SWRHL-93r

A COMPARISON OF FILM BADGES AND THERMOLUMINESCENT DOSIMETERS USED FOR ENVIRONMENTAL MONITORING

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Charles K. Fitzsimmons, William Horn, and William L. Klein
Environmental Surveillance
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ENVIRONMENTAL PROTECTION AGENCY

Published May 1972

This study performed under a Memorandum of
Understanding (No. SF 54 373)
for the Nevada Operations Office
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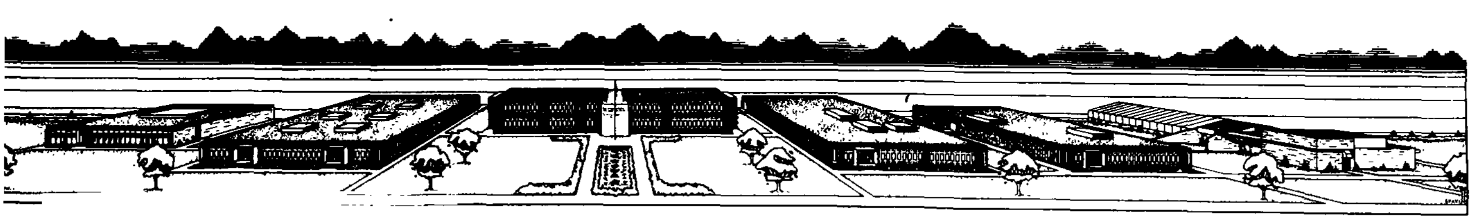

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*Formerly the Southwestern Radiological Health Laboratory, U. S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, Environmental Control Administration, Bureau of Radiological Health

ABSTRACT

Data obtained from two concurrent dosimetry networks operated by the Western Environmental Research Laboratory in Nevada, one utilizing film badges and the other thermoluminescent dosimeters (TLD's) are compared. Gamma exposures from a few mR to approximately 1R due to both natural background and fission products in the environment are more easily and accurately measured by the TLD system. Where the minimum detectable exposure for film is about 45 mR, the TLD sensitivity is on the order of 1 mR (which allows measurement of monthly background exposures). The insensitivity of TLD's to environmental heating, humidity, light damage, and pressure makes them ideal for use in the extreme conditions encountered in the desert. Heat damage to the film was seasonal with the greatest losses occurring in the summer. During July, 1967, 71% of the film badges issued were heat or light damaged, while no loss of TLD data occurred. No background information was obtained from film data during 1967, but the geographical variations in background exposure rates were clearly disclosed by the TLD's.

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INTRODUCTION

In accordance with Memorandum of Understanding, SF 54 373, the Western Environmental Research Laboratory (WERL) provides an off-site radiological safety program for the Atomic Energy Commission in support of nuclear tests conducted on the Nevada Test Site (NTS) complex.

As one portion of the off-site radiological safety program, the Dosimetry Unit of the WERL has a primary mission to document off-site gamma radiation exposures above environmental background resulting from specific nuclear tests.

Since inception of the program in 1954, integrating dosimeter readings have been used to supplement off-site exposure data. Film badges were the dosimeters of choice. However, because interest in the field of radiological health has shifted during recent years to the measurement of smaller exposures, the inherent properties of the film badge dosimeter severely limited expansion of the program into this area. The sensitivity, accuracy, and reliability of the film badge were found to be inadequate for the gamma radiation levels of interest.

During this same period, considerable research on thermoluminescent dosimeters (TLD's) was being done by a number of investigators. The properties of the TLD as described in the literature seemed more suitable for the needs of the WERL. In 1965, after considerable field testing, a TLD system was incorporated into the film badge dosimetry network. As a result, over two years of side-by-side data have been accumulated from approximately eighty field locations.

This report presents a comparison and discussion of the film badge and TLD data.

Film Badge Network

Before 1961, film badges were issued to off-site residents and placed at strategic locations for specific nuclear tests. The film packet used was DuPont type 556, containing a two-component packet, emulsion No. 508, with a claimed detection range from 30 mR to 5R, and emulsion No. 834, with a detection range from 3R to 10R. In 1961, 28 permanent stations were established with a monthly dosimeter exchange. By 1963, the number of permanent stations had grown to 66 in addition to a monthly dosimeter exchange with 130 off-site residents. The present program involves 100 permanent off-site stations and 119 off-site residents.

Although the DuPont 556 film packet was the most suitable field dosimeter available at the time, serious problems were encountered. A high percentage of the film badges were damaged by heat, light, and moisture. In 1963, an alternative to the DuPont 556 film packet was investigated. Since off-site radiation monitoring involved exposures less than 5R, it was felt that a single component low-range film packet would be adequate. As a result, a new film badge holder was designed incorporating DuPont type 545 film with a detection range from 30 mR to approximately 4R. Although this reduced the initial film badge cost by 50% and increased the sensitivity of the dosimeter somewhat, the new film packet was as susceptible to heat, light, and moisture damage as its predecessor.

During this same period, interest in the field of radiological health had shifted to the measurement of smaller exposures. At this point, the inherent limitations of the film badge became a major obstacle to the growing needs and obligations of the Dosimetry Unit. In 1965, several non-film dosimeters were investigated and evaluated.

TLD Network

After investigating various thermoluminescent and glass dosimeters, the Edgerton, Germeshausen, and Grier, Inc., (EG&G) Thermoluminescent Dosimetry System was field tested. The EG&G system utilized the TL-12 thermoluminescent dosimeter and the TL-2B dosimeter reader. The detection medium of the dosimeter consists of a layer of CaF_2:Mn bonded to a helical heater element that is encapsulated in a gas-filled glass envelope. The detector is housed in an aluminum-tin-lead shield designed to compensate for the detector over-response in the low energy region of the gamma ray spectrum and to protect the detection from light exposure. The dosimeter reader accepts the TLD in a light-tight chamber, heats it with a regulated current and converts the emitted light energy into an electrical signal for display on the built-in strip chart recorder.

Preliminary field investigation involved the use of ten TLD's for each of two NTS events: Sulky, a Plowshare experiment, and the Transient Nuclear Test (TNT) of a Kiwi Reactor. During each event, two TLD's were retained in Las Vegas as controls and eight were placed in strategic locations or carried by EPA monitoring personnel. Although the field dosimeters yielded slightly higher readings than the controls, evaluation on a larger scale was advisable. Consequently, EG&G furnished 55 dosimeters for monitoring of Project Palanquin in April 1965. During each evaluation, ten dosimeters were retained as controls. Each of the remaining 45 dosimeters was packaged in a polyethylene envelope with one DuPont type 555 film packet and one DuPont type 556 film packet. The type 556 film had been pre-exposed to 100 mR ^{60}Co radiation in an attempt to gain greater sensitivity to low exposures. The dosimetry packages were placed on stakes within the expected trajectory and carried in monitoring aircraft and by field personnel.

After a ten-day exposure in the field, the TLD's were taken to EG&G in Santa Barbara, California, for reading. The film badges were sent to Mercury, Nevada, for processing. The results obtained from Santa Barbara indicated that the manufacturer's claims concerning the minimum dose resolution of 5 mR and a coefficient of variation of 10% were, in fact, conservative. In addition, it was found that the pre-exposed film performed very poorly and this technique was abandoned. The TLD system held promise to fulfill the growing need for greater sensitivity and accuracy in measuring environmental gamma exposure.

An EG&G TLD system was obtained and put into operation during August 1965. The first four months of operation indicated that before the full potential of the system would be realized, a number of objectives had to be met. These objectives were to (1) perfect a system of reader calibration, (2) establish a correction factor for each dosimeter, (3) determine the internal background due to ^{40}K activity within the dosimeter, (4) ascertain the significance of fading over extended periods of time, and (5) determine the precision of the system. The results of studies and solutions to problems in these areas, as well as the development and growth of the TLD network, are discussed in another report.[1]

The bulk of the data used for comparison in this report was collected during 1966 and 1967 when 80 TLD stations were in operation. The data represent exposures to the gamma radiation of fission products in the range from 5 mR to approximately 1R. The energy response of any dosimeter is a function of the shielding employed as well as the detection medium. The energy response of the TL-12 is shown in Figure 1.

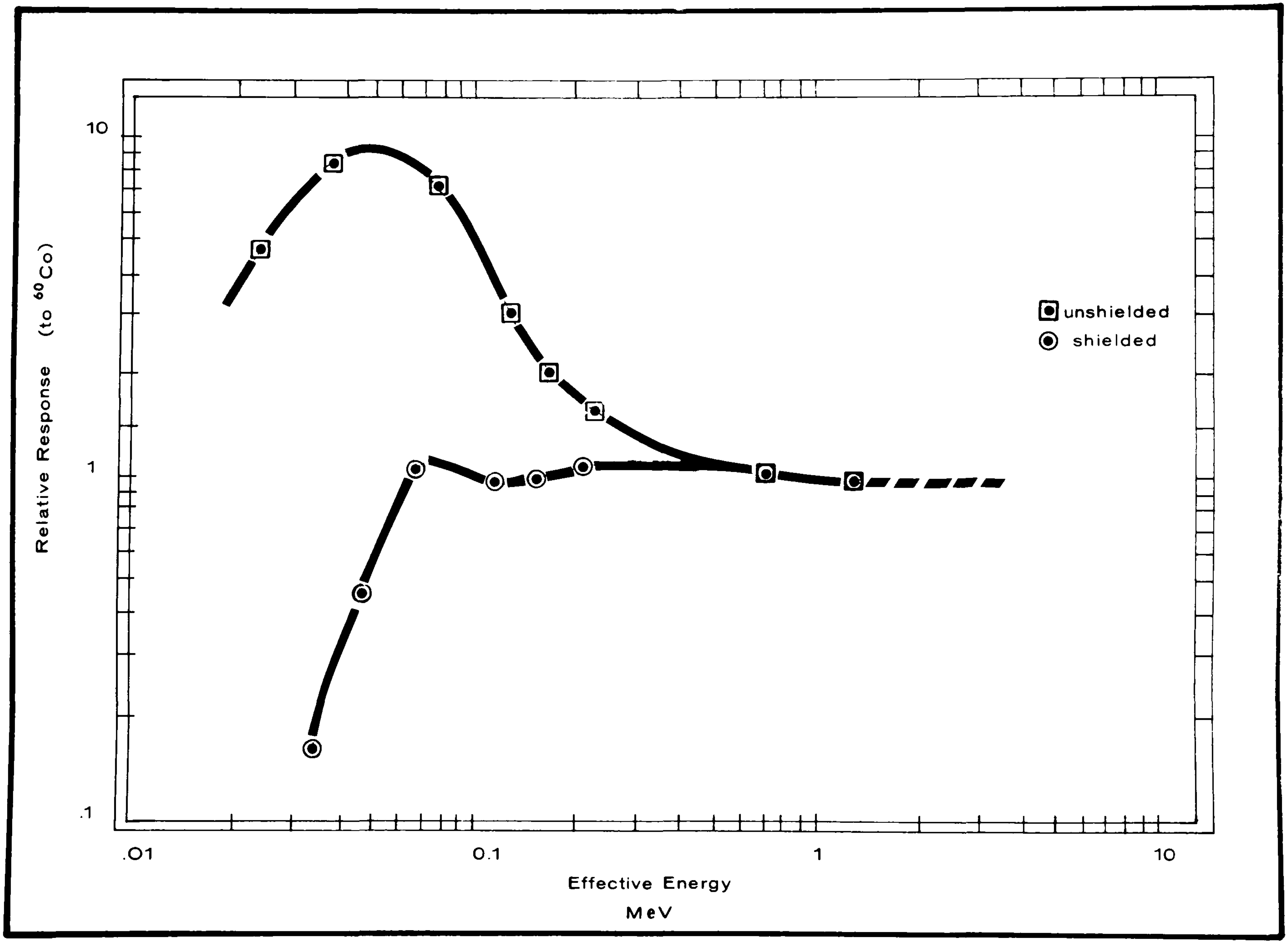

Figure 1. Gamma energy response of thermoluminescent CaF_2:Mn.

COMPARISON OF FIELD DATA

Data from the Routine Monitoring Network

Data from the routine stations are used primarily to establish background exposure rates, even though the network owes its existence to the need for measurement of possible biologically significant exposures due to specific nuclear tests. Background, in this sense, refers to the exposure from all ionizing radiation in the environment which can not be attributed to any specific man-made source. Thus, it is possible in some cases that background includes the exposure from a residual trace of long-lived fission products as well as from the naturally-occurring radionuclides and cosmic radiation. The observed variation in background levels from place to place is a function of the intensity of all three contributors, man-made, terrestrial, and cosmic.

The film badge has proven incapable of providing this background information. Out of 6454 film badges placed at the off-site stations during 1967, only 199 or 3.0 percent had a reported value greater than zero. Table 1 presents a summary of dosimeters issued, those damaged or lost, and those having a reading greater than zero. Of 2461 TLD's issued in 1967, only 10 failed to produce usable data. If film badges are left in the field long enough to obtain a reading over the 30 to 50 mR threshold, the chance of heat or light damage becomes a near certainty. Film badges left in the field for two months which do not become unreadable because of severe heat damage often read 40 to 50 mR, about 100 percent greater than the expected exposure. Figure 2 shows the seasonal variation in the precent of dosimeters which had usable data for the years 1966 and 1967.

Table 1. Summary of dosimeters issued to routine stations in 1967

Reporting Period	No. of Dosimeters used	No. Lost or Damaged	Percent lost or damaged	No. reporting values greater than zero	Percent greater than zero
		THERMOLUMINESCENT DOSIMETERS			
Jan.	209	0	0	209	100
Feb.	210	0	0	210	100
Mar.	207	0	0	207	100
Apr.	216	0	0	216	100
May	177	6	3.3	171	96.6
June	204	0	0	204	100
July	222	0	0	222	100
Aug.	248	1	0.5	247	99.5
Sept.	246	3	1.2	243	98.8
Nov.*	261	0	0	261	100
Dec.	261	0	0	261	100
Totals	2461	10	0.4	2451	99.6
		FILM BADGES			
Jan.	588	18	3.0	17	2.8
Feb.	482	12	2.4	18	3.7
Mar.	592	132	22.2	31	5.2
Apr.	574	64	11.2	50	8.7
May	491	146	29.7	20	4.0
June	600	400	66.6	24	4.0
July	580	413	71.2	0	0
Aug.	632	177	28.0	18	2.8
Sept	628	60	9.5	21	3.3
Nov.*	630	15	2.3	31	4.9
Dec.	657	12	1.8	27	4.1
Totals	6454	1449	22.5	199	3.0

* Reporting periods were longer than one month on the average, and only eleven reports were made in 1967. The gap was made up by skipping the October report.

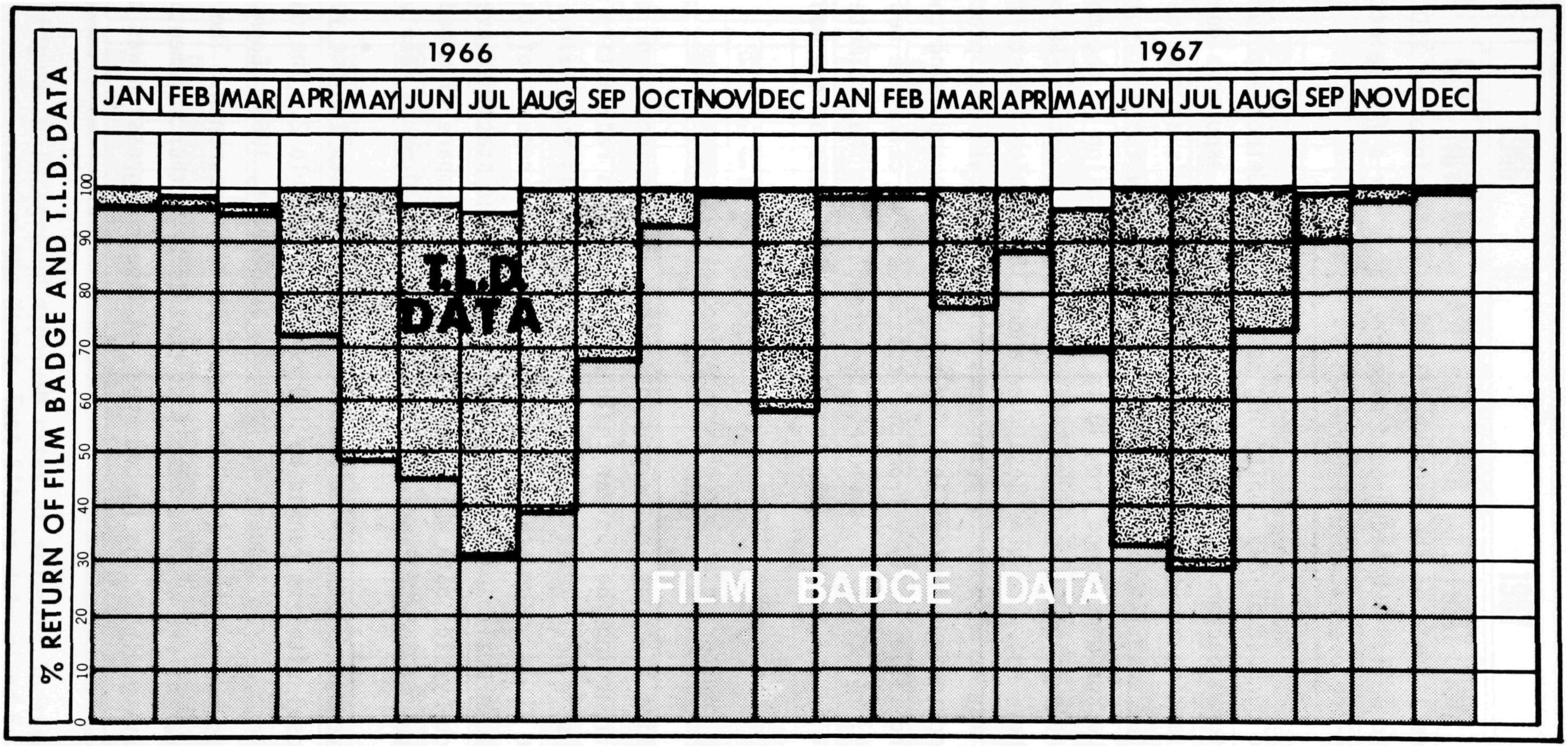

Figure 2. Percent return of film badge and TLD data during 1966 and 1967.

Little use is made of the routine film badge data since the TLD's perform so well. TLD background exposure rates for a few selected locations are presented in Figure 3.

The basic purpose of any monitoring network is to detect exposures above natural background. However, small off-site exposures due to nuclear testing are seldom detected even by the TLD's at routine stations because the signal-to-noise ratio is unfavorable. Typical monthly backgrounds range from 10 to 20 mR. Variation in the monthly background exposure at a given location can be as great as ±50 percent. Thus, net exposures less than about 10 mR which are still of interest may be missed. Greater sensitivity is obtained by placing special dosimeters in the field for specific events and using the background values derived from the routine data to calculate net exposures. In order to accumulate background data, the dosimeters used must be sensitive to the low background exposure of one month's time.

Data from Monitoring a Nuclear Waste Disposal Site

Four routine stations in the monitoring network are located on the fence surrounding the Nuclear Engineering Company's radioactive waste disposal site near Beatty, Nevada. Each station has five film badges and three TLD's. The stations were established on request of the Nevada State Health Department. Subsequently, the stations have provided side-by-side data which have been used to compare film badge and TLD performance. Exposures range from about 40 mR to nearly 700 mR.

Paired average values of TLD and film badge responses for one year at the disposal site are ranked by TLD response in Table 2. The data were collected from January 4, 1967, to January 11, 1968. Each value represents the exposure in mR for approximately one month. The great monthly variations are the result of burials and other movement of radioactivity within the fenced area. A linear regression was performed

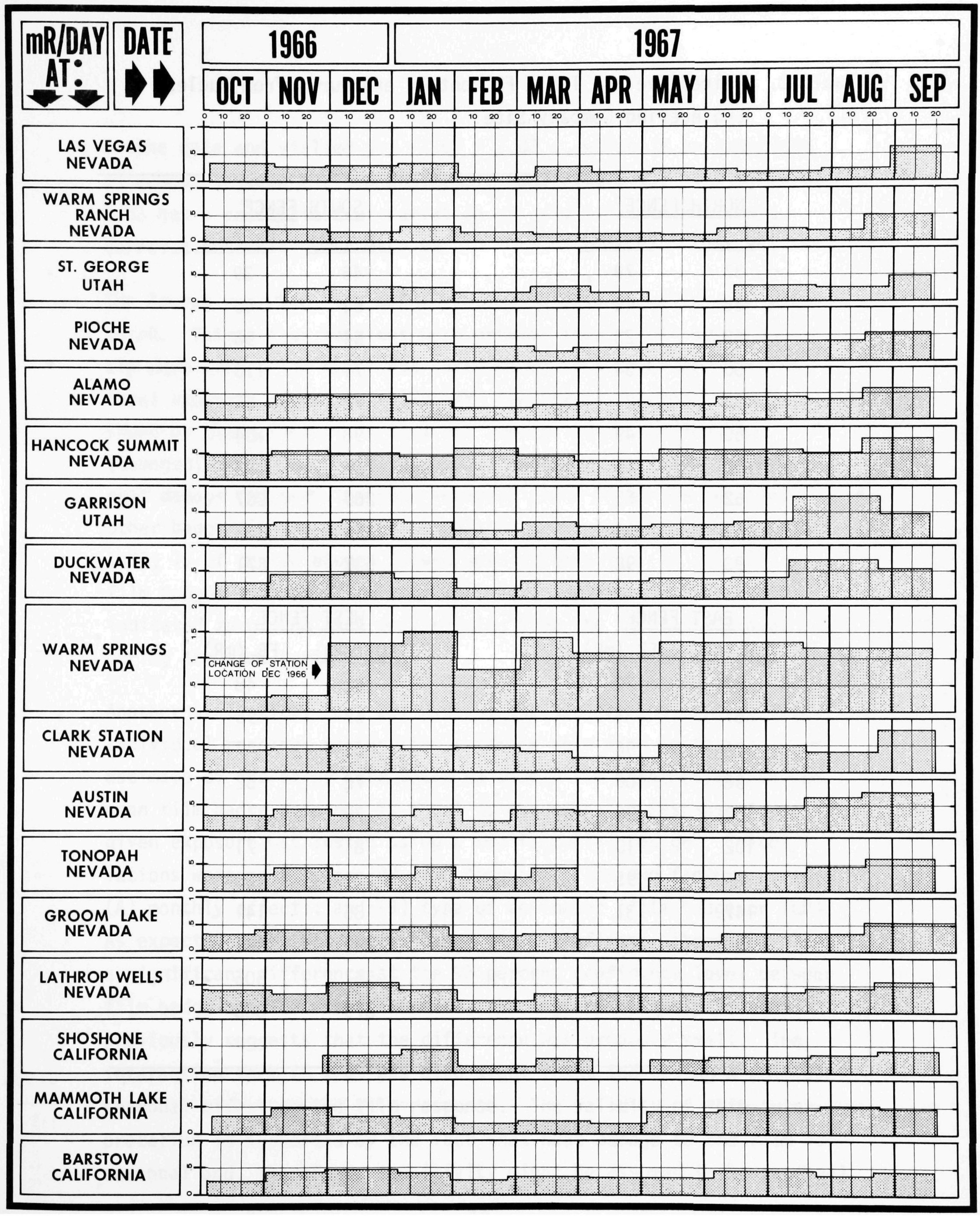

Figure 3. Background exposure rates at selected locations around the Nevada Test Site as determined by TLD's.

Table 2. Paired average TLD - FB monthly exposures from Nuclear Engineering Company Site.

NORTH FENCE

TLD (mR)	FB (mR)
37	79
38	44
43	23
50	34
52	81
60	49
62	48
62	55
63	58
93	98

SOUTH FENCE

TLD (mR)	FB (mR)
46	39
64	40
64	96
71	113
72	65
98	104
187	183
269	267
364	367
537	671

EAST FENCE

TLD (mR)	FB (mR)
61	70
67	34
75	96
98	106
101	90
102	110
126	95
147	131
150	182

WEST FENCE

TLD (mR)	FB (mR)
48	48
62	95
63	47
72	52
79	110
81	71
121	123
185	141
297	321
551	505
679	663

on the data and yielded y = -1.01 + 1.03 x, which is an excellent agreement between the two dosimeters (see Figure 4). The slope of 1.03 has a coefficient of variation of only 3.22 percent and a correlation coefficient of 0.98.

The lowest reported film badge reading in this group of data was 23 mR. Thirty-four readings were greater than 45 mR, while only six were less. The excellent correlation is attributable to the ideal exposure range, 40 to 700 mR, for the film. What is not shown by these figures is that all zero values or unreadable (damaged) film badges were deleted from Table 2. Frequency of heat damage followed the same seasonal trend as it did for the other badges in the network (Figure 2). For example, during July 1967, 19 of the 20 badges issued were unreadable. Of the 220 film badges issued, 27 percent were heat damaged, and 1 percent indicated zero. No data were missing from the 132 TLD's issued during the same period.

Another statistical test was made on the Nuclear Engineering data. Individual readings rather than averages were used so that a better estimate of the error term would be made. The hypothesis that the mean film badge response is equal to the mean TLD response for a given exposure was tested using a two factorial design. Calculations were made by an IBM 1130 computer. The two factors were: (A) monthly effects; and (B) type of dosimeter (film badge or TLD). As expected there was a very large monthly effect. There was also a significant difference at the 95 percent confidence level between film badge and TLD means; however, the regression analysis done previously suggests that the difference was probably small. The interaction term (A x B) was also significant indicating a possible seasonal effect on the film response. The validity of this interpretation is supported by the fact that heat damage to the film is seasonal and, therefore, sensitivity might be assumed to be seasonal

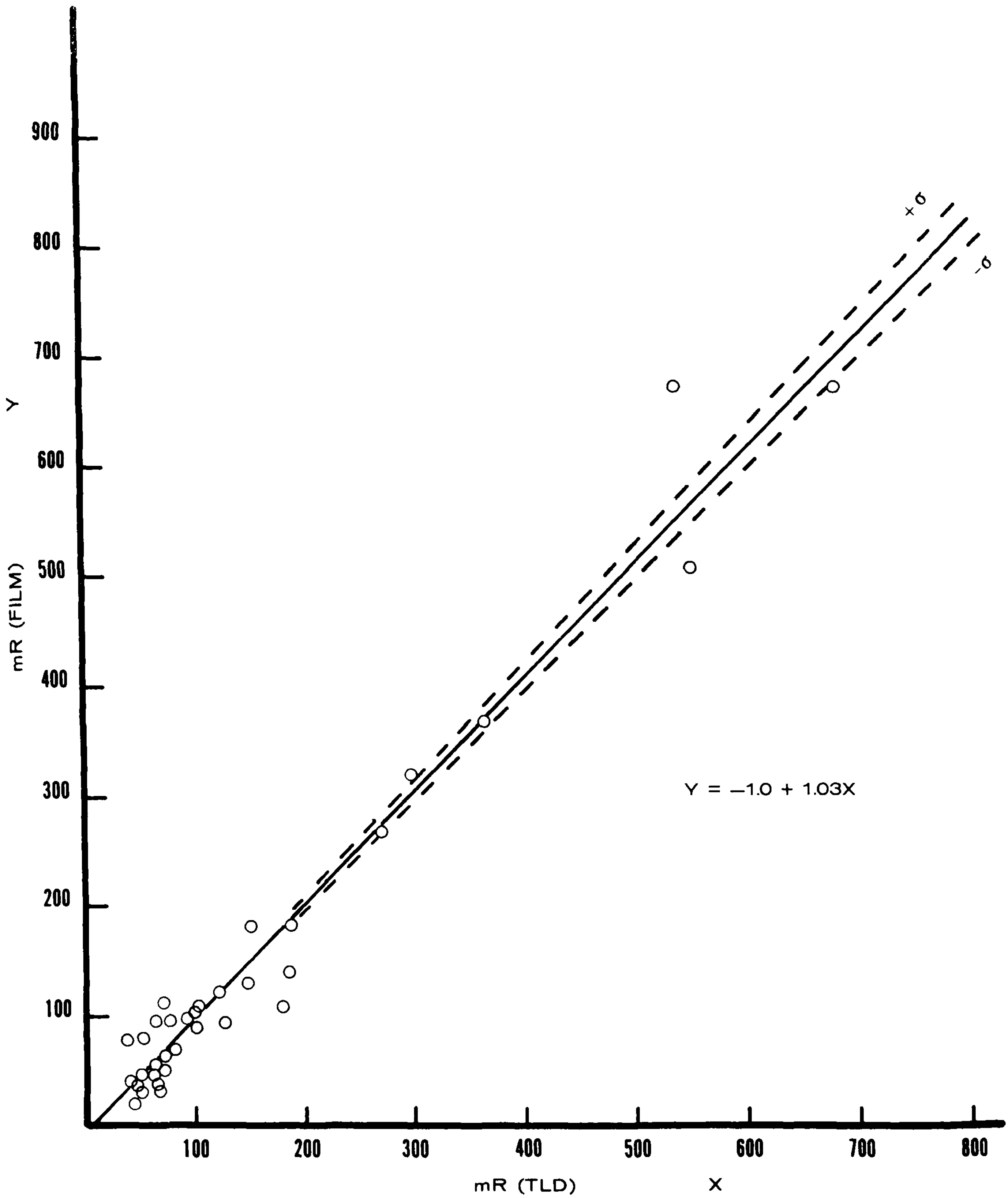

Figure 4. Correlation of Film and TLD Response from Nuclear Engineering Company Data.

also. Furthermore, studies have shown [(1)] that environmental temperature, humidity, and pressure have no detectable effect on TLD response. It is likely, then, that the interaction term reflects a greater degree of variation in film response than in TLD response.

Data from a Plowshare Experiment

EPA monitoring activities for Project Buggy I, a Plowshare nuclear cratering experiment conducted on March 12, 1968, included six arcs of thermoluminescent dosimeters placed across the expected cloud trajectory. The dosimeters yielded a series of exposure profiles across the cloud path at 8, 10, 35, 51, 82, and 170 miles downwind from ground zero. The data also defined the line of maximum exposure, the approximate cloud width with distance, and the decrease of exposure as a function of distance.

On two arcs, Arc 1 and Arc 4, film badges were placed alongside the TLD's. Arcs 1 and 4 were approximately eight miles and fifty-one miles from ground zero (GZ), respectively.

Two TLD's and two film badges were placed on each stake of Arc 1. One of each was collected at H + 3 hours and the data plotted as "first pickup" in Figure 5. The remaining TLD's and film badges were collected on D + 7 days. These data are plotted as "second pickup" in Figure 6. The difference in low level sensitivity is shown plainly in these two plots. Above 80 mR film and TLD responses are comparable, but there is increasing disagreement between the film badge and TLD data as the exposure level decreases. Below 45 mR there is no reported film response at all. Under these

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(1) A two-year study by Mr. William Horn, WERL, of TLD measurements of backgrounds at Las Vegas, Tonopah, Fallon, and Ely, Nevada, indicated no effect to the TLD's from environmental conditions. TLD's were placed inside USWB instrument shelters at all four locations.

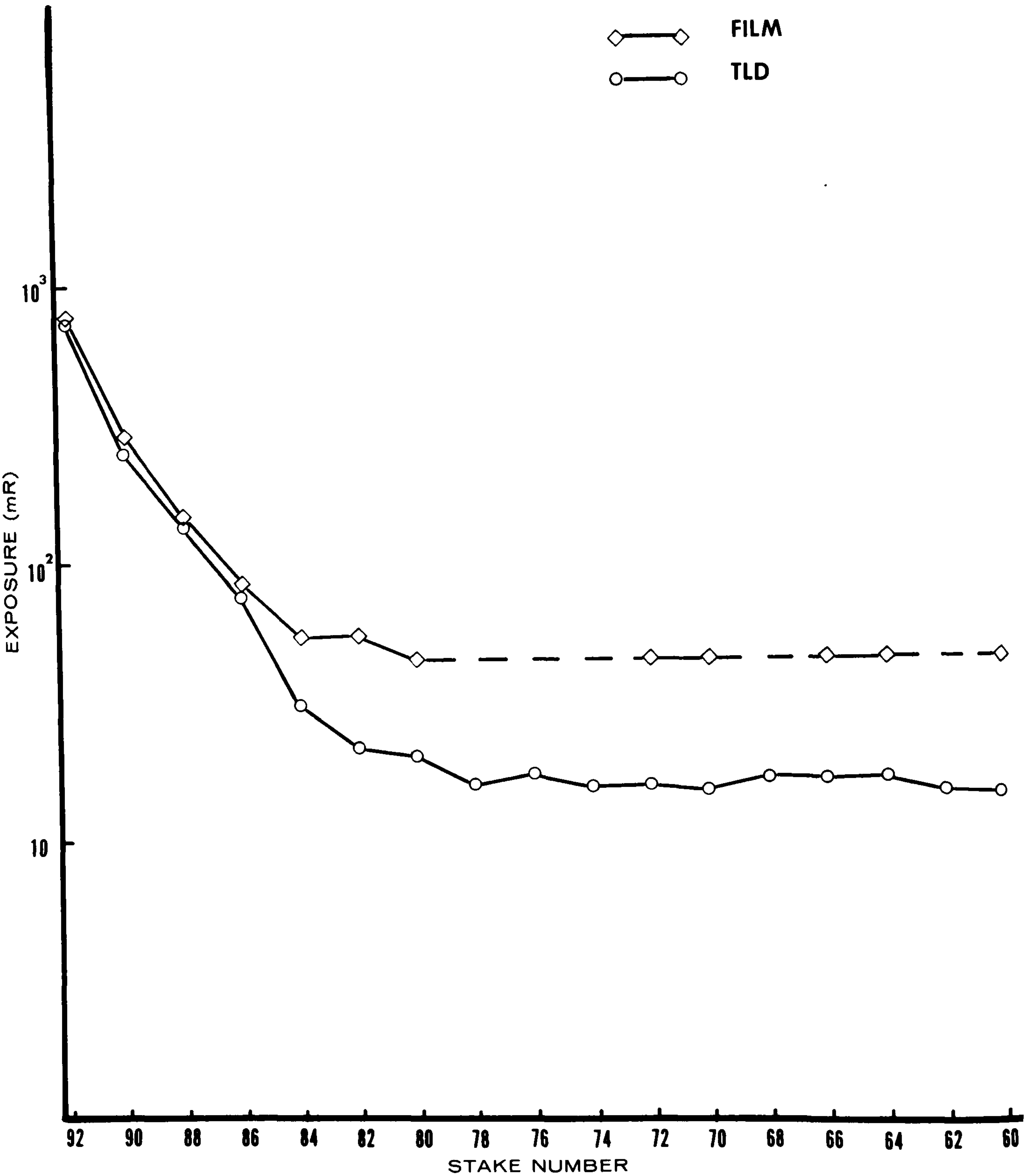

Figure 5. Cloud Profile, Arc I, Buggy I, First Pickup.

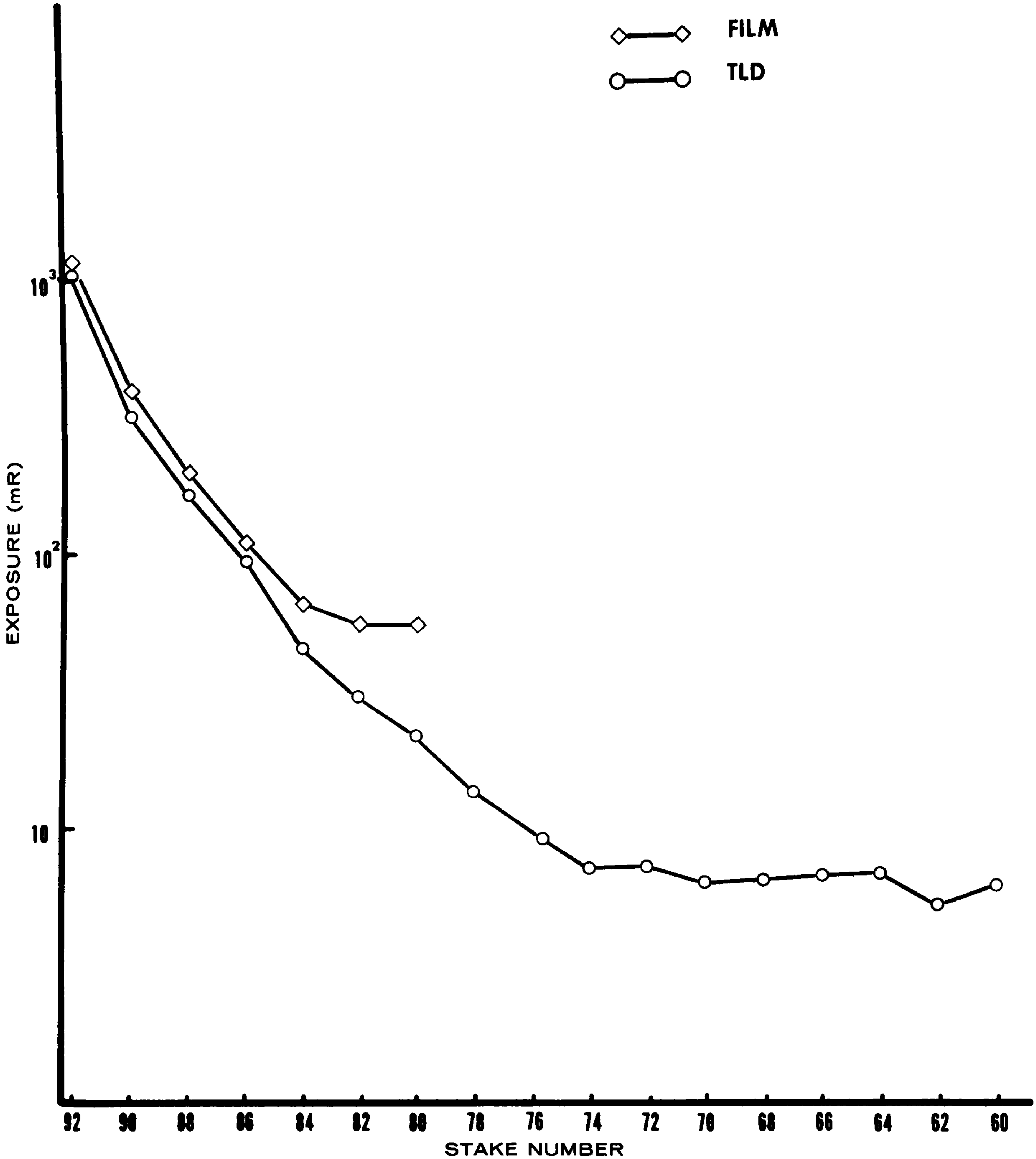

Figure 6. Cloud Profile, Arc I, Buggy I, Second Pickup.

experimental conditions, 45 mR appears to be the minimum detectable exposure for the film (DuPont 556 packet, the same as that used at the Nevada Test Site for personnel monitoring).

The film and TLD data were paired for a statistical comparison of response to common exposures. Of the 34 film badges issued, only 19 provided positive data. Consequently, only the 19 film badge-TLD data pairs shown in Table 3 were used in the analysis.

The first linear regression analysis, performed on all 19 data pairs, yielded the relationship $y = 21.36 + 1.086x$, where y represents the film response and x the TLD response. The data are plotted in Figure 7. The slope of the regression line was equal to 1.086 with a coefficient of variation of 1.64% and a correlation coefficient of 0.99.

As can be seen from Table 3, the film showed little sensitivity to small changes in exposures below 55 mR. A second linear regression analysis was performed on the lowest 13 data pairs. The result of the analysis (Figure 8), yielded the relation $y = 32.9 + 0.770x$. The slope of the regression line was equal to 0.770 with a coefficient of variation of 5.67% and a correlation coefficient of 0.98.

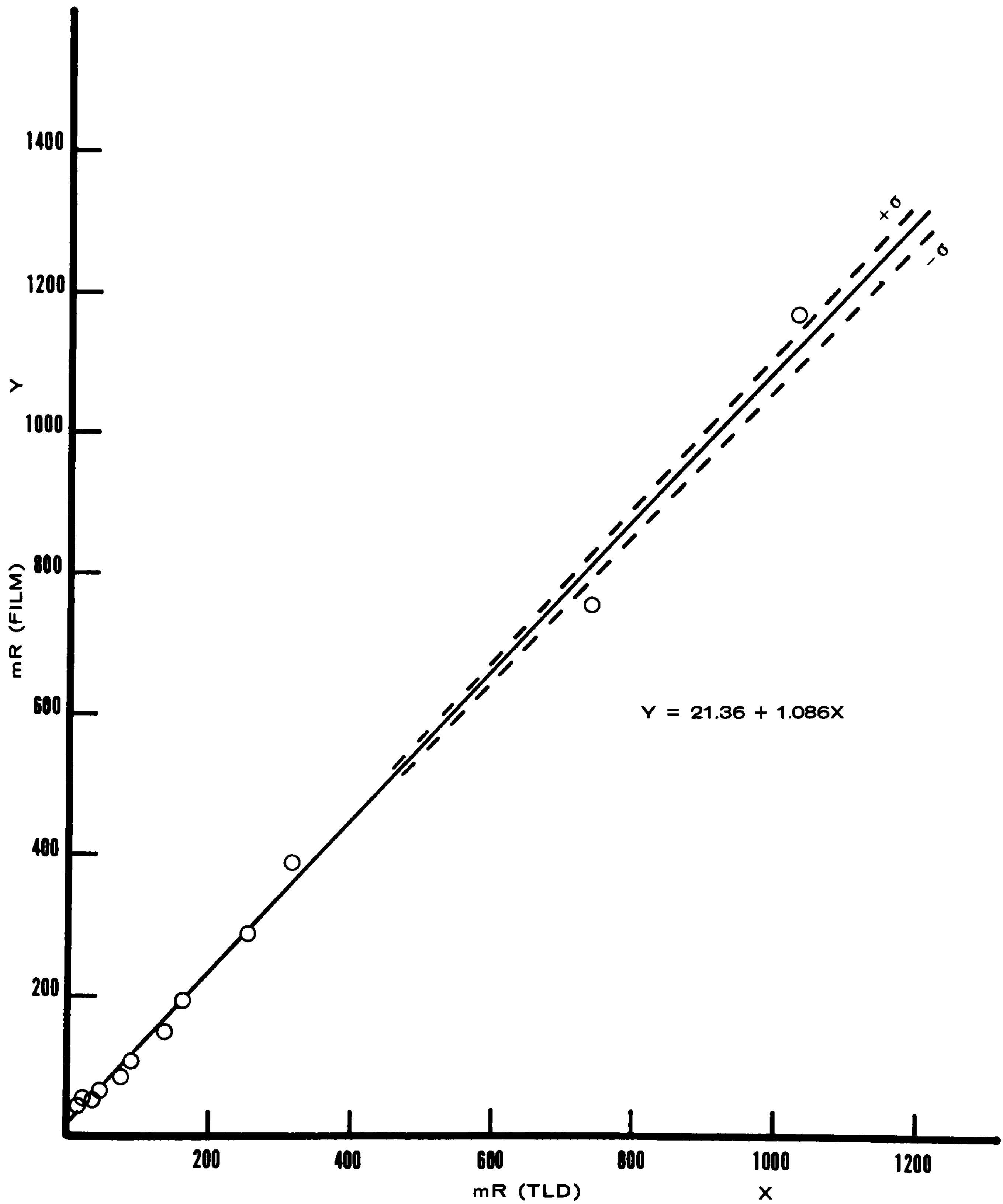

Figure 7. Correlation of Film and TLD Response from Arc I, Buggy I.

Table 3. Paired TLD - FB data from Arc 1, Buggy 1.

TLD (mR)	FB (mR)
14.8	45
15.4	45
16.0	45
17.0	45
17.2	45
20.4	45
21.4	55
21.7	55
29.8	55
31.1	55
44.5	65
75.6	85
92.8	110
135.5	150
162.1	195
252.9	290
313.8	390
734.3	760
1025.4	1175

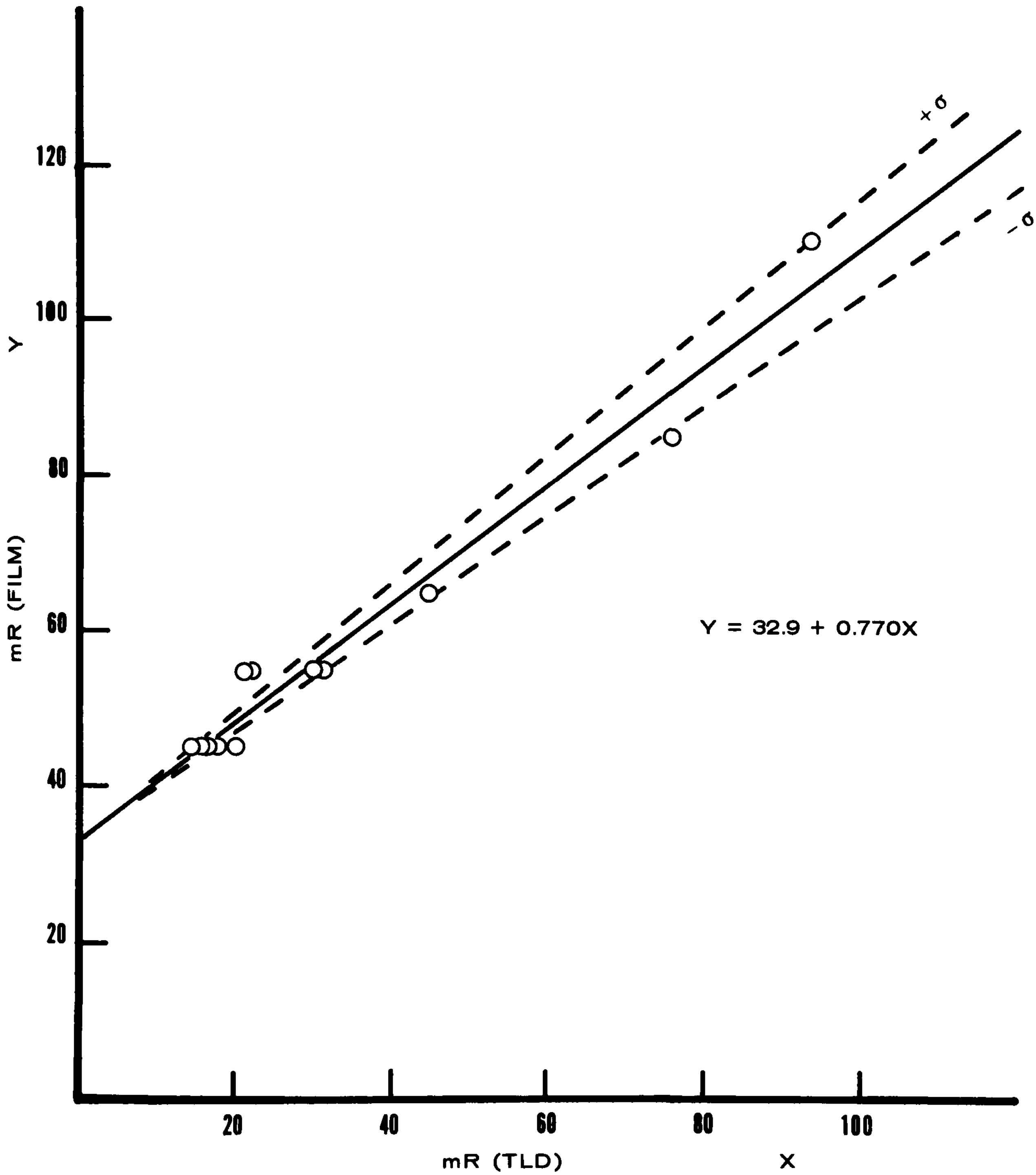

Figure 8. Correlation of Film and TLD Response from Arc I, Buggy I, Lowest 13 Data Pairs.

One DuPont type 545 film badge, the same type as is used in the dosimetry network, was placed on each stake along Arc 4, 54 miles from ground zero. Exposure profiles, as detected by both film badges and TLD's, are plotted in Figure 9. The conspicuous lack of film badge data points results from the exposure levels being near or below the minimum detectable limit of the film. Table 4 lists the paired values for which positive film data were available

A linear regression on the data of Table 4 yielded the relation, $y = 10.54 + 0.586x$, which is plotted in Figure 10. The slope of the regression line was equal to 0.586 with a coefficient of variation of 4.37% and a correlation coefficient of 0.94.

The data in Figures 7, 8, and 10, and their respective analyses are presented in the order of decreasing exposure levels. In general, as the level of exposure decreases, the correlation coefficient of film and TLD response decreases. The slope also decreases from unity, indicating that the range of exposure is near the minimum detectable limit of the film, i.e., there is a flattening of the curve at low exposures. An increasing degree of variation accompanies film response as exposure levels decrease, further indicating that the lower limit is being approached. The above data would indicate that the lower limits of the 556 and 545 film are approximately 45 mR and 30 mR, respectively.

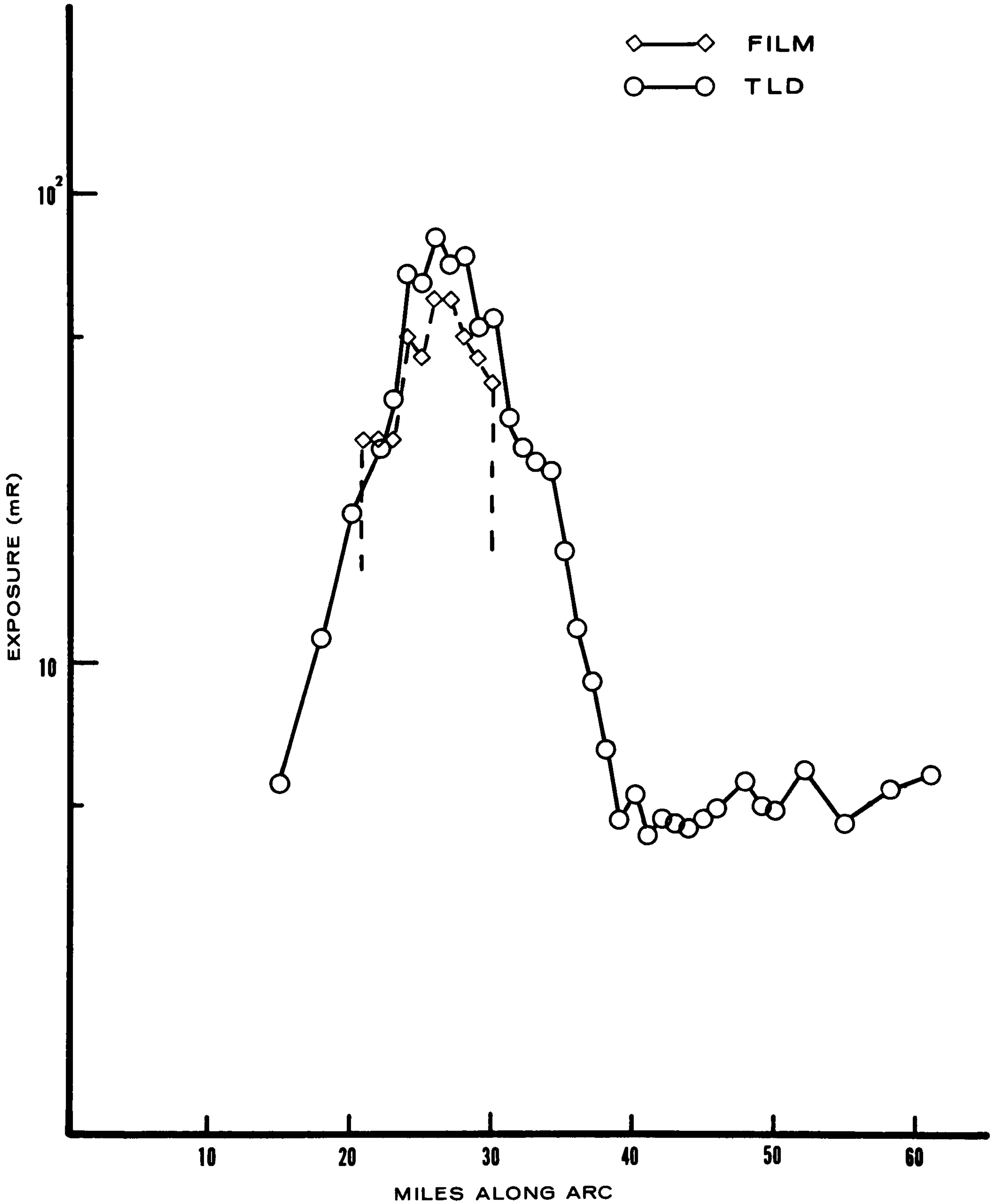

Figure 9. Cloud Profile, Arc 4, Buggy I.

Table 4. Paired TLD - FB data from Arc 4, Buggy 1.

TLD (mR)	FB (mR)
29.0	30
37.0	30
53.4	45
54.7	40
65.8	45
69.4	50
72.8	60
74.0	50
81.6	60

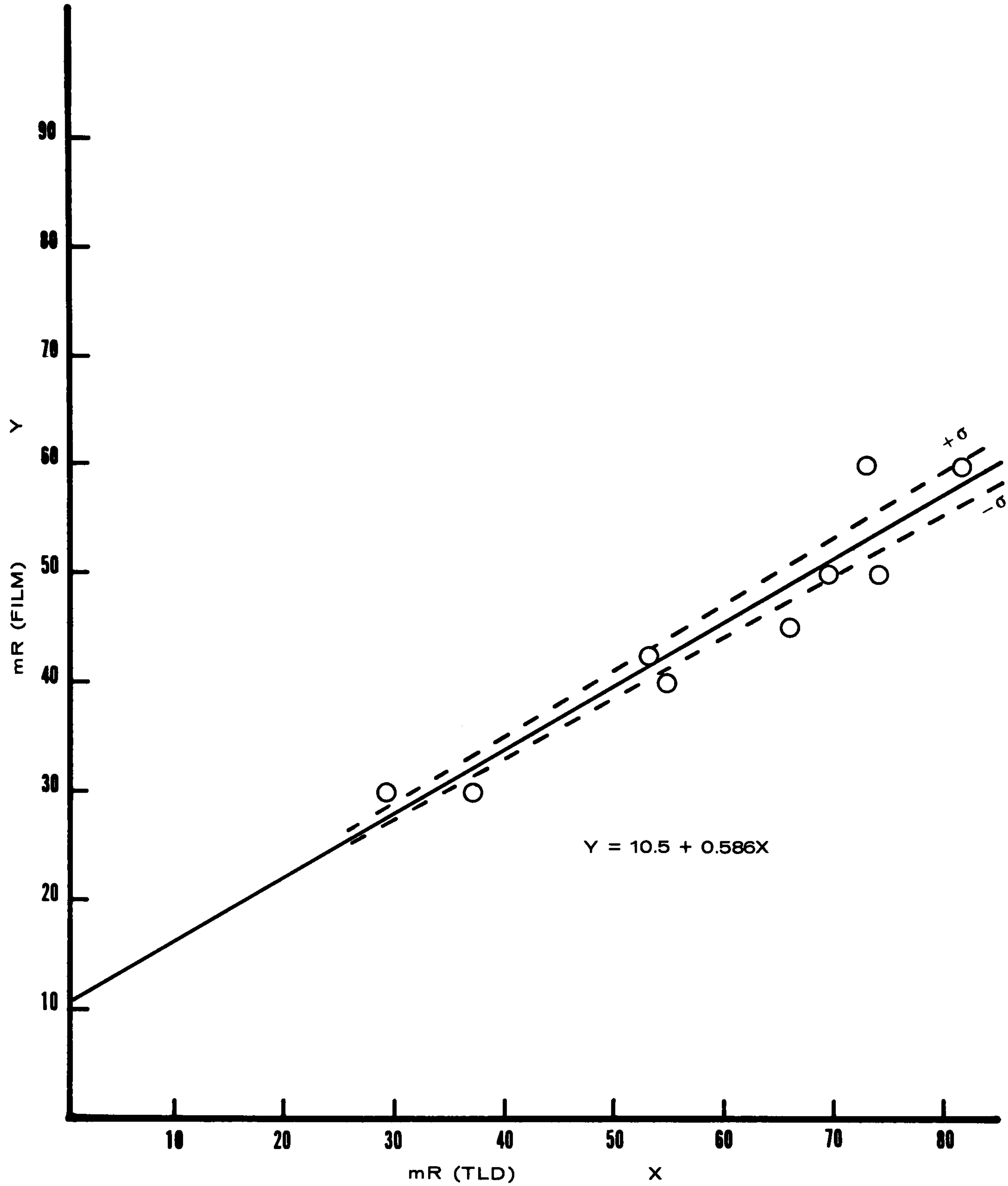

Figure 10. Correlation of Film and TLD Response from Arc 4, Buggy I.

DISCUSSION

It has been shown that the film badge as used by WERL in the off-site environment is incapable of providing background information. During 1967, only 3% of the 6454 badges issued had a reported value greater than zero. In addition, the data which were available varied from the expected exposures sufficiently that their validity was in doubt.

Data from both the Nuclear Engineering Disposal Site and the Plowshare project indicated that the minimum detectable limit for the film badge is approximately 45 mR.

The Nuclear Engineering Disposal Site film badge data which escaped heat damage showed an excellent agreement with the TLD data. The high correlation is attributable to the ideal exposure range, 40-700-mR, for the film.

The same situation was seen in greater detail in the investigation of Plowshare data. Analyses of data resulting from three different levels of exposure indicated that as exposure levels decreased, the correlation coefficient of film and TLD response decreased. This is an indication that at lower exposures, TLD and film results are less likely to agree. It was evident that the lower exposures were approaching the minimum detectable limit of the film because the slope of the linear regressions decreased from unity with decreasing exposures.

A definite relationship between ambient temperatures and film damage has been shown in both the routine network data and Nuclear Engineering Disposal Site data. During 1967, 22% of the 6454 film badges issued to routine stations were lost or damaged. The monthly damage percentage varied seasonally from a low of 1.8% in December to a high of 71.2% in

July. Frequency of heat damage to film badges located at the Nuclear Engineering Disposal Site followed the same seasonal trend seen in the routine data. In 1967, 27% of the badges were heat damaged.

A statistical test of the Nuclear Engineering data indicated a possible seasonal effect on film response, in addition to the seasonal fluctuation of heat damage. This, and other research, tend to indicate that the precision of film response is less than that of the TLD.

The TLD is more suitable as an environmental monitor than the film badge, and is quite capable of providing background information. In addition, it is unaffected by environmental heating both in terms of damage and response. Of 2461 TLD's issued to routine stations, only 10, or 0.4%, failed to produce usable data. No data were missing from the 132 TLD's issued to the Nuclear Engineering Disposal Site during this same year.

In addition to the results of this investigation, there are several pieces of recent supporting research. According to Johnson and Attix(2), most erroneous film data, including readings which occur when no exposure exists, can be related to heat and humidity damage. They compared a quartz fiber dosimeter and two types of TLD's with film badges worn by personnel. The first three dosimeters agreed within ten percent but the film badges were often off by a factor of two or three.

From a processing standpoint, film is subject to more variables than the TLD. The accuracy and reproducibility of reported film badge exposures by commercial dosimetry services often are quite poor.(3) The best accuracy appeared to be -50 to +200 percent. The film processing service at Mercury, Nevada, used by WERL is believed to be considerably better than this (±20% above 100 mR). This claim is supported by the good correlation of our film and TLD data in favorable exposure ranges.

Kathren[4] has shown that considerable fogging of dosimetry film occurs above 50°C, a condition often attained in the field situations under discussion. This high frequency of heat and light damage was one of the major reasons for investigating and acquiring a TLD system at WERL.

There have been several studies by other investigators in recent years, comparing the performance of a variety of dosimeters. A few are mentioned here to put WERL efforts in prespective. Becker[5] discusses the relative merits of photographic, glass, and thermoluminescent dosimeters. Cusimano and Cipperley[6] describe the personnel dosimetry program at Idaho Falls, using LiF_2 - Teflon dosimeters. Hall and LaRocca[7] report the use of TLD's for environmental monitoring at the Savannah River Plant, South Carolina. In each case, TLD's were favored over film because they had better precision, better accuracy, higher sensitivity, and a greater dynamic range.

CONCLUSIONS

The review of TLD and film badge data from the routine dosimetry stations, the Nuclear Engineering Disposal Site, and a Plowshare experiment, leads to conclusions which favor TLD's. The TLD is more sensitive to the exposures of interest than the film badge. Because of this, it has been possible to obtain average values for background exposure rates at the various dosimetry stations.

The high ambient temperatures encountered during the summer months cause an unacceptable amount of damage to film badges used as environmental monitors. In addition to heat damage, there is evidence that film sensitivity is temperature dependent, which may cause a seasonal effect on film badge results. TLD's at the same locations sustain no apparent effects from environmental heating.

Statistical treatment of dosimetry data shows the TLD to be more precise than the film. Typical TLD reproducibility is well within ±5 percent.

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