially heated by a solenoid-driven hot finger equipped with thermocouple feedback control for temperature reproducibility. The actual current integration and timing is performed by a Harshaw Model 2000B Integrating Picoammeter.

The main advantages of the system are the machine readable identification on each dosimeter, the automatic reading of many dosimeters in a carefully programmed heating cycle, the generation of computer-compatible output, and the capability for external program control. These are the essential features of any automated system, as they allow the use of computer control for flexibility and data processing techniques to produce several levels of

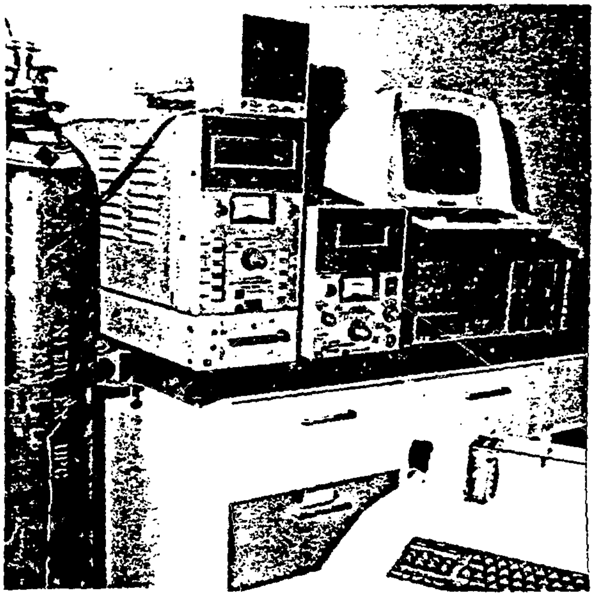

Figure 1 Harshaw 2271 Automated TLD System

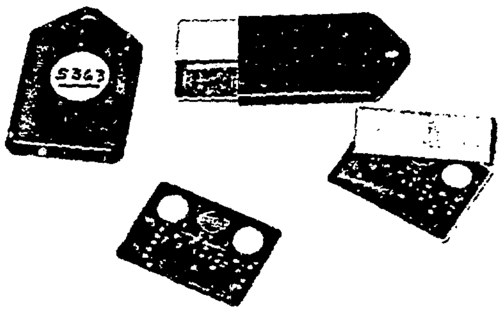

Figure 2 TLD Card

sophistication in dosimetry reports. The lack of flexibility in both dosimeter configuration and operating regimen is a disadvantage of the system. Only the specially designed dosimeter cards can be read by the system, thus restricting the actual dosimeter to the 3.2- by 3.2-mm chip. Furthermore, since the chip is permanently mounted to the card by the thin Teflon sheet, it may not be possible to optimize the heating cycle for the phosphor without damaging the plastic.

As the TLD system was designed primarily for use in personnel dosimetry, several adaptations were required to make it suitable for environmental measurements. The TLD material most commonly used, lithium fluoride, was not considered sufficiently sensitive for this application, and TLD-200 (CaF_2:Dy), a more sensitive phosphor, was selected. This, in turn, strongly influenced the design of the dosimeter card holder because an energy compensation shield was required to minimize the over-response of the TL material to photons in the 100- to 150-keV energy range. Sheets of 1.2-mm thick cadmium metal (99.99% pure) were chosen for this shield for both their physical characteristics and economy. Cadmium was considered a reasonable compromise since the dosimeters were not intended for use in any area with a significant neutron flux. A sheet of 0.1-mm polyethylene was placed between the dosimeter card and the metal shield to protect the card from abrasion. The result was an energy response which is uniform within ±25% from 80 to 1000 keV, but which drops rapidly below that range. This was considered acceptable as the data were intended to assess the whole body dose to the population, and low energy photons in typical background spectra contribute a negligible amount to the whole body dose.[3] The energy response of the dosimeter is shown in Figure 3. To provide a weatherproof, light-tight, and protective covering, a two-piece high impact polystyrene plastic holder was also designed. The holder is relatively tamperproof, but easy to assemble and disassemble. For identification, the dosimeter card number is written on a colored adhesive label and applied to the outside of the holder at the time of assembly.

All operations on the dosimeter cards, i.e., dedosing before use, post-irradiation annealling, and readout, must be done by the reader in some modification of the readout sequence. Oven annealling of the cards is not recommended. Therefore, when it was found necessary to employ a post-irradiation anneal prior to the readout in order to minimize the well-known fading characteristics of the TLD-200 phosphor, considerable experimentation was required. Heating the individual chips to 160°C for a 10-second period prior to the final readout minimized the signal contribution from the fast fading, low temperature traps.

To date only the TLD-200 dosimeters have been used routinely at this Laboratory but, as mentioned before, the Harshaw 2271 Automated TLD system has been used elsewhere for personnel monitoring. For that purpose lithium fluoride has been more commonly used, either in the form of lithium enriched in the ^{6}Li isotope, which is sensitive to both neutrons and gamma rays, or lithium enriched in the ^{7}Li isotope, which is insensitive to neutrons. With appropriate phosphors, packaging, and shielding, TLD cards can be used for beta, gamma, and neutron dosimetry.

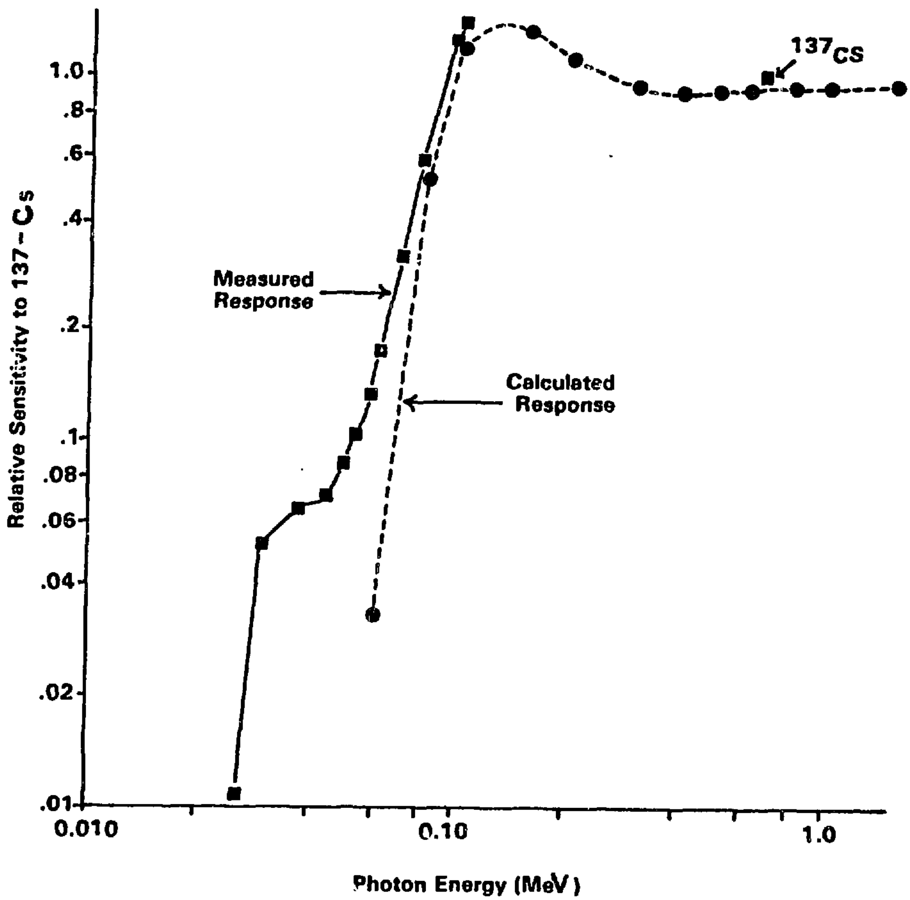

Figure 3 Dosimeter Energy Response (3.2- by 3.2- by 0.89-mm CaF_2:Dy chips with 1030 mg/cm^2 cadmium shield)

While the 2271 system has generally performed well, it is certainly not without problems — some of which are as unique as its design. For example, the glue which holds the Mylar mask to the aluminum card was a continuing source of annoyance until the manufacturer found a type which would neither dry out nor creep. Tiny drops of glue oozing from the early model cards were enough to foul the narrow clearances within the handling mechanism, causing a fault condition during processing. The newest cards use a superior glue which does not ooze, eliminating many of those problems. The close tolerances of the card handling mechanism presented other problems when a new batch of cards was found to be slightly oversize, requiring some modification of the card feeding chute. Because the TLD-200 material is not commonly used with this system, the manufacturer used his own readout regimen during the acceptance testing of a new batch of cards made for this laboratory; however, the results were different from those obtained by the purchaser, and considerable effort was required to resolve the discrepancy. While many improvements have been incorporated into the system design since its inception, there is no doubt that the weakest aspects are its mechanical features. Very few serious electronic problems have thus far been encountered.

Microcomputer Control

The 2271 system is designed to be used alone with a simple programmed reading sequence and visual fault indicators, or under external control with a more sophisticated programming device setting the operational sequence. We chose to implement the external control using a Northstar Horizon Microcomputer, consisting of a Z-80 microprocessor, 32 kilobytes of read/write memory, and dual Minifloppy magnetic disk drives. Parallel interface ports are available for connection to the 2271 reader and the 2000B integrating picoammeter, while a video terminal, 120-cps printer, and 1200-baud modem are connected via two RS-232C EIA-compatible serial interface ports. A block diagram of the system is shown in Figure 4.

An extended version of the BASIC programming language is available for this microcomputer and was chosen for the TLD Reader Operating System because of its simplicity and free data entry format. While a FORTRAN language compiler is also available, for our purposes its use would be unnecessarily complicating and the data entry format overly rigid. It is likely, however, that FORTRAN implementation would result in faster program execution. The programs that constitute the TLD Reader Operating System may be roughly divided into two categories: first, the data acquisition programs, in which the microcomputer and reader interact to produce the basic TLD readout and quality control data; second, the data manipulation programs, in which the microcomputer acts alone to perform a series of calculations and error checks on the data previously acquired and produces several types of reports and data files. Both of these are detailed as follows.

Data Acquisition

The most important program in the TLD Reader Operating System controls the readout of the TLD cards, and is designated TLDR. This BASIC program opens a data file on the disk, initializes the 2271 and 2000B components, prompts the operator to enter the date and other identification information,

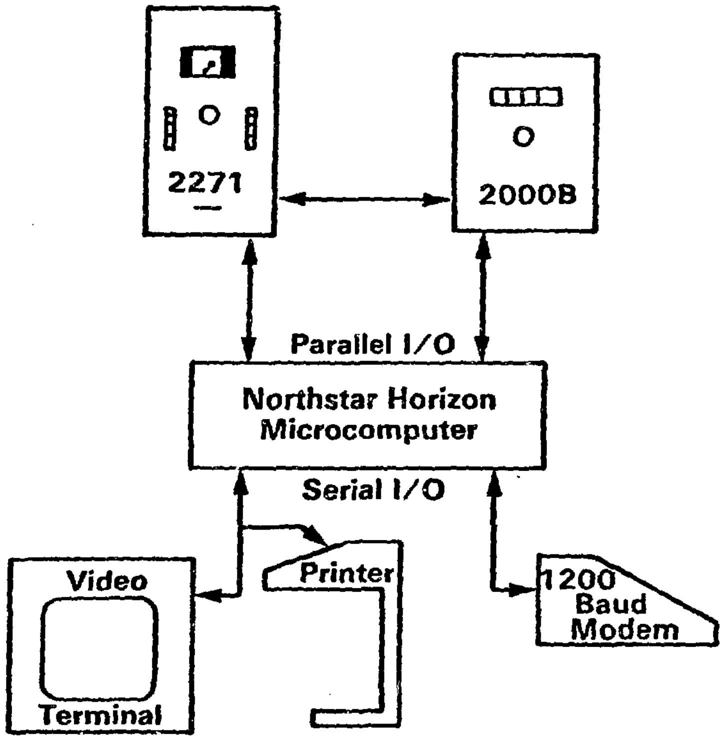

Figure 4 TLD System Block Diagram

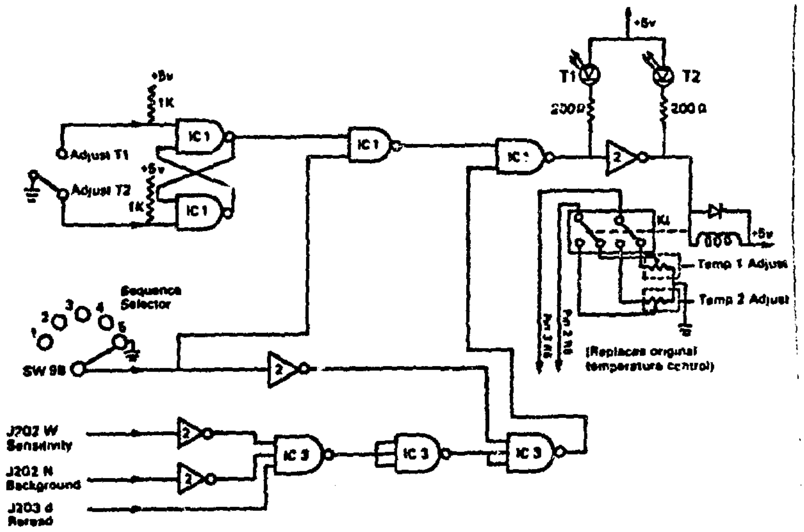

Figure 5 Dual Temperature Modification to Harshaw model 2271

provides for the acquisition of quality assurance information, and starts the actual readout sequence by a command to the 2271. TLDR controls the readout sequence while utilizing many of the capabilities of the 2271. These include measurement of photomultiplier tube dark current (or background) and a built-in light source (or reference light) for quality assurance. TLDR also interprets the fault interrupt logic of the 2271 to provide both audible and visual indications of any reader error, e.g., a jammed dosimeter card, a reversed card, a heater malfunction.

Under normal operation with microcomputer control, the TLDR program initiates the readout cycle for the first card, which drops by gravity until the first chip is in the reading position. This portion of the program is written in Z-80 assembly language because the 2271 operation is asynchronous and some events pass too quickly to be handled under BASIC program control. The chip is then heated in a carefully controlled time and temperature sequence, and the integrated photomultiplier tube current is measured by the 2000B. At the end of the heating cycle, signaled by a logic pulse from the 2000B, control is returned to the BASIC language program, which stores the accumulated reading on the disk file and also prints it out (if desired). The card then drops to the second chip position and the sequence is repeated. The card drops once more, and the coded identification number is read and stored on the disk file. The card then passes into the receiver tray and the next card is prepared for readout. Thus for each card a minimum of three pieces of information are stored: the TL readout of the first chip, the TL readout of the second chip, and the card identification number.

The 2271 has the internal program capability for both reading and rereading each dosimeter chip during the readout sequence. This capability, coupled with the need for post-irradiation annealling of the TLD-200 chips, led to the only significant modification that was made to the 2271 reader. Originally the post-irradiation anneal required every card in a readout group to be processed through the reader and each chip to be heated to a maximum temperature of 160°C. The cards were then manually reloaded, and the operation was repeated with a maximum temperature of 300°C. With the addition of a duplicate maximum temperature control and some switching logic to allow the "read" and "reread" functions to be accomplished at different maximum temperatures, the post-irradiation anneal and the readout now happen in a single processing of the card through the reader. A schematic diagram of the modification is shown in Figure 5.

Because the dual temperature modification complicated the readout sequence, separate data files were established on the disk to record the "read" function (post-irradiation anneal) and the "reread" function (the actual readout). While the former is not routinely used in further analysis, we have found "read" function data to be of value for diagnostic purposes when problems develop. At present the data files have a maximum length of 250 TLD card readings, but the length is somewhat arbitrary. The readout normally continues until all the cards in the tray have been read, at which time the data files are closed. If at any time during the readout a fault should develop, program TLDR will interpret the fault logic of the 2271 to determine the failure mode while simultaneously closing the data files to protect the data already written. Manual intervention is usually required to correct the fault, and the program then allows the data file to be reopened and the readout sequence to continue.

Microcomputer control of the 2271 has made it possible to perform operations that were previously both tedious and difficult. The dual temperature heating cycle, for example, became practical only when two data files could be established to store the anneal and readout data separately. Where it was previously necessary to insert a special blank dosimeter card into the tray to obtain background and reference light readings, program control now does this with ease. The microcomputer allows greater efficiency during the dedosing operation as well. While several passes through the reader formerly were necessary to dedose the dosimeter chips adequately before issue, program control now repeatedly applies the standard heating cycle to each chip until it gives an acceptably low signal. If this does not occur after a predetermined number of cycles, an alarm sounds to indicate an unacceptable dosimeter. This has saved considerable operating time while minimizing wear and tear on both the reader and dosimeter cards.

Data Manipulation

There are three general types of files used by the microcomputer for data storage and report generation. As previously outlined, a file is created to store the data from the dosimeter readouts and is formatted specifically to accept the output from the 2271 system. A second type of file is used to store the sensitivity correction factors for each serially numbered TLD card in the inventory. Before it is used for field measurements, each dosimeter is given several controlled exposures from which a sensitivity correction factor is calculated for each chip. This process is repeated periodically over the life of the card. The use of correction factors tends to minimize the variance of the corrected readouts and is essential for exposure calculations of background levels. The third type of file was developed to store the location, date and time information from the field cycle. These elements are necessary for the calculation of the average exposure rate. Field data cards provide such information as the monitoring location, TLD identification numbers, issue and collect dates, and any other pertinent observations, and are completed by the individuals who issue and collect the TLD's. A custom-designed key-to-disk program uses the video terminal and a prompting scheme to simplify the field data entry.

When a group of dosimeters is prepared for issue, a sample is set aside in a low background area in the laboratory for calibration. Midway through the field cycle, half of the sample is exposed to a known amount of radiation. The calibration dosimeters are read with the dosimeters returned from the field. Once the TLD data and the field data have been stored on the disk file, the operator should make several checks to see if the system is performing properly. The PM tube background and reference light readings indicate the stability and sensitivity of the reader. Readings of the calibration dosimeters provide a factor relating the amount of light output from the TLD to its radiation exposure. A program called CALFAC calculates the mean and standard deviation for both the PM tube background and the reference light readings. The program also computes the radiation calibration factor from the intentionally exposed dosimeters and the controls. This factor should be fairly constant with time if the other readout parameters are stable, and thus serves as a check on the entire system. CALFAC produces a simple report containing all this information used by the health physicist to assess the system's performance.

Each time a group of dosimeters is sent to the field, certain ones are designated transit controls. These are carried throughout the exchange and are read with the collected dosimeters. Following the determination of the calibration factor, the program GROSS1 retrieves information from the readout file, sensitivity correction factor file, and field data file. The information is matched by the dosimeter number, checked for logical integrity, and arranged by location identification code. Another code identifies the transit control dosimeters from which the average transit exposure rate is calculated. An error report is then prepared that lists any unmatched TLD's, unmatched field data, or logical inconsistencies in the field data.

Following the completion of GROSS1, program GROSS2 is automatically loaded and executed. This program uses the data previously assembled to calculate for each location the exposure adjusted for transit time and the average exposure rate. Since there are two chip readings per dosimeter and usually three dosimeters per location, the standard deviation of the exposure at a location is also calculated.

The preliminary report of adjusted gross readouts arranged by monitoring location is produced by a program called P-REPORT. Using data assembled by GROSS2, P-REPORT prints out a title page, an error report, listings of the readout and field data files, and a formatted listing of the exposure,

exposure rate, and monitoring dates for each location. An example of this listing is shown in Figure 6. In addition, a specially formatted output file called TEMP2 is produced and is transmitted to a Control Data Corporation CDC-6400 computer for the compilation of a final report. The TEMP2 file can be sent via a 1200-baud telephone data link using a specially designed communications program from the microcomputer. Once this data file is in residence on the CDC-6400 system, it can be merged with other similar files and used to produce the final periodic report. Usually 7 to 10 such files must be merged in this fashion to produce a typical quarterly report.

The historical data files for the offsite dosimetry network are stored on the CDC-6400 and are used in the production of the final periodic report. This is necessary because the environmental radiation background at a given location cannot be determined from a single measurement[4,5]. The background must be determined independently of the present measurement in order to find out if an exposure above background has occurred. There are several schemes[6] that can be used to calculate the background, including the assumption of invariance with location, the assumption of invariance with time at a given location, or a predictive model based on past performance and current conditions. While the third is by far the most accurate, it is also the most costly and complex. Such a model has been used on data from this network[7], but at present the assumption of invariance with time at a given location is employed. This allows the determination of net exposures above background in the range from 0.6 to 8 mR at the 95% confidence level for a typical quarterly measurement cycle. A FORTRAN program has been written to produce the final quarterly report for the network and to update the

PRELIMINARY REPORT - 0731791240 ADJUSTED GROSS READOUT VALUES HOPPER RTE 2ND QTR 79

STATION	DOSIMETER NUMBER	ISSUE DATE	COLLECT DATE	READOUT DATE	CHIP 1 RESULT	CHIP 2 RESULT	STATION MEAN	MR/DAY	PERCENT STD. DEV.
004STA010	4923	0426791500	0720791515	0731791240	27.30	28.50			
	4974	0426791500	0720791515	0731791240	27.84	29.05			
	4943	0426791500	0720791515	0731791240	24.92	26.01			
							27.27	.320	5.708
003STA106	4952	0428791200	0720791630	0731791240	10.99	12.18			
	4920	0428791200	0720791630	0731791240	11.02	12.69			
	4936	0428791200	0720791630	0731791240	12.56	13.61			
							12.17	.146	8.385
003STA240	4998	0426791900	0720791230	0731791240	21.24	22.49			
	4910	0426791900	0720791230	0731791240	20.28	21.12			
	4902	0426791900	0720791230	0731791240	20.05	20.97			
							21.02	.248	4.097
003STA245	4900	0428791400	0721790930	0731791240	19.80	20.53			
	4607	0428791400	0721790930	0731791240	20.18	21.78			
	4926	0428791400	0721790930	0731791240	23.54	22.46			
							21.38	.255	6.[illegible]25
097404140	4971	0426791900	0720791300	0731791240	16.96	18.48			
							17.72	.209	6.065
545647304	4982	0426791900	0720791230	0731791240	19.69	20.18			
							19.93	.235	1.738

Figure 6 Preliminary TLD Report

historical data files automatically. Other programs are also available to compile and list selected data from the historical files for additional analysis when required.

Dosimeter System Performance

In order to judge the adequacy of a particular dosimetry system for making environmental radiation measurements, a performance standard[8], ANSI N545-1975, was drafted by the American National Standards Institute. This voluntary standard provides a guide for anyone making environmental radiation measurements to check his performance against a satisfactory level determined by a group of knowledgeable experts. ANSI N545-1975 addresses such aspects of dosimeter performance as *uniformity*, *reproducibility*, *photon energy dependence*, and sensitivity to environmental insults. Table 1 summarizes the results of tests on the dosimetry system described here. The system exceeded the minimum acceptable levels set by ANSI N545-1975 except for energy dependence. Although the energy response of these dosimeters decreases rapidly below 100 keV, this has been considered adequate in the past for the assessment of whole body dose. It may be possible to improve the response to low energy gamma rays by adjusting the energy compensation shielding, but this is not currently being contemplated.

Conclusion

A gamma radiation monitoring system utilizing a commercially available automatic TLD reader, unique microcomputer control, and automatic data

Table 1. Dosimeter Performance Compared to ANSI N545-1975

Performance Aspect	ANSI N545-1975 Requirement	EPA 2271/TLD-200 Dosimeter System
Uniformity	Response of TLDs within a batch shall not differ from each other by more than 30% at an exposure of 20 mR for quarterly monitoring.	24%
Reproducibility	Responses for a single badge given repeated exposures and readouts shall not differ by more than 10% for an exposure of 20 mR.	8%
Length of Field Cycle	The ratio of the response obtained for the field cycle period to twice that obtained for half the field cycle period shall not be less than 0.90.	0.96
Energy Dependence	Response shall not differ from that obtained with the calibration source by more than 20% for photons with energies from 80 keV to 3 MeV.	± 25% from 80 keV - 3 MeV
Directional Dependence	Response averaged over all directions shall not differ from the response in the usualy calibration position by more than 10%	6%
Light Dependence	The results of the light shielded TLDs shall not differ from those obtained for the non-shielded TLDs by more than 10%.	no difference
Moisture Dependence	The response of the TLDs exposed to moisture shall not differ from those not exposed to moisture by more than 10%.	no difference
Self-Irradiation	The self-irradiation of the dosimeters shall not exceed a rate equivalent to 10 μR per hour for the duration of the field cycle.	no measurable self-irradiation

processing techniques has been designed and implemented by the U.S. Environmental Protection Agency to assess the external radiation exposure to the resident population in the vicinity of the Nevada Test Site. The system's maximum use of automatic equipment has reduced operational costs and increased the efficiency of data presentation, storage, and retrieval. The system is designed to accommodate over 100 fixed locations with monitoring periods of 1 month or longer. It is most useful where continuing data storage is a requirement and where rapid access to historical data is desirable. Although this particular system was designed specifically for gamma radiation monitoring, the use of other thermoluminescent phosphors and packaging techniques could allow the measurement of the absorbed dose from beta radiation or from neutrons. The microcomputer carries out the data acquisition, quality control checks, and preliminary exposure calculations through programs written in BASIC, while the preparation of the final report and historical data storage are done on a larger computer with FORTRAN programs.

References

1. Fitzsimmons, C.K., and Horn, W.H., "Environmental Monitoring with Thermoluminescent Dosimeters" USPHS Report SWRHL-58r, October 1969

2. Cox, F.M., and Lucas, A.C., "An Automated Thermoluminescent Dosimetry System for Personnel Monitoring (Part I)," Health Physics, Vol. 27 (October), pp. 339-345, 1974

3. Becker, K., Rosa, H.L., and Wing, P-S., "Environmental and Personnel Dosimetry in Tropical Countries," Proc. of Third Intern. Conf. on Luminescence Dosimetry: Riso, 1971, Riso Report NO. 249

4. Burke, G. de P., "Thermoluminescence Dosimetry: Environmental Monitoring Near Nuclear Reactor Sites," IEEE Trans. on Nucl. Sci., NS-23, No.3, 1224-1236, 1976

5. Brinck, W.L., Gross, K.C., Blanchard, R.L., Kahn, B., "Natural Radiation Measurements for Environmental Surveillance at Nuclear Power Stations," Proceedings of the Tenth Midyear Topical Symposium of the Health Physics Society, 1976

6. Burke, G. de P., "Variations in Natural Environmental Gamma Radiation and Its Effect on the Interpretability of TLD Measurements Made Near Nuclear Facilities," USAEC Report, HASL 289, 1975

7. Lantz, M.W., "A Predictive Model of Background Radiation Rates," Master's Thesis, San Diego State University, 1977

8. American National Standards Institute, "American National Standard Performance, Testing, and Procedural Specifications for Thermoluminescence Dosimetry (Environmental Applications)," ANSI N545-1975, 1975