White Paper:

LANL Neutron-to-Photon (NP) Dose Ratio Analysis

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Introduction:
This White Paper describes analyses performed to calculate the statistical parameters of lognormal distributions of neutron-to-photon (NP) dose ratios using LANL provided recorded doses for LANL workers (SRDB reference 27261) during the period of 1944 through November 2008. This information extends information contained in ORAUT-TKBS-0010-6 (2009), “Los Alamos National Laboratory – Occupational External Dose.

Purpose:
The purpose of this white paper is to document the method of analysis, and to present the calculated statistical lognormal distribution parameters [i.e., Geometric Mean (GM), Geometric Standard Deviation (GSD) and the 95th Percentile] for each year and selected multi-year periods.

Method:
The analysis of neutron to photon (NP) dose ratios for LANL workers used the LANL recorded dose data contained in SRDB 27261. Only annual neutron and photon doses, respectively, that equal or exceed 50 mrem were used. The analysis results are presented in SRDB 104692.

Summary:
The calculated NP dose ratio parameters for each year from 1950 through 2008 are presented in Table A-1, Attachment A (SRDB 104692). The pattern in the GM and 95th Percentile parameters are shown in Figure 1 with inclusion of significant events obtained from the history of LANL dosimetry presented in Attachment B. A documented personal communication with a LANL external dosimetry site and subject expert, who performed many workplace dose measurements and evaluations, was also done (SRDB reference 107058). The statistical parameters, presented in Table A-1, are based on 412,000 (1950-2008) measured annual dose results. Significant events noted in Figure 1 include:

- Implementation of the use of Kodak Nuclear track emulsion type A (NTA) in 1951 (Littlejohn 1960). LANL had earlier used a very similar nuclear track emulsion glass plate for routine dosimetry. The use of NTA to measure neutron dose continued until 1995 when the routine use of track-etch dosimetry (TED) was implemented.
- LANL had available an instrument capability to measure the neutron dose equivalent in rem which was used in 1963 (Hankins 1963). This capability provides a means to assess the performance of dosimeter measured workplace doses with an accurate instrument measurement.
- LANL introduced thermoluminescent dosimetry (TLD) capabilities over a period of many years. The earliest noted studies occurred in 1970 (Hankins 1969) whereas regular assignment of TLDs to all workers was occurring in 1978 (Lawrence 1978).
- LANL participated in performance testing of the standard that eventually was issued as ANSI/HPS N13.11 in 1983. This standard formed the basis of the DOE Laboratory Accreditation Program (DOELAP) for personnel dosimetry. LANL was DOELAP accredited in 1985 for requested DOELAP categories.

- LANL implemented updated TLD capabilities with the Bicron/Harshaw 8823 system in 1998 which also utilizes TED capabilities for selected workers (Hoffman and Mallett 1999).

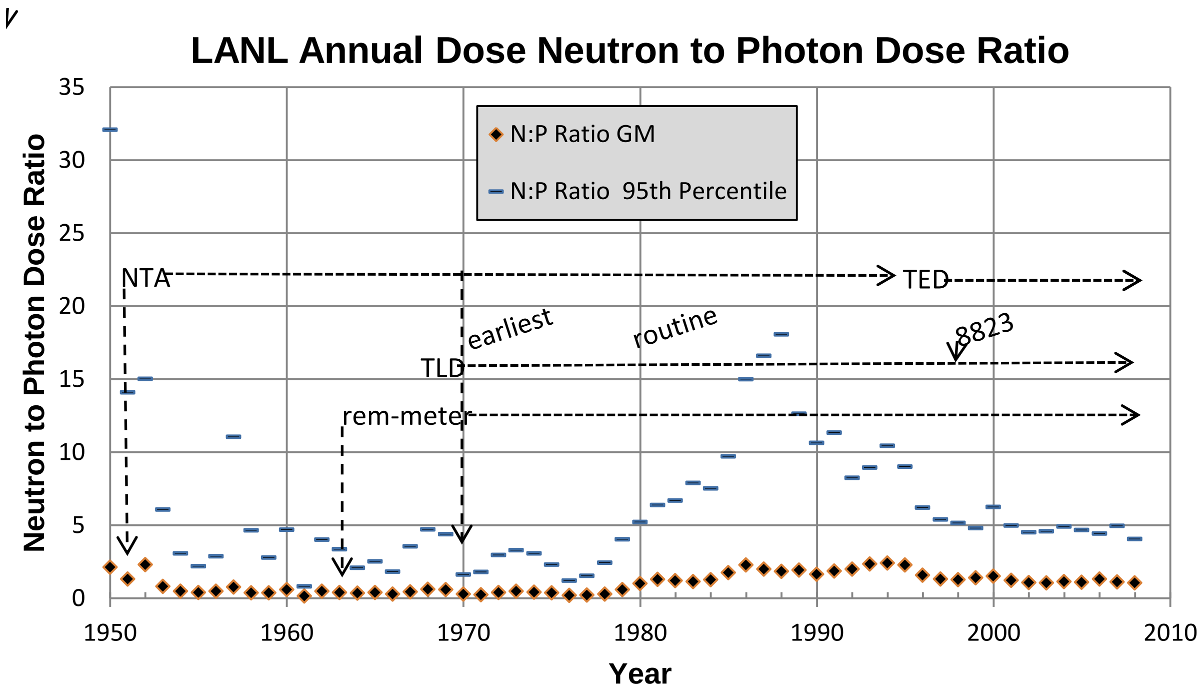

Figure 1. Illustration of LANL worker GM and 95th Percentile NP Dose Ratio for 1950-2008.

The data illustrated in Figure 1 can be summarized over selected time periods based on the foregoing dosimetry operational considerations. Several options are shown in Table 1.

Table 1. Statistical parameters for selected periods of LANL recorded doses

Period	Description	Neutron-to-Photon Dose Ratio		
		GM	GSD	95th Percentile
1950-2008	All years of NTA, TLD or TED dose data	1.04	3.06	6.43
1979-2004	ORAUT-TKBS-0010-6 (2009) time period	1.55	2.73	8.27
1979-2008	ORAUT-TKBS-0010-6 (2009) plus 2005-2008	1.50	2.68	7.77
1980-2008	Era of dosimeter performance testing	1.53	2.66	7.90
1985-2008	DOELAP accredited dosimetry systems	1.60	2.61	8.15

It is evident that neutron dose reconstruction using a distribution with a GM of 1.6 and a GSD of 2.7 could reasonably be done.

ORAUT-TKBS-0010-6, Rev 02 (2009):

ORAUT-TKBS-0010-6 (2009), "Los Alamos National Laboratory – Occupational External Dose," Table 6-22, contains a summary of recommended NP dose ratios for identified sources of neutron radiation. The analyses in this White Paper primarily pertain to Neutron Source Types A and D in Table 6-22. Table 6-22 does not present the GSD values which are used as input IREP. It is evident from the GM and 95th Percentile values that the results of the current analysis and those used in the development of ORAUT-TKBS-0010-6 (2009) recommendations are equivalent.

ORAUT-TKBS-0010-6 Table 6-22. Recommended distributions for neutron-to-gamma ratio.

	Neutron-to-photon dose ratio	
Neutron source type	**Median**	**95th percentile**
A. Plutonium facilities (predominantly Pu-239)	0.7	2.8
B. Plutonium facilities (documented involvement with Pu-238 operations; applies only to 1969 or later; most likely at TA-21, TA-3-29 [CMR Building], or TA-55)	3.9	5.5
C. Criticality experiments (>50 m distant)	2.3	2.5
D. Other operations (1979 to 2004)	1.6	6.4

References:

Hankins, D. E., 1963, *Monitoring Intermediate Energy Neutrons,* Health Phys., Vol. 9, pp. 31-39.

Hankins, D. E., 1969, "Los Alamos Scientific Laboratory Neutron Dosimetry," Presented at AEC Workshop on Personnel Neutron Dosimetry, September 23-24, 1969, BNWL-1340, Pacific Northwest Laboratory, Richland, WA [SRDB Ref ID: 11096]

Hoffman, J. M., and M.W. Mallett, 1999, The LANL Model 8823 Whole-Body TLD and Associated Dose Algorithm, Health Physics, Vol. 77, No. 5, Supplement, pp. S96-S103.

Lawrence, J. N. P., Letter to Photodosimetry Evaluation Book, dated September 28, 1978, entitled "Reportable TLD Exposures," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

Littlejohn, 1960, *Photodosimetry Procedures at Los Alamos*, LA-2494, Los Alamos National Laboratory, Los Alamos, NM, August, [SRDB Ref ID: 951]

ATTACHMENT A
Calculated NP Dose Ratio Statistical Parameters, 1944-2008

Table A-1. Summary of statistical analysis of LANL recorded doses (SRDB 104692)

Year	Number of Workers			Neutron-to-Photon Dose Ratio				
	Total Monitored	Positive Recorded Dose	Photon, Neutron Dose ≥50[a]	Mean	Max.	GM	GSD	95th Percentile
1944	9	7	0					
1945[b]	812	413	2	139.32	275.00	31.62	1.47	261.43
1946[b]	508	391	7	14.02	16.94	13.93	1.12	16.53
1947	1,237	1004	0					
1948	2,080	1383	0					
1949	3,177	1817	21	3.32	10.88	2.25	2.32	10.63
1950	3,895	1981	75	4.86	24.00	2.12	2.64	14.78
1951	4,257	2538	142	3.01	25.75	1.32	3.37	11.52
1952	2,366	1262	97	3.81	39.94	2.31	2.08	9.40
1953	1,878	1151	131	1.53	9.18	0.80	3.04	5.45
1954	2,068	1166	99	0.85	5.14	0.48	2.77	2.92
1955	1,984	956	100	0.63	4.80	0.39	2.11	1.62
1956	2,287	1189	112	0.84	8.75	0.49	2.60	2.28
1957	2,539	1054	78	2.66	31.17	0.77	4.87	10.53
1958	3,032	1378	133	1.01	8.27	0.36	4.43	4.29
1959	2,930	1552	186	0.75	11.57	0.37	3.16	2.30
1960	3,622	1718	179	1.04	6.80	0.58	2.44	2.88
1961	3,973	1395	24	0.24	0.83	0.16	2.10	0.63
1962	4,119	2101	45	1.02	4.42	0.49	3.63	3.93
1963	4,176	1702	71	1.01	8.40	0.40	5.36	5.46
1964	4,103	1580	89	0.60	3.38	0.35	2.90	2.02
1965	4,222	1352	101	0.75	10.00	0.40	2.71	2.14
1966	4,446	1514	98	0.53	4.14	0.29	3.41	1.89
1967	4,072	1493	84	0.95	9.60	0.44	3.22	3.42
1968	3,861	2044	114	1.26	9.00	0.62	3.59	4.79
1969	3,980	2679	159	1.18	9.29	0.59	3.17	3.87
1970	4,031	1018	150	0.49	6.80	0.28	2.59	1.48
1971	3,775	806	85	0.48	2.45	0.25	3.24	1.69
1972	3,877	938	127	0.78	5.40	0.39	3.48	2.86
1973	3,866	924	202	0.91	10.20	0.48	2.71	2.67
1974	4,337	1392	250	0.92	18.07	0.42	3.46	3.17
1975	4,716	1874	229	0.67	10.20	0.38	2.91	2.23
1976	5,254	2165	136	0.37	2.80	0.20	3.39	1.42
1977	5,624	1851	130	0.47	8.67	0.22	3.47	1.69

Year	Number of Workers			Neutron-to-Photon Dose Ratio				
	Total Monitored	Positive Recorded Dose	Photon, Neutron Dose ≥50[(a)]	Mean	Max.	GM	GSD	95th Percentile
1978	7,045	2070	135	0.64	6.50	0.29	3.92	2.44
1979	7,549	2511	288	1.14	11.33	0.59	3.33	4.15
1980	7,638	3443	340	1.63	12.80	1.00	2.82	5.51
1981	7,966	5034	463	1.96	14.50	1.30	2.14	5.35
1982	7,997	4297	456	1.89	15.30	1.21	2.19	5.07
1983	8,144	4419	445	1.85	11.57	1.13	2.08	5.00
1984	8,622	6069	535	1.94	11.57	1.26	2.05	5.29
1985	9,487	4921	434	2.63	21.40	1.76	1.94	6.36
1986	9,612	2262	324	3.72	21.40	2.27	2.24	11.59
1987	9,202	1621	253	3.54	17.71	1.99	2.27	10.75
1988	9,469	1548	271	3.68	25.80	1.85	2.58	12.59
1989	10,605	1616	244	3.24	14.33	1.93	2.43	9.58
1990	10,796	1538	207	2.69	14.71	1.64	2.40	8.80
1991	11,284	2356	156	3.05	19.90	1.85	2.28	8.73
1992	11,560	1687	131	2.85	17.24	2.00	2.11	7.29
1993	11,772	1948	132	3.23	15.03	2.34	2.29	9.18
1994	11,783	3145	170	3.38	15.88	2.41	2.19	9.37
1995	12,448	3219	188	3.21	20.92	2.27	2.18	8.21
1996	10,959	2358	197	2.14	11.69	1.57	1.91	5.09
1997	10,860	2992	215	1.86	10.78	1.31	2.50	5.61
1998	11,168	2201	171	1.78	9.16	1.40	2.21	4.50
1999	11,212	1720	158	1.85	8.34	1.40	2.25	4.94
2000	10,456	1485	122	2.10	7.03	1.52	2.07	5.22
2001	10,443	1435	156	1.74	6.91	1.22	2.61	5.39
2002	10,931	1760	199	1.55	6.91	1.07	2.39	4.22
2003	10,752	2101	239	1.57	7.91	1.25	2.66	4.77
2004	10,192	1731	156	1.64	9.86	1.13	2.52	4.79
2005	10,826	2176	193	1.71	7.47	1.29	2.24	4.42
2006	10,104	2021	215	1.93	9.24	1.51	2.21	4.70
2007	9,745	1525	203	1.79	8.01	1.34	2.36	4.73
2008[(c)]	8,148	941	106	1.48	5.91	1.05	2.52	4.42

a. Number of workers with recorded neutron and deep photon doses, respectively, ≥ 50 mrem.
b. Doses anticipated to have been estimated following accidents and not routinely measured.
c. Anticipated to represent <1 year of dose data (i.e., November 2008 last noted dose entry).

ATTACHMENT B
History of LANL Radiation Associated Events

1944

U.S. Department of Energy, 1997, Linking Legacies, Office of Environmental Management, US Department of Energy, Washington, D.C., [SRDB Ref ID: 11930]

Construction of Los Alamos as a centralized laboratory for atomic bomb research and production began in November 1942. In March 1943, technicians and scientist began arriving at the Laboratory. The laboratory's mission was the design and manufacture of the first nuclear weapons. DP-Site (also known as TA-21), and its successor, TA-55, was built in 1945 as a production plant for plutonium bomb cores and polonium-beryllium initiators. DP-Site also handled tritium. The DP-Site housed a variety of plutonium research, design, and fabrication activities for more than 30 yr until operation of TA-55. TA-55 began operations in 1978. TA-55 can perform a wide variety of small-scale component fabrication operations, including all of the operations that were conducted at Rocky Flats on a large scale.

Maraman, W. J., W. D. McNeese and R. G. Stafford, 1975, "Confinement Facilities for Handling Plutonium," Health Physics, Vol. 29, pp 469-480.

This paper includes an historical overview of plutonium handling practices at LANL. The earliest work with plutonium began in D Building in the old Main Technical Area in the mid-1943 on a microgram scale. Multi-gram quantities became available in early 1944. In 1944 and 1945 a facility was built at DP Site specifically for chemical and metallurgical work on kilogram quantities of plutonium. This facility has been in continuous operation since 1945 until the date of this paper in 1975. The program at DP Site in 1975 included metallurgical and chemical research and development with 239Pu for the weapons program and the advanced fuels (e.g., mixed uranium-plutonium carbides and nitrides) for the Liquid Metal Fast Breeder Reactor Program; and recovery of 239Pu from all scrap generated at the LANL; the preparation and characterization of 238Pu fuels for the Artificial Heart Program and advanced fuels for Space Nuclear Systems; for the recovery of certain reactor-grad plutonium in scrap; and for certain studies on the characterization of transuranium waste.

LANL Medical Group, Health Report, August 9, 1943, Manhattan Engineer District, Los Alamos, NM [SRDB Ref ID: 29302)

The program of the Medical Group is concerned not only with the specific health problems, i.e., the toxic effects of radiation and uranium, but also with the elimination of industrial hazards and with the administration of first aid in the technical areas. With regard to the specific health problems, the most important deals with the protection of personnel from exposure to dangerous amounts of radiation. Our plan is to follow the suggestions of the Chicago Health Group, namely, frequent surveys of laboratories to determine radiation intensities, daily record of exposure to each person, monthly blood counts (oftener when safe daily dose is exceeded) , and semi-annual physical examinations. The problem of preventing poisoning by uranium has not been as urgent as above, but routine urinalysis on all persons who will work with this metal or radiation will be instituted within the next week.

1944

Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume 1a Procedures 1944-1959,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181]

This document provides a tabulation of letters, memorandum, studies, etc., for the LANL dosimetry program during the period of 1944 through 1959. The earliest memorandum is dated January 19, 1944 from L. H. Hemplemann to S. L. Warren regarding use of film to check radiation exposure.

Hemplemann, L. H., Letter dated May 18, 1944 to S. L. Warren concerning film badge dosimeter distribution, “Photodosimetry Evaluation Book "Bible" Volume IA Procedures 1944-1959,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181]

This letter states that film monitors have begun to be distributed among the various personnel however this has been limited by the fact that only one set of standard exposures arrived in the initial shipment. A request is made for more sets of the standard exposures so the film monitors could be used regularly.

Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume 1a Procedures 1944-1959,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181]

There are several reports describing various aspects of Los Alamos film dosimetry methods. It appears from this documentation that capabilities of dosimeters are selected depending upon the workplace as follows: 1) a selection of filters (i.e., brass, cadmium, lead, etc., 2) an open window for beta radiation (also finger rings and film placed inside gloves), 3) film is processed at the University of Rochester, 4) film is exchanged weekly, and 5) recognition of the importance of calibrated film and control dosimeters from the same film batch.

Farwall, G., Memorandum entitled “Neutron Yields of Initiator Assemblies Fired to 7/4/1944,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 69427]

Eleven active gun assemblies designed by Ayers have been fired by the E-4 20 mm testing crew. The neutron emission of each assembly has been measured, after hand assembly where possible and after gun assembly in every case. Determination of absolute neutron yields is based upon comparison of the active assemblies with a calibrated Po-Be standard. Results are estimated to be accurate within ±5%. Comparisons are made with a BF_3 detector. An 8% correction is made for absorption by the walls of the target assemblies. This correction has been determined by comparing the count of the Po-Be standard in the standard paraffin geometry to the count of the Po-Be standard placed in a steel target dummy in the position occupied by the polonium and beryllium in an active assembly. Differences in target design have no measurable effect on the magnitude of the correction.

Breslow, B. A., Memorandum to Distribution, dated June 28, 1944 entitled "Safe Operation of the 20 MM Gun Progress Report," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 69427]

All workers working with dirty material will wear coveralls, respirator, skull caps and rubber gloves. The maintenance of clean clothes and servicing the dirty has been assured.

Los Alamos Dosimetry, "Photodosimetry Evaluation Book "Bible" Volume IB Procedures 1944-1959," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8266]

This document provides a tabulation of dose algorithms used with LANL dosimeters and operating facilities during the period of 1951 through 1959 to evaluate beta and gamma doses. The earliest algorithm appears to be Method 1 with starting dates during the period of December 24-27, 1944 depending on the facility. The algorithm and processing instruction allows a determination of the dosimeter design. Multi-element film dosimeters appear to have been used for all facilities.

Lawrence, J. N. P., Letter to File, dated October 6, 1978, entitled "Los Alamos Criticality Accidents 1945-19461 Personnel Exposures," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

The purpose of this memo is to document the exposures to be entered in the H-I Dosimetry Computer Record for persons involved in the three criticality accidents occurring at Los Alamos in 1945-1946. None of the personnel involved wore film badges or other personnel dosimetry detectors. Calculations of the personnel exposures exist in several source documents (referred to herein), but a simple reference to this material is inadequate because of differences in the calculated results. This memo will designate the exposures to be entered in the computer record, identify the source documents, point out the differences in the exposure estimates, and provide an explanation of why the particular exposure estimates were chosen.

1945

Anonymous, 1956, Film Badge Techniques Prior to 1/1/1952," Los Alamos National Laboratory, Los Alamos, NM, February 16, [SRDB Ref ID: 882]

The information in this reference is dated February 16, 1956, and apparently extracted from document that describes the history of LANL dosimetry methods. This reference is specifically for the time period prior to 1/1/1952 stating that the various film badge techniques and special evaluation methods are provided. Only a few methods were used prior to 1/1/1952. This judgment was apparently based on examination of the Accession Books used for film records from ?/17/1945 to 2/17/1951 and also by contacting persons who worked at LASL beginning in 1945. According to summary data, film badges were started at LANL as early as 1943 using Eastman Kodak film and a badge with a lead filter. In 1944, a brass filter was being used. During the period of 9/10/1948 through 3/11/1949, a new type of film badge was introduced with a brass filter and also an unfiltered (open window) region that was regularly used until 4/20/1950. Calibrations were made using radium and uranium for gamma and beta radiation, respectively. Around 8/29/1949, the first nuclear track plates (NTP) were issued for the monitoring of fast neutron exposures. The first written reports on fast neutron exposures occurred during May 1950. In April 1951, the brass and cadmium filter type of dosimeter holder was implemented.

Dunlap, R. H., Memorandum to Dr. Hemplemann, dated January 1, 1945, entitled "Report on room surveys," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 40103]

As stated in this reference, "Attached hereto are 66 sheets, consecutively numbered, representing the statements of group leaders or room occupants as to the nature of their work and toxic materials used. I have prepared a room-by-room index which in all instances refers to the proper sheet number. The monitoring procedure, in accordance with the terms in your letter dated October 10, 1945, are designated as follows:

Color	Material	Monitoring Procedure
Red -	49, Po, or 25	Pluto and swipes daily
Blue -	Tuballoy	Pluto and swipes daily
White -	offices and labs in which contamination is possible but not probable	swipe monthly

Materials other than Alpha type are so indicated. Inasmuch as many of the rooms indicated by red, handle only minute quantities, and these infrequently, or in some instances merely receive the material in double bottles, it seems wise that yon and I re-discuss the monitoring procedures as it is a rather severe strain to have to monitor these substantially clean rooms by our most thorough and time consuming procedure."

<u>1946</u>

Aebersold, P. C., W. H. Hinch, J. C. Hoffman, and F. W. Molley, 1946, "Radiation Health Monitoring," Los Alamos Technical Series, Los Alamos National Laboratory, Los Alamos, NM, January 24, [SRDB Ref ID: 69522]

This is a radiation protection styled document with discussion of radiation, radiation types, tolerances, etc. Much of the document provides information and operating instructions for several types of portable radiation instruments. Electrical schematics are included for several instruments.

1947

Evans, C.E., Letter dated August 4, 1947, to J. W. Newland, University of Rochester, concerning description and use of film dosimeters to monitor exposure to workers, Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref Id: 8181]

This letter describes the use of LANL constructed brass film holders with varying thickness between 4 and 8 (difficult to read) mm with no window or any other metal into which film is placed to measure gamma exposure to workers. The film is apparently exchanged monthly. As many as three types of film have been used in each badge. One is the Eastman Industrial Type K X-ray Safety Film. The second is the DuPont D-C Special Type X-Ray Film which has sensitive and insensitive sides and the third is the Adlux Film made also by DuPont which is extremely insensitive. Recently only the Eastman film has been used because of good experience with this film however for highly hazardous work all three films are used. Generally, the tone of this letter is that the method is comparatively successful and more accurate than pocket ionization chambers which apparently are also used. The concern was stated that exposure could be missed if the dosimeters were not worn by workers and also that too much radiation exposure is calculated for contaminated dosimeters.

Smith, F. S., 1947, Procedure for Pick Up and Disposition of HCT Trash from Bayo Canyon, Los Alamos National Laboratory, Los Alamos, NM August 14, [SRDB Ref Id: 37969]

This reference concerns procedures for providing protection to avoid overexposure to beta/gamma radiation to the personnel hauling trash and waste from Bayo Canyon to the Contaminated Dump. Personnel are to be prepared by the supervisor or Health Instrument Escort as follows:

a) Each man will be provided with a film badge containing at least two packets of film of different sensitivity.
b) Each man will be provided with two (2) gamma-ray dosimeters.
c) A film badge will be planted in the cab of the contaminated truck.
d) A film badge will be planted in the sedan that makes the trip to the Site.
e) Two red flags are to be mounted on the front of the contaminated truck, two on the rear of the contaminated truck, one on the left front of the sedan and one on the left rear of the sedan
f) The H. I. Escort for the contaminated truck will carry with him one Watt Meter and the respective conversion chart, one Victoreen Gamma Survey Meter and a Radium shielded standard. The Watt meter is to be adjusted to a zero reading in any convenient non-active area and carefully calibrated with the shielded radium source.

1948

Kenney, W. K., Memorandum dated February 28, 1948 to J. F. Tribby, entitled "Analysis of Beta, Gamma Radiation Exposure of Sigma Building Personnel," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181, p 43]

Brass film badges were issue to all Sigma and RT personnel October 20, 1947 in order to maintain a complete record of the exposure of the people in that area to beta, and gamma radiation. They have been changed and reissued every two weeks since that time. The following persons have received at least one exposure reading of over 0.290 roentgen for a two week period (over one quarter of an average tolerance dose, 0.1 r/day – gamma, 0.1 rep/day – beta, or beta, gamma). *[List of workers follows*]

Hardy, H. L., Memorandum dated June 7, 1948 to H. Whipple, entitled "Film Badges – DP East," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181, p 51]

This memorandum provides an explanation as to why DP East workers were not wearing their film badges. It was stated that the workers stopped wearing the film badges in the spring of 1947 after a trial period of three months which showed no measureable exposure whatsoever. Plastic wrist badges are worn at times. The question is posed as to the merit to persuade the DP East personnel to wear film badges routinely regardless of past negative dose results.

Whipple, H. O., Memorandum dated June 8, 1948 to H. L. Hardy, entitled "Film Badges – DP East," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181, p 52]

The memorandum contains an analysis of DP east exposures. A three month study of exposure to workers at DP East working with polonium sources showed very low exposure from gamma radiation in comparison to their alpha activity. Expected doses would actually be less-than natural background exposures. The worst workplace exposure occurs in the vault. It would require Po of about 2,000 Ci to result in an 8-hour day tolerance dose. It was suggested that if this much Po was in the vault then consideration should be given to requiring badges to be worn.

Anonymous, 1948, Group CMR-12 Progress Report, Health and Contamination, July 20 - August 20, 1948, Los Alamos National Laboratory, Los Alamos, NM August 14, [SRDB Ref Id: 13465]

Photographic Dosimetry. During the month, 694 films were developed servicing 627 brass badges. Results were read on the Weston Photographic Analyzer and recorded. It was necessary to read the DuPont film in only two cases. One was the high reading mentioned below; the other was due to a lost film. In addition to the brass badges worn on the body, 67 plastic wrist badges were processed. Each film emulsion in both plastic and brass holders was calibrated using gamma radiation from a 0.5 mm platinum shielded, radium source in equilibrium with its decay products. A 100 millicurie source is used for the Eastman Type K film (accurate to approximately 3 Roentgens) and a 500, millicurie source was used for the DuPont type D-2 film (covering from 2 to 30 roentgens). For the exposures reported, 576 were worn by personnel and 43 were planted in various locations. Twelve badges, including wristlets, were planted in the various badge storage racks as blanks. The average personnel exposure, neglecting one high reading, was 0.004 roentgens per week; the average exposure for the planted badges was 0.185 roentgen per week. The maximum rack blank reading for a two week period was 0.003 roentgen.

1949

U.S. Department of Energy, 1997, Linking Legacies, Office of Environmental Management, US Department of Energy, Washington, D.C., [SRDB Ref ID: 11930]

LANL was the lead site for U.S. nuclear component fabrication until 1949, when the Hanford Plutonium Finishing Plant in Washington began making *pits*, the central cores of the primary stages of nuclear devices.

Littlejohn, 1949, Memorandum dated January 10, 1949 to staff entitled "Method of Reporting Beta Exposures on Personnel Exposure Reports," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8181, p 57]

Changes in the LANL film dosimeter were recently made which allow separate determination of the beta and gamma dose. The change consists of a film packet inserted in a brass clip that provides only partial shielding of the film surface. The brass thickness used is sufficient to absorb almost all beta radiation present while having negligible effect on the gamma intensities. By a comparison of the film densities under brass with those not under brass, a separate evaluation of the beta exposure received can be made.

1951

Littlejohn, 1960, *Photodosimetry Procedures at Los Alamos*, LA-2494, Los Alamos National Laboratory, Los Alamos, NM, August, [SRDB Ref ID: 951]

This reference provides some historical information as follows: "The Los Alamos Scientific Laboratory film badge in use today (i.e., 1962) has remained unmodified since its inception and adoption in 1951." The dosimeter included a body film-badge dosimeter using Du Pont 502 dental film and utilizing a 20 mil cadmium filter, a 20 mil brass filter, and an unshielded area.

Storm, E.,, 1951, *The Response of Film to X-Radiation of Energy up to 10 MeV*, LA-1220, Los Alamos Scientific Laboratory, Los Alamos, NM, March 22, [SRDB Ref ID: 978]

The response of Eastman Kodak type K and DuPont 552 film to high energy x-rays was investigated. The densities on the unfiltered portion of the DuPont film and those under the brass and cadmium filters are very nearly identical from 0.3 to 2.0 MeV, beyond which point the brass and cadmium densities become slightly greater. For a given roentgen (R) value, a greater response in terms of density is obtained on the film as the effective energy is increased beyond 2.0 MeV. A method of determining the effective energy by means of an additional lead filter on the film is described. When a film is exposed to beta radiation in addition to photon radiation, the probit density under the brass minus the probit density under the lead can be used to determine the effective energy due to the photon radiation. The exposure is then found from the calibration curve made with this energy. Any increment in density on the unfiltered film above that due to the photon radiation is attributed to beta radiation.

Storm, E., G. M. Angleton, and G. H. Pettengill, 1951, *The Response of Sensitive 552 DuPont Film to Beta Radiation*, LA-1284, Los Alamos Scientific Laboratory, Los Alamos, NM, August 13, [SRDB Ref ID: 976]

This reference is a technical report concerning the response to beta radiation of sensitive 552 DuPont film, enclosed in the usual manufacturer's packet, was measured in terms of rep. Seven beta emitting isotopes covering a maximum energy range from 0.26 to 3.50 MeV were used. The exposures were measured in rep by means of an air ionization extrapolation chamber. For each source, thirteen different exposures were made covering a range from 0.1 to 5.0 rep, three separate films being run for each specific exposure. A 30 me/em2 cellulose acetate filter was placed over the end of each film, and the calibration curves obtained under the filtered and unfiltered portions of
the film. The film response was found to diminish sharply below 0.8 MeV, and become nearly energy independent beyond 2.5 MeV. A method for determining both the energy and the exposure of a film exposed to gamma and beta radiation is described in the report.

<u>1952</u>

The first edition of the LANL "General Handbook for Radiation Monitoring" was prepared in 1952 by Robert F. Barker (Healy 1970, SRDB 943)

<u>1953</u>

<u>1954</u>

Barker, R. F., 1954, “General Handbook for Radiation Monitoring,” LA-1835, Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 968]

This document was written specifically for use at Los Alamos. Each individual at the Los Alamos National Laboratory who has contact with radioactive materials or radiation is responsible for:

1. Keeping his own exposure to radiation as well as that of others as low as possible and specifically below the maximum permissible levels of 300 mr for gamma or 500 mrep for beta plus gamma radiation per week except in case of extreme emergency or exposure incurred during medical examinations and treatments. Health Division approval should

be sought in advance for other urgent situations requiring exposures in excess of the above values.

2. Wearing the prescribed monitoring equipment (pocket dosimeters, film badges) in gamma, beta, and neutron radiation areas. Requesting neutron film badges where significant neutron exposures are anticipated. Surveying hands, shoes and body for radioactivity and removing loose contamination to the tolerance levels before leaving the Laboratory, in accordance with the recommended decontamination procedures.

3. Wearing appropriate protective clothing whenever clothing contamination is possible, and not wearing such clothing outside of the Laboratory area. Using gloves, hoods, and respiratory protection (respirators or supplied air masks as recommended by the Health Division) where necessary. Using proper techniques and facilities in operations involving radioactive or toxic materials.

Total Body Exposure

Xrays and gamma rays	**300 mr per week**
Beta	500 mrep per week
Beta and Gamma	500 mrep per week
Xray (below 15- kev average)	500 mr per week

The maximum permissible exposure for neutrons, as adopted at the Tripartite Conference in Harriman, New York, April 1953, (NBS Handbook 55) varies with energy.

1955

Kalil, F., 1955, *A Film-Badge Method of Differential Measurement of Combined Thermal-Neutron and Gamma-Radiation Exposures*, LA-1923, Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 964]

A body film-badge dosimeter using Du Pont 502 dental film and utilizing a 20 mil cadmium filter, a 20 mil brass filter, and an unshielded area was calibrated by exposure to combinations of thermal neutrons and gamma radiations from the thermal column of a homogeneous reactor and a radium source. A method was devised whereby combined thermal neutron and gamma-radiation exposures can be differentiated and evaluated. The method of differentiating and evaluating the thermal-neutron exposure is accurate, provided the gamma ray energy spectrum lies between 0.15 and 10 MeV. The gamma radiation exposure can be accurately evaluated, provided the gamma-ray energy lies between 0.3 and 3 MeV, a range over which the film-badge response is independent of the gamma ray energy. Beta-ray exposures, under restricted conditions, can also be roughly evaluated by previously established techniques.

1956

Anonymous, 1956, Procedure entitled "Modification of Nuclear Track Plate Evaluation Procedure,", Los Alamos National Laboratory, Los Alamos, NM., November 1, [SRDB Ref ID: 8181, p 231]

This reference describes changes in the nuclear track plat evaluation procedures that went into effect shortly after 11/1/1956. The fact of recording exposures of less than 10% as zero exposure was started with the third quarter of 1956 (i.e., NTPs pertaining to the month of July and thereafter). The step by step NTP evaluation procedure follows.

1957

Anonymous, 1957, Procedure entitled "Changes in Certain Portions of Permanent Personnel Exposure Record of LASL Personnel,", Los Alamos National Laboratory, Los Alamos, NM., April 3, [SRDB Ref ID: 8181, p 233]

Plans are underway to transcribe all permanent radiation exposure records of LASL personnel to an IBM system which requires certain changes prior to the changeover.

Meyer, D. D.., LANL, Letter to A. R. Keene, Hanford, dated March 12, 1957 concerning policies for personnel with plutonium intakes, Los Alamos Scientific Laboratory, Los Alamos, NM, [SRDB Ref ID: 37969]

Current plutonium in urine assay capabilities are such that establishing body burdens les-than the maximum permissible limit (0.04 µC) cannot be done with any degree of accuracy. For situations where personnel have intakes of 100% or more of the maximum permissible limit, personnel work assignments are restricted from intimately working with plutonium solutions, powders, or metal though sealed-hood gloves or in ventilated laboratory hoods. These persons are assigned to further plutonium work in operating locations where the risk of further exposure to plutonium would require a major plant accident.

1958

Dummer, J. E. Jr., 1958, "General Handbook for Radiation Monitoring," LA-1835 3rd Edition, Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 967]

1959

1960

Los Alamos Dosimetry, "Photodosimetry Evaluation Book "Bible" Volume II Procedures 1960-69," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8173]

This reference contains many documents describing the Los Alamos dosimetry system, calibration, and dose assessment.

(LASL 1969)
As of April 1960, the brass-cadmium film badge was being worn by about half of University of California employees, all of the Security Force, and 75% of Zia employees. At most sites, film badges were reportedly issued "only to personnel who need them." The stated plan was to combine the film badge with the site security badge to increase compliance with the requirement to wear dosimeter badges, and it was proposed that badges be issued to all LANL and AEC personnel on a regular basis. As of 1960, the following external radiation dose data were recorded (Littlejohn 1961):

- Gamma dose (rem)
- Beta dose (rad)
- Thermal neutron dose (from cadmium optical density minus brass optical density, rem)
- Fast neutron dose (from NTA film, rem)

Littlejohn, 1960, *Photodosimetry Procedures at Los Alamos*, LA-2494, Los Alamos National Laboratory, Los Alamos, NM, August, [SRDB Ref ID: 951]

The Los Alamos Scientific Laboratory film badge in use today has remained unmodified since its inception and adoption in 1951. It has, however, become more versatile than its original counterpart by the inclusion of a high-range-gamma, fast-neutron film packet. Subsequent experimentation has also enabled the badge to be used in the detection and measurement of thermal neutrons. For routine personnel monitoring, the LASL badge utilizes two film packets: the DuPont 543 and the Eastman Experimental Personnel Neutron Monitoring Film Type B.

<u>1961</u>

Storm, E., and S. Shlaer, 1961, The Development of Film Badges Containing Multi-element Filters to Reduce the X-ray Energy Dependence of Photographic Film, LA-3001, Los Alamos National Laboratory, Los Alamos, NM, July [SRDB Ref ID: 947]

This report describes the experimental work leading to the development of flat roentgen response film badges containing multi-element filters. The films were exposed to fluorescent x rays from 30 to 100 keV, heavily filtered direct x-ray beams from 100 to 250 keV, and isotope gamma rays from 250 to 1250 keV. Measurements showed that the unfiltered response of personnel films was 15 to 30 times greater to 40 keV x rays than to 1250 keV gamma rays. Calculations indicated that a filter consisting of several elements with K-edges evenly spaced from 40 to 90 key could reduce the energy dependence of the film to within acceptable limits. Such multi-element filters were placed in cycolac plastic film badges. It was necessary to place copper between the multi-element filter and the film to reduce the effects of fluorescent radiation produced in the filter. Measurements made with low energy radiation showed that the film blackening behind the filter was due primarily to radiation scattering in the plastic and not to radiation passing directly through the filter. Two plastic film badges were developed with either lead frames or lead lattices placed around the filters to reduce the amount of radiation scattering into the filtered area.

The lead-frame badge contains a multi-element filter (gadolinium, erbium, tantalum, gold, and bismuth) and a 0.02 in. thick copper filter; the response of DuPont 502, DuPont 508, DuPont 555, Eastman Type II, and Ilford PM-I film in this badge is flat within 30 per cent from 40 to 1250 keV; the badge is directionally independent within 30 per cent over this energy region, but the density under the filtered area at low energies is non-uniform, the edges being darker than the central region. The lead-lattice badge contains a multi-element filter (Same elements as in the frame badge, but in different proportions) and a copper filter whose thickness varies with the film type; the response
of the same films listed above is flat within 30 per cent from 50 to 1250 keV; it is directionally dependent at low energies, and the density under the filtered area is uniform

The badges were modified to permit the evaluation of thermal neutron and beta radiation; these modifications did not affect the photon film response of the lattice badge, but the frame badge was now directionally dependent by as much as a factor of 3 because of the reduced size of the filters. A method of measuring thermal neutrons was devised using two multi-element filters having similar photon responses; one filter containing gadolinium gave a Co-60 gamma ray to thermal neutron exposure ratio of 1.43 R/rem, and a second filter containing molybdenum instead of gadolinium gave a ratio of 0.70 rem. The film badge response on a phantom was higher than in air by a factor of 1.56. An estimate was made of the accuracy of the gamma exposure evaluation when the film is exposed to both gamma and fast neutron radiation; film badges exposed to the Godiva critical assembly read 70 per cent higher than glass dosimeter rods exposed at the same time and in the same location.

1962

1963

Dummer, J. E., Memorandum to D. D. Meyer dated March 3, 1963 entitled “Correlation between Brass-Cadmium and Cycolac Film Badges,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8173, p 63]

Beginning in October 1962, the new multi-element filter film badge (hereafter referred to as the cycolac badge) was issued to about 100 persons who had a history of appreciable or out of the ordinary radiation exposure. After a month’s use, one user at the DP West plutonium facility appeared to be receiving considerably more exposure than had been measured with the old badge (hereafter referred to as the brass-cadmium badge). An investigation was initiated to examine the cause.

The radiation in the workplace is stated to be:

Percentage	Photon Energy, keV
65 – 70	L X-rays (~17 keV) + 26
10 – 20	60
1 – 10	100
~0 - 7	>200

The investigation showed that the cycolac badge measures the dose correctly within ±10% when the source is unfiltered. When filtered by glass or steel, the hard component is measured correctly but the soft component is overestimated, making the total dose in error by as much as 60%. The brass-cadmium badge underestimates the dose by a factor of 2 in the unfiltered cases and a factor of 3 in the filtered cases. Considering there is no way to know whether badges worn at DP are exposed to a "filtered" or "unfiltered" source, the badges must be interpreted as if "unfiltered" when potential sources of soft radiation exist.

Hankins, D. E., 1963, *Monitoring Intermediate Energy Neutrons,* Health Phys., Vol. 9, pp. 31-39.

This paper describes intermediate-energy neutron monitoring techniques studied at the Los Alamos National Laboratory. A recently developed instrument for simultaneously monitoring neutrons with energies from thermal to 7 MeV is discussed. Experimental data obtained using several instruments and techniques with various neutron spectra are compared. The relative dose rates of thermal, intermediate, and fast neutrons under various shielding conditions are presented, and the techniques for monitoring intermediate energy neutrons are evaluated.

Hankins, D. E., Letter to distribution dated August 28, 1963, entitled "NTA Film Badge Response to PuF_4 Neutrons," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 22660]

This reference contains the dose results for an eva1uation of the NTA neutron film response to PuF_4 neutrons at Building 501, DP West. The results of ten film badge exposures are provided in the letter. An area of ten (10) mm was used to read the number of tracks for each film instead of the one (1) mm normally read for personnel exposures. As noted in the reference a deviation of about a factor of 2 was observed in the number of tracks/film. The neutron source strength was measured with one of the 10" portable units and is probably accurate to ±20%. The average mrem/track value of about 16 is considerably less than the 80 mrem/track found in a previous study. As a result of the above, it is recommended in this reference that 15 or 16 mrem/track be used in the future to evaluate personnel films.

<u>1964</u>

AEC, Immediate Action Directive, dated February 17, 1964, entitled "Posting Requirement for Contractors – Radiation Protection Standards," [SRDB Ref ID: 1287]

Effective upon receipt of this directive, AEC contractors are required to post copies of the following notice at a location or locations in such plants or facilities where it can be readily viewed by the contractor's employees.

NOTICE TO EMPOLOYEES
U. S. ATOMIC ENERGY COMMISSION'S
STANDARDS FOR PROTECTION AGAINST
RADIATION

Standards for protection of employees against radiation are established by
the Atomic Energy Commission. These standards cover:

a) Measuring, recording and reporting to employees and the AEC the amount of radiation received by employees in the performance of their work.
b) Monitoring and controlling the handling and use of radioactive material in the plants, and the discharging of radioactive materials to the environment outside of the plants.
c) Other matters dealing with the control of possible hazards that might result from the handling or use of radioactive materials in all AEC facilities.

REPORTS ON EMPLOYEE RADIATION EXPOSURE
HISTORY

Your employer is required to establish procedures to assure that employees are:

1. Advised, upon written request, of their occupational radiation exposure as indicated in the exposure record.
2. Notified immediately of any radiation exposure which exceeds the limits specified by

the AEC's standards.

3. Provided, at the time of or after their terminations, upon request and within forty-five days after the request, with a written summary of their cumulative recorded occupational radiation exposures received during the period of employment.

POSTING

Your employer is required to post, or otherwise make available to you, a copy of AEC radiation protection standards, and the approved operating procedures relating to radiation protection applicable to the work in which you are engaged.

YOUR RESPONSIBILITY AS A WORKER

You should familiarize yourself with those provisions of the AEC standards for radiation protection and the operating procedures applicable to your work. You should observe their provisions for your own protection and that of your fellow workers.

AEC, Immediate Action Directive, dated March 3, 1964, entitled "Notice to Employees," [SRDB Ref ID: 1287]

Further information similar to the forgoing posting but to include a section as follows;
Reports on Employee Radiation Exposure History
Your employer is required to establish procedures to assure that employees are:

1. Advised, upon written request, of their occupational radiation exposure as indicated in the exposure record.
2. Notified immediately of any radiation exposure which exceeds the limits specified by the AEC's standards.
3. Provided, at the time of or after their terminations, upon request and within forty-five days after the request, with a written summary of their cumulative recorded occupational radiation exposures received during the period of employment.

AEC (Atomic Energy Commission), 1964, Radiation Protection Standards, Form AEC-9 with Note No. 1 and Note. No. 2. Atomic Energy Commission, [SRDB Ref ID: 1287].

A. Radiation from sources external to the body.

Type of Exposure	Period of Time	Dose (rem)
Whole body, head and trunk, active blood forming organs, gonads, or lens of eye	Accumulated dose Calendar Quarter	5 (N-18) 3
Skin of whole body and thyroid	Year Calendar Quarter	30 10
Hands, and forearms, feet and ankles	Year Calendar Quarter	75 25

AEC assigned weapon surveillance and repair mission to Pantex, while both Pantex and Burlington shared the retrofits and modifications mission.

<u>1965</u>

<u>1966</u>

<u>1967</u>

Hankins, D. E., 1969, *The Response of Selected Neutron Monitoring Instruments to Several Types of Neutron Sources,* Health Phys., Vol. 13, pp. 587-592.

This paper compares the response of several neutron-monitoring instruments in use at Los Alamos to nine neutron sources and concludes that differences in the neutron spectra of the sources and differences in the energy dependence of the instruments significantly affect calibration results. Neutron sources of ^{238}PuBe, ^{239}PuBe, AmBe, PoBe, RaBe and spontaneous fissioning ^{244}Cm were used. The sources were calibrated in the Los Alamos Scientific Laboratory's standard pile with a probable error of ±5 per cent for the reported absolute source strength, and a probable error of ±3 per cent for the comparison made in this study. The instruments used were the Hurst absolute fast-neutron dosimeter, the Ludlum Model 11 neutron detector, the Eberline Portable Neutron Counter (PNC), The Eberline Fast-Neutron Detector (FNIA) (Scintillator), the 10-inch, single sphere neutron-monitoring instrument, and the 8-, 3- and 2-inch spheres of the multisphere technique. The results indicate that all the instruments have essentially the same response to the ^{238}PuBe, AmBe, and PoBe neutron sources. The moderated BF_3 instruments have a high response (~14 per cent) to the ^{239}PuBe and RaBe sources, and a high response (~38 per cent) to the ^{244}Cm. The fast-neutron scintillator had a response 58 per cent low to the ^{244}Cm. More results are shown in the paper.

<u>1968</u>

Group HS-1, 1968, *The New LASL Film Badge and Neutron Dosimetry Packet*, LA-3889, Los Alamos National Laboratory, Los Alamos, NM, January [SRDB Ref ID: 35008]

This is a basic document apparently provided to all employees at LASL (see Jalbert 1974 letter) describing the implementation of the new Cycolac plastic dosimeter which contains multi-element filters, two film packets, and identification plates. The two film packets used with the LASL film badge are the DuPont Type 545 Dosimeter Film pack and the Kodak Personal Neutron Monitoring Film Type B pack. The DuPont pack contains a single gamma-sensitive film of type 555 emulsion in a light-tight wrapping. This film is used to measure the monthly exposures to x rays or beta, gamma, and thermal neutron radiation. The useful range is approximately 0.03 to 10 rem. The Kodak film packet contains gamma-insensitive film, a nuclear track film, and two thin aluminum absorbers in a light-tight wrapping. The gamma insensitive film has a useful range from about 10 to 1,000 rem. The nuclear track film (Kodak NTA) is used in conjunction with aluminum absorbers to measure fast neutron exposures from about 0.03 to 10 rem. Processing NTA film is a time-consuming activity, requiring a minimum of six minutes per film as compared with a half minute for determining the density in the three filter areas of the DuPont film. Neither personnel nor facilities permit the H-1 Photodosimetry Section to analyze all the NTA films which are issued; however, all issued NTA films are developed and stored. In many laboratory areas a detectable number of fast neutrons does not exist, and the NTA films worn in these areas are not evaluated. In general, only those NTA films worn by persons suspected of having received significant fast neutron exposure are evaluated; these are approximately 10% of all NTA films issued.

The PND neutron packet consists of a bare indium foil, a cadmium-covered indium foil, a cadmium-covered copper foil, and a sulfur pellet, all encased in a clear plastic wafer. When these packets are exposed to a spectrum of neutrons, several activities are induced in the foils. Upon counting the foils and pellet, the rad dose of the neutron exposure may be estimated in several neutron–energy bands.

Hankins, D. E., *A Study of Selected Criticality-Dosimetry Methods,* LA-3910, Los Alamos National Laboratory, Los Alamos, NM {SRDB Ref ID: 27248]

This reference describes several methods for determining the dose received by persons accidentally exposed to a criticality excursion. The dosimetry methods included use of film badges, thermoluminescent dosimeters, threshold detector units, Hurst proportional neutron counters, 10-in.-sphere neutron detectors, the multisphere technique, blood sodium activation, and Geiger counter readings at the abdomen. Five critical assemblies with leakage spectra varying from a fast neutron spectrum to a highly moderated spectrum were studied. The effects of distance from the assembly, room scatter, shielding, and assembly height above the floor were investigated. The results indicate that considerable information must be available before an accurate assessment of a person's dose can be made. If no information about the accident is available, dosimetry using a ratio of the hair and blood-sodium activation will give the dose to within ±20 to 30% except where massive uranium or iron shielding occurs.

1969

Vallario, E. J., D. E. Hankins, and C. M. Unruh, "AEC Workshop on Personnel Neutron Dosimetry, September 23-24, 1969," BNWL-1340, Pacific Northwest Laboratory, Richland, WA [SRDB Ref ID: 11096]

This was the first of a series of AEC/DOE workshops that focused on methods of personnel neutron dosimetry. AEC laboratory and contractor representatives from ten sites presented summary reports of personnel neutron dosimetry methods at their respective sites. Since there is no personnel neutron monitoring system for all neutron energies, a summary description of several techniques is provided such as neutron to gamma ration, rem dose meter, etc. Most sites have relied upon nuclear track emulsion type A (NTA) film to measure fast neutron dose which under adequately controlled conditions and appropriate calibration may be entirely satisfactory. The document summary states that "There are several acceptable thermal neutron monitoring dosimeters available and in general use. Under proper conditions the NTA film can provide reliable and satisfactory fast neutron dose equivalent monitoring. Several laboratories are using NTA film to good advantage for fast neutron dosimetry. For the intermediate neutron exposure around reactor facilities and for the moderated fast energy neutron sources NTA personnel neutron dosimeters cannot be effectively used. This leaves a major gap in the personnel dosimetry program which at many installations may be quite serious. New approaches, methods, and equipment to improve monitoring for intermediate energy neutrons are need and constituted the bulk of discussions at the workshop.

Hankins, D. E., 1969, "Los Alamos Scientific Laboratory Neutron Dosimetry," Presented at AEC Workshop on Personnel Neutron Dosimetry, September 23-24, 1969, BNWL-1340, Pacific Northwest Laboratory, Richland, WA [SRDB Ref ID: 11096]

Four methods of personnel neutron dosimeter development have been investigated at Los Alamos as follows:

1. Direct response of TLD detectors to fast neutrons
2. Fission fragment tracks in solid state devices
3. Use of albedo (reflected) neutrons
4. Activation of metallic foils as described in LA-3910.

Several graphs and tables are contained in this reference.

DS Myers and CT Prevo, 1969, Personnel Dosimetry Associated with the Handling of a Large Numbers of 3 Kg ^{239}Pu Billets, Lawrence Livermore National Laboratory, Livermore, CA [SRDB Ref ID: 53745]

Paper describes process for measuring whole-body neutron doses using a neutron-to-gamma dose rate ratio. Since the neutron-to-gamma dose rate ratio is dependent upon the size, spacing, and moderation of the array, a new ratio is determined for each array. A neutron-to-gamma dose ratio was also established for billet surface radiation using computer techniques. The neutron dose is then established by applying the measured neutron-to-gamma ratio to the whole-body gamma dose as measured by the film badge, and to the gamma hand dose as measured by thermoluminescent dosimeters. The monthly neutron-to-gamma dose ratio ranged from 2 to 5 and the hand dose was about a factor of 2 greater than the whole body dose.

1970

Healy, J. W., 1970, Los Alamos Handbook of Radiation Monitoring, LA-4400, Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 943]

The first edition of the LANL "General Handbook for Radiation Monitoring" was prepared in 1952 by Robert F. Barker to provide basic information for members of the Monitoring Group at the Los Alamos National Laboratory. A second edition was prepared by Barker in 1954 for updating and to remove a few local terms that were cryptic to the large audience the book had attracted. A third edition, compiled by Jerome E. Dummer, Jr., was issued in 1958. This handbook contains substantial information regarding radiation safety regulations, workplace monitoring, instruments, etc. It is stated that “the policy of the LANL is that exposure of individuals to radiation shall be kept to a minimum commensurate with the needs of the work and should not exceed the maximum permissible values recommended by the National Council on Radiation Protection and Measurements and prescribed by AEC Manual Chapters 0524 and 0502 and appendices.” The specific assignments of the Health Physics Group (H-1) within the Health Division include:

- Consult on all aspects of radiation protection.
- Maintain routine surveillance of all radiation or contamination areas.
- Issue and maintain reports on personnel monitoring.
- Review and monitor all shipments of radioactive materials.
- Provide limited decontamination service for large or expensive items.
- Routinely test all encapsulated sources and provide a facility for storage of unused encapsulated sources.
- Review and approve all operating procedures involving use of radioactive materials.
- Collect and interpret data from supplementary programs such as bioassay, whole-body counting, or wound counting.
- Supervise disposal of solid wastes.

This document contains substantial information such as methods for monitoring for beta/gamma and neutron radiation; and capabilities of instruments in use at LANL.

US Atomic Energy Commission, Albuquerque Office, 1970, “Annual Summary of Whole Body Radiation Exposures to External Penetrating Radiation Accumulated During 1969,” Los Alamos National Laboratory, Los Alamos, NM, February 9, [SRDB Ref ID: 13800]

This document concerns annual statistical dose data reported to the AEC REIRS system for calendar year 1969. The data for LANL organizations are shown in the following:

Organization	Total not monitored	No. of annual doses (rem) in each category						Total Monitored
		0-1	1-2	2-3	3-4	4-5	5-6	
LANL	1,897	2,624	43	27	7	6	4	2,711
Zia Company	219	840	1	0	0	0	0	841
AEC/AL	29	306	3	2	1	0	0	312
Visitors	6,397	559	0	0	0	0	0	559

<u>1971</u>

US Atomic Energy Commission, Albuquerque Office, 1971, "Annual Summary of Whole Body Radiation Exposures to External Penetrating Radiation Accumulated During 1970," Los Alamos National Laboratory, Los Alamos, NM, February 9, [SRDB Ref ID: 13801]

This document concerns annual statistical dose data reported to the AEC REIRS system for calendar year 1970. The data for LANL organizations are shown in the following:

Organization	Total not monitored	No. of annual doses (rem) in each category						Total Monitored
		0-1	1-2	2-3	3-4	4-5	>5	
LANL	1,736	2,507	57	17	18	16	6	2,621
	6,630	663	0	0	0	0	0	663
Zia Company	140	907	0	0	0	0	0	907
	2,250	0	0	0	0	0	0	0

Johnson, L., Memorandum to JNP Lawrence, dated July 1, 1971, entitled "NTA Fading at DP," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This reference describes three studies of NTA fading in the workplace. Radiation survey results at DP for both gamma and neutron radiation indicate a higher proportion of neutron radiation than shown in the measured film doses. The results were interpreted as indicating possible significant NTA fading at both two and four weeks development delay times (i.e., Table III, Time of NTA development following exposure, mean NTA response at: 6 hrs – 1.62, 2 weeks – 1.42, 4 weeks – 0.97) . No significant gamma film fading was observed. The neutron energy spectrum was measured in the 3rd workplace study during June 1971 using the multisphere technique. The average neutron energy was in the range of 1.0 to 1.25 MeV. There is a hand-written note on the memo to the effect that the calibration factor for NTA film to be used for DP only would be changed to 0.024 rem/track effective July 1971.

Vallario, E. J., D. E. Hankins, and C. M. Unruh, "Second AEC Workshop on Personnel Neutron Dosimetry, July 8-9, 1971," BNWL-1616, Pacific Northwest Laboratory, Richland, WA [SRDB Ref ID: 78604]

This was the second AEC workshop to focus on methods of personnel neutron dosimetry following the first workshop help approximately two-years previously. Neutron dosimeters utilizing the Albedo neutrons were described by representatives from several facilities within the reference. The albedo systems require a fixed or generally well known spacing between the dosimeter and the body of the individual. Usually direct contact is recommended. Energy dependence is still an important problem, but the dosimeters can give good results when properly worn and when calibrated with neutron spectra approximating those to which they will be exposed.

Littlejohn, G. J., Memorandum to Personnel Dosimetry Staff, dated July 8, 1971, entitled "NTA Fading at DP," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This memorandum notes the L. Johnson (1971) study findings and documents the change in NTA calibration from 0.016 rem/track to 0.024 rem/track for DP West personnel beginning with the July 1971 dosimeter issue.

Johnson, L., Memorandum to File, dated July 9, 1971, entitled "NTA Fading at DP," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This memorandum describes at study of film versus thermoluminescent dosimeter (TLD) components in that beginning in September 1970 selected individuals at DP were issued film badges modified to receive a TLD ribbon-containing plastic insert. Each badge insert had one TLD-600 and one TLD-700 ribbon placed in it. The primary purpose for the modified badges was to estimate individual exposures during the period between film development and evaluation. As noted in this memorandum and attached tables, the TLD component showed significant values for persons working in ^{238}Pu areas due, as noted in the memo, to intermediate energy neutrons. The varying amounts of neutron shielding materials in the ^{238}Pu areas provides a larger proportion of intermediate energy neutrons than in the ^{239}Pu handling areas. The results of this study are stated to illustrate the complexity of neutron dosimetry with TLDs under circumstances where the neutron-energy spectrum is variable and greater or lesser amounts of gamma ray component are present.

Johnson, L. J., Memorandum to J. N. P. Lawrence, dated November 11, 1971, entitled "Recommendations for assignment of Neutron Exposure Dose to Extremities," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This reference describes an evaluation of neutron dose to the extremities using TLDs and NTA. As noted in the memorandum, there was no reasonable means available to routinely measure neutron dose to the extremities. In the past, no neutron exposure dose to the hands was taken into account. This memorandum recommends that a neutron exposure dose equal to the gamma exposure dose as measured by TLD be assigned to those individuals working with ^{238}Pu, or any high specific alpha activity radionuclide in a low Z compound form. Although there is variability inherent to estimating each individual's extremity neutron dose in this manner, the associated uncertainty may be minimized or averaged over the long term. Individuals presently working with ^{239}Pu at DP receive a small neutron exposure to the hands compared to the gamma exposure and therefore do not need special extremity neutron dose assignment.

Johnson, L. J., Memorandum to W. J. Maraman, dated December 3, 1971, entitled "Neutron Hand Exposure Dose Assignment," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This memorandum formalizes implementation of assignment of a neutron exposure dose equal to the TLD-measured gamma exposure dose beginning January 1, 1972. This only applies to individuals handling ^{238}Pu. A review of past hand exposure records indicates that doubling the measured gamma dose will significantly effect only 3 or 4 individuals with respect to AEC exposure guidelines. The present extremity exposure guidelines, as listed in AECM Appendix 0524, are 75 rem/yr and 25 rem/calendar quarter. Based on past records, only a few cases would have accumulated a total hand exposure approaching these guidelines had a gamma-equivalent neutron dose been assigned. This method of assigning neutron exposure doses to the hands will not be made retroactive and will be under continuing review to assure proper extremity dosimetry.

<u>1972</u>

Hankins, D. E., 1972, "Factors Affecting the Design of Albedo-Neutron Dosimeters Containing Lithium Fluoride Thermoluminescent Dosimeters," LA-4832, Los Alamos National Laboratory, Los Alamos, NM, January, {SRDB Ref ID: 76956]

The neutron film packet used in film badges has often proved unsatisfactory for measurement of the fast neutron dose. Two of the major reasons are that the latent-image track fades rapidly where the humidity is high, and the lowest-energy neutrons detectable in routine evaluations are ~0.8 to 1.0 MeV. These and several other undesirable features have led many organizations to stop using the neutron film. One technique that has been considered to replace the neutron film and to measure the dose from lower-energy neutrons is through use of albedo-neutron dosimeters.

When the human body is exposed to neutrons, some of the incident neutrons are backscattered to create a flux of neutrons of various energies leaving the body. These neutrons are called albedo neutrons, and a dosimeter placed on the body to measure this flux of backscattered neutrons is called an albedo-neutron dosimeter. Such dosimeters are usually designed to detect thermal neutrons, and when cadmium is used to eliminate incident thermal neutrons, the dosimeter response is largely from the thermal neutrons that return from the body.

Hankins, D. E., and G. W. Neely, 1972, *Correction Factors for 9- and 10-in. Sphere Neutron Instruments and 1-in.-dia. Bare BF_3 Tubes Used to Monitor Small Beams and Slits*, Health Phys., Vol. 22, pp. 65-71.

LANL developed 9- and 10-inch sphere neutron survey instruments (remmeters) for use in measuring work area neutron doses. Routine practices at LASL showed that these instruments were also being used to measure dose rates from small beams and slits in which the sensitive volume of the instrument was not uniformly irradiated. This paper provides measured correction factors obtained with thermal neutron fields. These factors can be used in many cases to adjust the observed reading to a reasonably accurate dose rate.

Voelz, G. L., 1972, "H-Division Progress Report April through June 1972," Los Alamos National Laboratory, Los Alamos, NM, January, {SRDB Ref ID: 75433]

This reference appears to be a routine progress report. The content of the report includes evaluation of health physics issues from throughout LANL facilities. The report describes the status of implementation of the LANL thermoluminescent personnel dosimeter and the use of 9-inch and 3-inch spheres to measure the neutron dose and spectra.

Oak Ridge Associated Universities Team (ORAUT), 2004, "Technical Basis Document for the Los Alamos National Laboratory – Site Description," ORAUT-TKBS-0010-2, National Institute for Occupational Safety and Health (NIOSH), Division of Compensation Analysis and Support (DCAS), Cincinnati, OH

Los Alamos Meson Physics Facility (LAMPF) becomes operation during the summer of 1972 as the world's most powerful linear accelerator reaching at full energy generated pulses of 800-million-volt protons at a repetition rate of up to 120 per second, and an average current of 1 milliampere. Weapons Neutron Research (WNR) facility, an adjunct to the LAMPF, was built in the early 1970s to provide an intense neutron source that could be used to obtain nuclear data needed for weapons design. The present day Manuel Lujan, Jr. Neutron Scattering Center grew out of the WNR facility. These facilities are key elements of Los Alamos Neutron Science Center (LANSCE) research program.

Hankins, D. and J. N. P. Lawrence, Memorandum dated November 9, 1972 to J. Combs, AEC OS, Washington, concerning neutron exposure," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This reference contains a few notes pertaining to ^{239}Pu and ^{238}Pu workers and apparently the accuracy of the recorded total (gamma plus neutron) dose.

- For ^{239}Pu workers, not in fluoride area, none had high neutron/gamma ratio. The observed ratio was 0.7 with a spread from 0.3 to 1.7.
- For ^{239P}U fluoride, data on only one person with a ratio of 2.8 but this person was a monitor and not a chemical operator.

The conclusion was stated: "LANL has at most 3 persons with high neutron to gamma ratio for persons working with ^{239}Pu. Appropriate amount of neutron exposure in records already.

- For ^{238}Pu workers, all types, average ratio is 3.9 neutrons/gamma with a range from 2.7 to 5.5.
- For ^{238}Pu monitors, average ratio is 3.3 neutron/gamma with a range of 1.9 to 4.6."

The conclusion was stated: "^{238}Pu exposures began three years ago and appropriate amount of neutron exposure in records already."

1973

H-1 Personnel Dosimetry Section, Memorandum dated January 16, 1973 to H-1 Section Leaders, concerning "Evaluation Method Changes," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

This reference describes the practice for determining the assigned dose. It states "On numerous occasions, film badges have not been evaluated correctly. You may or may not be aware that a correct evaluation depends on knowing the radiation environment in which the badge was worn. That is, was the film badge and wearer exposed to plutonium, x-rays, betas, gammas, etc. Quite often, usually through group changes, a person has changed radiation environment and the H-1 Personnel Dosimetry Section has not been informed.

In the future, this information should be supplied to the Personnel Dosimetry Section Office in memorandum form for each person requiring a film badge. We are also to be informed as to the status of an individual who transfers from one group to another or who works as a casual. This information is requested in writing since verbal communication can and has resulted in a considerable amount of confusion."

Maraman, W. J., W. D. McNeese and R. G. Stafford, 1975, "Confinement Facilities for Handling Plutonium," Health Physics, Vol. 29, pp 469-480.

Reference under "Radiation Instrumentation" section states that "neutron survey meters capable of detecting fast neutrons were developed in the early 1950s… The first was a modified PeeWee for use with a boron-lines probe, 2.5-cm-thick polyethylene moderator and 0.5-mm-thick cadmium absorber. This instrument measured in neutron flux (in n/cm2-sec), was extremely energy dependent, and correction factors had to be applied for magnitude of flux reading and neutron energies. Modified versions of this instrument have been used at DP Site up to 1973 when all neutron surveys were performed with a polyethylene sphere rem meter which was first developed in the early 1960s at Los Alamos.

Lawrence, J. N. P., Letter to File, dated May 1, 1973, entitled "Eastman Type II, Open Window Factors," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

In evaluating the Cycolac film badge, two constants are required. One is the excessive exposure indicated in the open window due to the penetrating exposure recorded under the filter and the other is the factor to correct the net exposure under the open window to the delivered $^{90}Sr/^{90}Y$ beta exposure. Using ^{60}Co exposures, the ratio of the open window response to the filtered area response was determined to be 1.14 with a range from 1.09 to 1.23. Since this was not significantly different from the factor (1.17) used for many years, this factor was not changed. Badges were exposed to a series of $^{90}Sr/^{90}Y$ beta exposures from the front and rear of the badge. The response of the window was evaluated using a ^{60}Co calibration. The ratio of the actual exposure to the evaluation of the open-window area averaged 1.88 for exposures from the front and 2.50 for exposures from the rear. The factor used since 1964 is 2.0. Since the new factor of 1.88 differs so little from 2.0, and since the film badge has been observed to be worn with the rear side forward a significant amount of the time, the old value of 2.0 will be retained as the beta calibration factor.

Lawrence, J. N. P., Letter to File, dated May 1, 1973, entitled “Evaluation Procedure for Cycolac Film Badges,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

The last memo on this subject to the photodosimetry historical book, dated November 27, 1963, did not discuss two procedures which have been in use since about 1968. One procedure was the evaluation method which evaluated only the penetrating x- or gamma-ray exposure, but did not evaluate beta or soft x-ray exposure. This method has been used in areas where the primary source of exposure was x-ray machines with an effective energy of 40 keV or higher. The second procedure was to use the F21 density for the evaluation of gamma exposure, where there was no significant thermal-neutron exposure. (The November 27, 1963 memo called for the use of F20 density to be used.) Another change which has been incorporated in the late sixties was the use of blank fields when no exposure was calculated for that particular type of radiation, i.e., when beta was not evaluated, the field was left blank (zeros were <u>not</u> inserted)..

The present computer program used to evaluate Cycolac film badge response uses three methods (EVM) designated 1, 4 and 7 as follows:

- EVM-7 is used to evaluate thermal neutrons and penetrating gamma exposures only. The same exposure is recorded in the gamma-R and gamma-rem fields, and the beta field is left blank (no zeroes).
- EVM-4 is used to evaluate thermal-neutron, hard-gamma and beta exposures. The same exposure is recorded in the gamma-R and gamma-rem fields.
- EVM-1 is used to evaluate exposures to radiations originating from plutonium. In this case there is no beta component (and the beta field is left blank), and part of the very soft x-radiation does not penetrate to the gonads (and the gamma-R field is larger than the gamma-rem field). For EVM-1, the film badge is calibrated against the simulated-plutonium x-ray spectra, described in J. E. Dummer’s memo “Correlation between Brass-Cadmium and Cycolac Film Badges,” dated March 5, 1963.

Since the March 1963 simulated-plutonium calibration work, an unexpected phenomenon was the observation that 60 keV x-rays backscattered from the body to a very significant extent. This is particularly important because 1) film has its maximum over-response at about 60 keV and 2) 60 keV photons are a significant component of the simulated-plutonium spectra.

Hankins, D. E., 1973, "Neutron Dosimetry Studies at LASL," Article in AEC 4th Personnel Neutron Dosimetry Workshop, Los Alamos National Laboratory, Los Alamos, NM, June, [SRDB Ref ID: 18245]

This article describes a LASL conducted a 6-month comparison study using a simulated TLD system and the film badge. The albedo-neutron dosimeters were taped to the bottom of the film badges to assure us that both were similarly exposed. In the actual dosimeter one pair of TLD's would be used but in this study, eight TLD's were placed in the albedo-neutron dosimeter and the average reading of the four ^{6}Li and four ^{7}Li TLD's was used. Additional TLO's (four compared to two that one would normally use) were placed inside the film-badge holder to measure the gamma exposure and thermal-neutrons. The extra TLD's were used to study statistical variation one would obtain from the use of fewer TLDs.

The results of the study were rather complex but generally indicated that for the neutron component of the dose, reasonable agreement was found in the ^{238}Pu areas. In areas where the dose rates were low, <1 mrem/h) the film reported only a small part of the total neutron dose. For the total neutron and gamma exposures, we found that an overresponse of the film to low-energy gamma rays gave a net reported penetrating whole body dose that was approximately correct except for one area of the plant where it was high.

Hankins, D. E. 1973, *A Small Inexpensive Albedo-Neutron Dosimeter*, LA-5261, Los Alamos National Laboratory, Los Alamos, NM, July, {SRDB Ref ID: 8081]

This reference describes a small albedo-neutron dosimeter that can be worn by attaching it to an existing film badge. The badge is designed to use ^{6}Li and ^{7}Li chips. The dosimeter is very energy dependent, having the same energy dependence for fast neutrons as other albedo-neutron dosimeters. Workplace calibrations can be determined using the ratio between 9-inch rem-meter and a cadmium covered 3-inch sphere. A maximum of eight chips can be placed into the dosimeter.

Lawrence, J. N. P., Letter to File, dated December 15, 1973, entitled "Rem/Track Neutron Conversion for LAMPF Film Badges," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

For all laboratory areas except those where plutonium is processed, the standard fast neutron dose equivalent for each proton recoil track per square millimeter on a developed NTA film has been 8 mrem. This corresponds to a neutron energy of about 4 – 5 MeV. For areas where plutonium is processed, it has been determined that the average neutron energy is about 1 MeV, and the appropriate dose equivalent per track (per square millimeter) is 24 mrem/track.

Using the multisphere technique the neutron energy outside the biological shield at LAMPF, it was found that the average neutron energy was 50-100 keV. Since this is closer to the energy at DP West than the standard 4 – 5 MeV, it was decided that the 24 mrem/track per square millimeter conversion would be used in evaluating LAMPF NTA films. This use of this factor became effective for the December 1973 badge issue.

When LAMPF operations resume on a continuous, predictable basis, a comparison of albedo-TLD vs. NTA film exposure study will be conducted to establish experimentally the appropriate dose equivalent per track factor.

<u>1974</u>

Lawrence, J. N. P., Letter to PhotoDosimetry Evaluation Book, dated January 23, 1974, entitled "Albedo-TLD Versus Film Badge Study for Plutonium-239 Recovery Workers at DP West," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 22627]

During the six-month study of the prototype albedo-neutron-TLD versus film badge exposures of the DP West in the last half of 1972, the following observations were made:

1. The film badge gamma exceeded that measured by the TLDs. The excess was by a factor of 2 for most of the classes of workers at DP West, but was by a factor of 4 for the ^{239}Pu recovery workers.
2. In general, the film badge fast neutron exposure was only a small (inconsistent) fraction of the albedo-neutron-TLD measured exposure.
3. For all of the DP West workers, except the ^{239}Pu recovery workers, the sum of the film badge gamma plus neutron exposure was approximately equal to the albedo-neutron-TLD gamma plus neutron exposure. However, for the ^{239}Pu recovery worker the film badge neutron plus gamma exposure exceeded the albedo-neutron-TLD measurement by 1.5

A special X-ray exposure study of the film badge was conducted to determine why the film badge would indicate larger exposures than the TLDs.

Lawrence, J. N. P., Letter to J. E. Dummer, dated March 15, 1974, entitled "Personnel Neutron Dosimetry for LAMPF Personnel" Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

Description of H-1 Personnel Dosimetry practices at LAMPF as follows:

A. For the month of February (January 19 to February 19), H-1 read only one-third of the nuclear track (NTA) films issued to MP Division personnel, all films issued to MP Division and LAMPF visitor personnel were photographically processed. All films are examined for gamma exposure. All films, including the developed nuclear track films, are retained permanently. The one-third of the nuclear track films which were read for February are those used by personnel whose Group Leaders believe were the most likely to receive a detectable exposure.
B. In the event of an eventual lawsuit by a person whose nuclear track films had not been read, the nuclear track films for that person would, at that time, be recalled from permanent storage and read then.
C. It is readily agreed that neutron exposure is most probable at LAMPF. However, we also note that the average energy of the neutrons measured at this time is 200 keV or less. Nuclear track films are not capable of measuring neutrons in this energy range. The few neutrons which nuclear track films do detect are the high energy tailing of the observed average spectrum. To compensate for this lack of sensitivity to neutrons below 800 keV, the dose conversion of 0.024 rem per proton recoil track (counted in a one square millimeter area) is used. This particular dose conversion is three times larger that that used for neutron exposures to 5000 keV neutrons.
D. Nuclear track films are "read" by counting the proton recoil tracks over an area of one square millimeter. Using our oil immersion microscopy procedures, the one square millimeter area reading is accomplished by counting all tracks within a swath (0.19 millimeter wide) for a distance of 5.15 millimeters long. This is equivalent to counting the tracks in 26.5 microscope fields. Using our TV microscope-pickup procedure, the swath is 0.16 millimeters wide and 6.25 millimeters long, which is equivalent to 39 microscope fields.

This reference continues further to describe other features of LANL NTA counting procedures.

Lawrence, N. P., Memorandum dated March 15, 1974 to J. E. Dummer, entitled "Personnel Neutron Dosimetry for LAMPF Personnel," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 110072]

This reference concerns a response to the comment by L. Rosen, LANL, that it was his understanding that only one badge in three is read for MP Division and LAMPF visitor personnel whereas he thought it prudent to process all badges. The reference contains a description of many elements of the routine LANL personnel dosimetry program for LAMPF. It is stated that all beta/photon films issued to MP division and LAMPF visitors are processed, and read whereas all NTA neutron films are photographically processed but only one-third are read to determine neutron tracks. This occurs apparently because during this time period (January-February 1974) the average energy of measured neutrons is about 200 keV or less, and thus below the energy threshold for NTA film. To compensate for the unmeasured fluence of neutrons less-than the NTA energy threshold, LANL dosimetry applies a dose conversion factor of 0.024 rem per proton recoil track which is three times larger than the factor used for 5 MeV neutrons. The memorandum does describe a method to allow processing and screening more NTA films which will be evaluated and also the effort underway to develop an albedo neutron TLD system to be implemented sometime during FY1976 depending on funding.

Lawrence, J. N. P., Office Memorandum, dated March 22, 1974, entitled "Regular Versus Visitor Film Badges" Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

Apparently memo sent to LANL staff with a record of using visitor film badges. The memo states: "Visitor film badges are processed the same as regularly issued film badges. However, if the film from the visitor film badge indicates no significant exposure, no entry is made in the radiation exposure file of the person who wore the visitor film badge. The film and identification card for the visitor film badge is retained permanently but no radiation exposure record is generated for the person's file. In the case of regularly issued film badges, the identification information for each person is already on file, and non-significant or zero exposures are entered in the person's file.

The lower detection limit for the film badge is about 20 mrem for gamma exposures. If a person actually received 20 mrem, but 10 mrem was received by each of 2 visitor film badges, it is most probable that neither film badge would record a significant exposure. Had a single film badge been worn for this exposure (whether a visitor badge or a regularly issued film badge), the 20 mrem exposure would be detected and would appear on that person's radiation exposure record.

To secure a regularly issued film badge, please complete the attached form and return to me.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated April 4, 1974, entitled "Kodak Type 2 Audit Program," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

In September 1973, an audit program was initiated by H-1 Personnel Dosimetry in accordance with a suggestion from AEC Albuquerque. The program monitors the accuracy of reported personnel exposures as derived from film badges. Audit films receive known dosages from ^{60}Co ranging from 0.10 R to 2.0 R. The films receive no preferential treatment and are processed along with the personnel and calibration films. The processing technician is not informed as to the exposures given the audit films.

Audit procedures are as follows:

1. On or about the 15th of each month, 8 audit badges receive exposures ranging from 0.10 R to 2.0 R: (^{60}Co @ 40 cm – dose rate on 3/20/74, 67.64 mR/min)
2. Two audit films are selected at random and placed with each set of calibration films which will subsequently be developed with the personnel film.

3. Positive densities are normally measured on the FD-11 densitometer. The Ansco is used when densities extend into the filter areas or when unusual filter patterns occur. Since the two densitometers differ in response, calibration films must be read on one or both densitometers when necessary.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated April 4, 1974, entitled "Change in the reading of DP West NTA Films," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

In April 1973, certain procedures were employed in the reading of fast neutron films issued to persons employed at D. P. West. In an attempt to increase the accuracy of the evaluated exposures, NTA films were read at least twice – each time by a different technician. The procedures followed are outline in greater detail in a memorandum dated 1/23/1974 entitled "Albedo-TLD versus Film Badge Study for Plutonium-239 Recovery Workers at D.P. West" by J.N.P. Lawrence.

The multiple reading technique was discontinued in January 1974. Demands placed on H-1 by LAMPF for increased fast neutron coverage, combined with a shortage of trained technicians, made it necessary to return to the 1 mm^2 scan by one technician. The evaluation factor of 24 mrem/track about background (3 tracks) remains in effect.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated June 4, 1974, entitled "Reading of NTA Film Issued to LAMPF Connected Personnel," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

Starting with the May 1974 film issue, all NTA films contained within the black and white cycolac badges are to be read in the following manner:

1. Scan four random fields in the F20 composite filter area. If no tracks are found, the reading is completed. Do not record a zero on the work sheet – leave blank. Enter 225 as the remark code.
2. When one or more tracks are observed in any or all of the four random fields, proceed with a full 1 mm^d scan. Enter fast rem dose (zeroes included) on a work sheet, using an evaluation factor of 0.024 rem/track. Do not use 225 as a remark code.
3. A full 1 mm^2 scan must be made on films which were worn with attached albedo neutron dosimeters.
4. To aid in the compiling of statistics on the four field method, certain information is to be maintained by each technician.
   a. Total number of NTA films read
   b. Number of films not requiring full 1 mm^2 scan.
   c. Number of films requiring full 1 mm^2 scan.
   d. The rem dose for each film which required a 1 mm^2 scan.

Reference is made to the above reading technique in a memorandum to J. E. Dummer "Personnel Neutron Dosimetry for LAMPF Personnel," dated March 15, 1974, written by J.N.P. Lawrence.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated June 4, 1974, entitled "New Practice in the Reading of NTA Films,," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

In the past, most NTA film track counting on a given film has been performed by a single technician. Experience has shown that variations can and do occur when the same film is counted by two or more technicians. To minimize track counting error and also to serve as a verification procedure (beginning with the August 1974 issue), all films which indicate a dose of 200 mrem or more will be examined by a second technician. The average of the two readings will be fast neutron dose assigned to the badge wearer.

Engelke, M. J., Memorandum to G. Littlejohn, dated October 11, 1974, entitled "Neutron Film Badge Evaluation," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

Average neutron energy measurements made on October 10, 1974 show a harder neutron energy than previously encountered at LAMPF. These measurements were made in the P-DOR Trailer and immediate environs.

As a result of these measurements and the fact that the people listed herein spend 90% of their working time in the P-DOR area, their neutron film badge should be evaluated for 7.0 MeV neutron average energy.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated October 24, 1974, entitled "Recording of NTA Film Counting Results," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

A computer program has been devised to directly convert the gross number of tracks counted in 1 mm2 of film area to the fast neutron rem dose. Effective with the October 1974 issue period, the following information is to be entered on the NTA work sheets:

1. Gross number of tracks under page headings 44 to 47. (Do not subtract 3 track background)
2. When the film has been read by two or more persons, record initialed gross count under headings 44 to 47. Record the single averaged count under headings 48 to 51.
3. Between headings 56 to 59, record either an 8 or a 24. This determines whether 8 mrem/track or 24 mrem/track is to be used in the evaluations.
4. Use remark codes when applicable as in the past.

5. The new criteria for the reading of a film by a second person (replacing the old 200 mrem or more) is 28 or more gross tracks when the track evaluation number is 8; 11 or more gross tracks when the evaluation number is 24.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated October 24, 1974, entitled "NTA Film Rem/Track Conversion for LAMPF P-DOR Trailer Area Personnel," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8176]

In December 1973, an investigation of the fast neutron energies present outside of the biological shield at LAMPF indicated energies between 50-100 keV. See memorandum dated 12/15/1973 to the Evaluation Book by J. N. P. Lawrence, "Rem/Track Neutron Conversion for LAMPF Film Badges." As a result of this study, a dose of 24 mrem/track was applied as the evaluation factor.

During routine track-counting of films issued to P-DOR Trailer Area Personnel, it was noted that track lengths (about 4-5 MeV) appeared to be produced by energies higher than originally measured. This was confirmed in a survey by A. J. Miller, H-1, "Neutron Energy Levels at P-DOR Trailer Area." The confirmation of higher neutron energy levels made it necessary to correct, for certain individuals, reported neutron exposures for January through September 1974. The correction was made by applying the 8 mrem/track factor, thereby reducing the earlier reported exposures by one-third.

The memorandum from M. J. Engelke (October 11, 1974) presents the names of persons whose records were changed. Since the workers occupying the trailer are primarily off-site users, the list may vary from one month to the next. A list of the appropriate users will be supplied by H-1 Personnel Dosimetry by the LAMPF Physics Section as changes occur.

Jalbert, R. A., Letter dated December 9, 1974 to J. N. P. Lawrence entitled "Neutron Dosimetry at HS-1," Los Alamos National Laboratory, Los Alamos, NM {SRDB Ref ID: 22666, 8176]

Each film badge contains three films, two for beta-gamma and thermal neutron exposures, and one, an NTA film for registering proton recoils from fast neutrons. Tracks of protons with energies less than about 1 MeV are difficult or impossible to see by routine scanning. The neutron DE at these intermediate neutron energies must usually be inferred from the tracks registered at the higher energies. Thus the NTA film must be calibrated for the different neutron spectra that may be encountered. It has been found that two calibration factors cover pretty well the different fast neutron spectra at LASL likely to be involved in fast neutron exposures. The areas covered by these factors are DP West and the Los Alamos Meson Physics Facility (LAMPF) (except the P-DOR trailer area - Jim Simmons' group) on the one hand and the rest of the Laboratory (including the P-DOR trailer area) on the other.

Because of the higher component of intermediate and low energy neutrons at most areas of LAMPF and DP West, a higher DE per proton recoil track is assigned (24 mrem/track/mm^2) at these areas. A lower value (8 mrem/track/mm^2) is assigned to the badges worn by personnel working in all other areas (including the P-DOR trailer area). Since reading each NTA film is a tedious process, normally only 1 mm^2 of the film is read. In this film area background is 0 to 9 tracks with 3 tracks being the average which is subtracted. Thus a negative net reading is possible although a zero DE is reported and recorded in such cases. For the same reason it is possible that a small reported fast neutron DE of up to approximately 50 mrem (140 mrem at DP West or LAMPF) may not be real. Of course higher DE's or repeated "insignificant" DE's are likely to be, at least partly, significant. Administratively-high or significant DE's may be followed up by an investigation resulting in a more accurate determination of the DE.

LAMPF film badges (black or white) contain the same films as the others (blue or gray). Each LAMPF NTA film is checked monthly since all LAMPF exposures may include a fast neutron component. Since most people who wear the blue/gray badges never see fast neutrons, the NTA film of these badges is only read for the small minority who may be exposed to fast neutrons. Many of those belonging to this group are determined from the form sent each month to the secretaries of those groups having people who are issued film badges (G. Dvorak receives the form for P-DOR.) All processed personnel films, whether read or not, are placed into permanent storage and are available for evaluation or re-evaluation if necessary. It is possible for a person's badge to be exposed to fast neutrons of an unusual spectrum or of different spectra involving, therefore, the possible requirement of· a still different calibration factor. The solution is to let H-l know each month on the same form used for determining which NTA films are to be read where the neutron exposures were obtained for that month. If a significant fast neutron exposure is registered and a calibration problem is involved, H-l will contact the individual in question.

Much of the above information is contained in the booklet LA-3889 generally provided to LANL personnel containing information on the film badge or the Personnel Neutron Dosimetry Packet.

Hankins, DE, 1975, The Energy Response of TLD Badges Located on Personnel, *Health Physics*, Vol. 28, pp 80-81.

Article describes studies of various filter combinations to achieve a tissue-equivalent energy response with LiF dosimeter as would be worn by personnel.

1975

Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume IIIb Procedures 1975-77,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8192]

This reference contains many letters, memorandum and reports regarding Los Alamos personnel dosimetry system design, calibration, use, and dose assessment.

Vallario, E. J., D. E. Hankins, and C. M. Unruh, "Fifth AEC Workshop on Personnel Neutron Dosimetry, May 6-7, 1975," BNWL-1934, Pacific Northwest Laboratory, Richland, WA [SRDB Ref ID: 18233]

The fifth AEC Personnel Dosimetry Workshop includes summary reports from several AEC Site contractors concerning their respective neutron dosimetry programs. A report by the National Bureau of Standards (NBS) is included describing the availability of new low energy monoenergetic neutron calibration facilities using funding provided by the AEC. Beams of 2 keV and 25 keV have been developed by the NBS.

Blackstock, A. W., 1975, "LASL Automated Personnel TLD System to be Supplied by Harshaw Chemical Company," Article in AEC 5th Personnel Neutron Dosimetry Workshop, Los Alamos National Laboratory, Los Alamos, NM, June, [SRDB Ref ID: 18233]

This article describes an automated LASL TLD system with a four chip dosimeter to be manufactured by Harshaw Chemical Company. The article describes several features of the planned automated system.

H-1 Dosimetry & Records Section Letter dated July 29, 1975 to H-1 Health Physics Personnel, Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8192]

Evaluation Method (EVM) numbers are placed in the dose records to identify the algorithm used to calculate the dose. The EVM numbers used to evaluate the Kodak Type 2 Film contained within the cycolac badges are as follows:

- EVM 1: used to evaluate personnel exposures to plutonium or americium in significant quantities during chemical and metallurgical operations. During these operations, the material is usually contained in dryboxes, hoods or cells. Beta is not reported.
- EVM 4: used to evaluate thermal-neutrons, hard gamma and beta exposures.
- EVM 7: used to evaluate thermal-neutrons, x-rays and penetrating gamma exposures only.

Hankins, D. E., 1975, *The Energy Response of TLD Badges Located on Personnel*, *Health Physics*, Vol. 28, No. 1, pp 80-81.

Publication concerns measured photon energy response characteristics of TLD material in-air and positioned in the open window position of a TLD placed on a phantom..

1976

Lawrence, J. N. P., Letter to A. E. Dummer and A. M. Valentine, Memorandum dated October 18, 1976, entitled “Personnel Neutron Dosimetry for LAMPF Personnel,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8192]

This reference describes ongoing evaluation neutron exposures of LAMPF personnel using NTA film and notes a March 15, 1974 memorandum in which LAMPF Management requested that all LAMPF workers be assigned film badges, and that all film badges be examined for neutron exposures. H-1 Personnel Dosimetry agreed to examine all LAMPF (black and white) film badges for neutrons on a trial basis. Presently (i.e. 10/18/1976) a large number of LAMPF film badges (~500) are issued each month. The time to read one square millimeter of the NTA fill requires extensive time for so many badges. Alternatively, it was decided to scan four microscope fields on each NTA film. If no proton recoil tracks were found, no neutron exposure would be recorded but a remark code would be attached to the record indicating that the film had been examined. If proton recoil tracks were found, the film would be read for the full one square millimeter area. For a total of 3 or less proton recoil tracks, zero exposure would be recorded (Cosmic ray background averages about 3 proton recoil tracks per square millimeter at LANL). Positive exposures would be recorded for film with more than 3 proton recoil tracks per square millimeter at the rate of 0.024 rem per track (in excess of 3). This procedure has been in effect since June 1974 for those months when LAMPF has been generating neutrons.

The March 15, 1974 memorandum stated plans to determine if gamma exposure could be used as a neutron exposure indicator and the work underway to develop an albedo neutron TLD system which was expected to have greater sensitivity than NTA film for the leakage neutron spectra anticipated from LAMPF operations. No correlation has been established between measured gamma and neutron exposures. The new albedo TLD system is planned for implementation during late 1976 or early 1977.

The conclusion of this letter states: “It is apparent that the four-field-scan technique should be abandoned for LAMPF NTA films. A list of about 60 names has been received and starting with the September 1976 film badge issue a full one square millimeter area will be read. It is expected that the H-1 LAMPF Section will be kept informed of changes to this list.

Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume V Procedures 1976-1980,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8192]

This reference contains many letters, memorandum and reports regarding Los Alamos personnel dosimetry system design, calibration, use, and dose assessment.

<u>1977</u>

Hankins, D. E. 1977, Energy Dependence Measurements of Remmeters and Albedo Neutron Dosimeters at Neutron Energies of Thermal and Between 2 keV and 5.67 MeV, Lawrence Livermore National Laboratory, Livermore, CA, {SRDB Ref ID: 13994]

This reference describes the use of improved NBS calibration facility capabilities that extend the measured response of remmeters and albedo neutron dosimeters about 1 decade lower in energy than has been possible previously. The NBS and cyclograph exposures were made with greatly differing experimental procedures. This is stated to give confidence in the accuracy of experimental procedures.

<u>1978</u>

Los Alamos Dosimetry, "Photodosimetry Evaluation Book "Bible" Volume IVa Procedures 1978-80," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

This reference contains many letters, memorandum and reports regarding Los Alamos personnel dosimetry system design, calibration, use, and dose assessment.

Parrish, B, Memorandum to Health Physics Surveyors, dated July 17, 1978, entitled "Beta-Gamma and Neutron Surveys," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 55566]

Beta-gamma and neutron surveys shall be taken daily of all gloveboxes which are contaminated or contain radioactive materials. Readings shall be posted and dated on glovebox stickers. Stickers are available in the H-l storage area if needed. A written report and room map shall be submitted to the H-l Office along with your personal log book each Friday. This will include the PF-4 Basement Vault. Readings shall be posted and updated on each individual vault entrance door. H-l Health Physics Surveyors assigned to the 100, 200, 300, 400 and Pu shipments are responsible for conducting the surveys.

LANL Staff novice, August 18, 1978, entitled "Film Badges to be Replaced," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

The LANL Film badge is being replaced by a thermoluminescent dosimeter (TLD) badge. The TLD badge records personnel exposures from the same radiations measured by the current film badge. The TLD component is reusable and requires less time to process than film. The TLD badge has been used for visitors since May 1978. Certain LANL groups will be issued the TLD badges instead of film badges starting with the September 1978 badge issue. The complete conversion to these badges is expected to take several months.

Dummer, J. E., Group H-1 Health Physics, "Quarterly Progress Report, Group H-1 Health Physics July-September 1978," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 13694]

On August 28, 1978 TLD badges were issued for the first time to regularly badged personnel. Only personnel issued badges by Maria Quintana received the TLD badges. These included the Fire department, Supply and Property, DOE, Pub, ISO, ENG, E, Q and H divisions. On September 26, 1978, personnel issued badges by Tish Peterson (WX, P, AT and J division) and

Mary Garcia (MP, TA-55 OP, and CMB-5, 6, 11) will receive TLD badges. A handout, briefly describing the badge and how it should be worn, will accompany each badge. Due to the increased usage of TLD badges at LAMPF, 1000 black and white neutron badges are on order. TLD badges were calibrated to ^{252}Cf in order to obtain correction factors to evaluate the exposures given by the University of Michigan in the Pilot Study on Dosimetry Performance. A summary of the Dosimetry Performance Pilot study stated that it appears that both the gamma and neutron exposure can be estimated within an accuracy of 15% when the badge is exposed to a mixture of ^{252}Cf and ^{60}Co radiations.

Miller, A. J., Memorandum dated September 14, 1978 to E. Storm, entitled "Personnel Neutron Exposures," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 110073]

This reference states that neutron energy measurements in the LAMPF experimental areas have shown that the average neutron energy is generally ~0.5 MeV in personnel occupied areas. Since NTA dosimetry film is insensitive to neutrons of energy <~0.7 MeV, the personnel dosimetry film has been calibrated to the track producing high energy neutron that are present in the neutron spectrum whose average energy is ~0.5 MeV. This calibration technique results in a "dose to track/mm^2" conversion that is ~3 times that used for neutrons in the 1-14 MeV energy range, i.e., 24 mrem/track/mm^2 of film area, compared to 8 mrem/track/mm2 film area. The memorandum describes a review of assigned doses for two workers determined with the 24 mrem/track/mm^2 dose conversion factor which were too high because of work in areas with predominantly higher neutron energies. Based on this memorandum, the doses to these two workers were modified to lower assigned doses.

Blackstock, A. W., J. R. Cortez, G. J. Littlejohn, and E. Storm, 1978, Neutron Response of a New Albedo-Neutron Dosimeter, LA-UR-78-40, Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 27246]

This reference describes the transition of the Los Alamos Scientific Laboratory (LASL) from a film badge to a badge containing thermoluminescent dosimeters (TLD's). This document describes the new LASL TLD badge, the response of the TLD badge to continuous spectra neutrons and to monoenergetic neutrons as a function of energy, a calibration method that does not require a detailed knowledge of the neutron energy spectrum, the accuracy to be expected from the dosimeter in neutron measurements and its limitations.

Field measurements were made to obtain 9- to 3-inch sphere ratios in two potential neutron exposure areas at LASL: a plutonium chemistry facility and the Los Alamos Meson Physics Facility (LAMPF). At LAMPF, the mean value of the ratio, measured in 18 different locations, was 0.17, with a standard deviation of 30%. At the plutonium facility, the average value of the ratio measured in 13 different locations was 0.57±35%. Assuming the relationship of the measured ratio to the neutron energy is correct, these ratio values indicate an average neutron energy of <100 keV at LAMPF and of ~200 keV at the plutonium facility. This situation may explain why few neutron exposures have been observed at these facilities, since NTA film cannot detect neutrons with energies less than about 700 keV.

As described in this report, these measurements allow using measured calibration factors to increase the accuracy of neutron dose determinations providing (1) a person's exposure can be determined to have occurred in one, or a very few, workplaces, and (2) that the ratio at each location does not change very much with time. The report describes the relative advantages and disadvantages of the NTA film dosimeter and the LASL albedo-neutron dosimeter utilizing TLDs. Although the sensitivity of the NTA film increases with increasing neutron energy, the film cannot measure exposures due to neutrons with energies less than about 700 keV. The TLD albedo-neutron badge response varies rapidly with incident neutron energy, decreasing with increasing energy. However, it can measure exposures from neutrons with energies < 700 keV, since its response continues to increase down to the cadmium cutoff. The LASL albedo-neutron badge is designed so that NTA film can be added to complement the TLD measurements for higher energy neutrons. The method was devised by Hankins (SRDB 8081) for calibrating the dosimeter in spite of the strong dependence of its response on neutron energy. Our measurements thus far indicate that the method gives reasonably accurate exposure measurements in two LASL facilities where neutron exposures may occur.

Lawrence, J. N. P., Letter to Photodosimetry Evaluation Book, dated September 28, 1978, entitled "Reportable TLD Exposures," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

For reporting purposes, in compliance with the DOE Manual Chapters, non-zero exposures as recorded by the LASL TLD Badge, are defined to be total-rem exposures of 0.04 rem or more. In the B-1 Dosimetry records system, all measured values from 0.00 rem upwards will be recorded and attributed to the appropriate individual. This procedure is not appreciably different from that followed with the LASL film badge for the past 10 years, except that for film badge exposures less than 0.04 rem, no entry was made for the individual in the computerized record system. (The developed film was filed along with the completed visitor card, and the card-film pairing were sent to permanent record storage.) The TLD procedure is justified because of the statistical uncertainties in evaluating low exposures. The procedure is desired to reduce the excessive man-effort required to obtain mailing addresses, if reporting 0.00, 0.01, 0.02, and 0.03 rem measurements were necessary.

The use of LASL TLD badges for visitors began in May 1978. The evaluated results for May and June were reported completely, demonstrating the enormity of the problem of ascertaining mailing address. The new reporting procedure becomes effective for the July 1978 visitor TLD issue. For regularly issued TLD badges (starting with the September 1978 issue), exposures will be reported as measured, until such time that a statistical study is completed which defines the minimum detectable level for the system.

Lawrence, J. N. P., Letter to File, dated October 6, 1978, entitled "Los Alamos Criticality Accidents 1945-19461 Personnel Exposures," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

The purpose of this memo is to document the exposures to be entered in the H-I Dosimetry Computer Record for persons involved in the three criticality accidents occurring at Los Alamos in 1945-1946. None of the personnel involved wore film badges or other personnel dosimetry detectors. Calculations of the personnel exposures exist in several source documents (referred to herein), but a simple reference to this material is inadequate because of differences in the calculated results. This memo will designate the exposures to be entered in the computer record, identify the source documents, point out the differences in the exposure estimates, and provide an explanation of why the particular exposure estimates were chosen.

Vallario, E. J., D. E. Hankins, J. Harvey and P. E. Bramson, "Seventh DOE Workshop on Personnel Neutron Dosimetry, October 23-24, 1978," PNL-2807, Pacific Northwest Laboratory, Richland, WA [SRDB Ref ID: 26723]

This workshop was the seventh of a series and was held on October 23-24, 1978, at the Central Electricity Generating Board, HQ, London, England. This Workshop was held in London to permit greater involvement of the European experts than has been experienced at past workshops. It was hoped that work being performed in Europe might be leading to new dosimetry techniques for application within the DOE contractor organization. Generally, no new ideas, concepts or breakthroughs were identified during two days of informal discussions. The detection of intermediate energy-neutrons continues to be an unsolved problem.

<u>1979</u>

Cortez, J., Letter to Photodosimetry Evaluation Book, dated May 10, 1979, entitled "TA-55 Vault Area Doubled Badge Experiment," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

On February 26, 1979, two non-cadmium TLD badges were requested for two employees working in the vault area of TA-55. These badges were issued and were worn along with their respective, regularly issued, TLD cadmium badges during the month of March, 1979. Badges for both employees were read and evaluated on April 3, 1979. The following table has the results.

Employee	**Badge Type**	**Calculated dose, mrem**		
		Nonpenetrating	Penetrating	Neutron
Employee #1	Non-cadmium Badge	82	85	194
	Cadmium Badge	63	62	171
Employee #2	Non-cadmium Badge	119	117	230
	Cadmium Badge	121	117	210

Health Safety and Environment Technical Manual, Technical Bulletin, “Thermoluminescent Dosimeter Badge,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

This bulletin describes the components, operation, and limitations of the thermoluminescent dosimeter (TLD) badges used at LASL for personnel radiation exposure monitoring. It also describes the procedures for reading the badges, recording dose information, and distributing dose reports. A number of recommendations are included for those who wear TLD badges.

Lawrence, J.N.P., Letter to Distribution, dated October 26, 1979, entitled “Discontinue Use of Pancake Probe Instruments For Alpha Monitoring Until Further Notice,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 55566]

Effective immediately, the use of pancake probes on G-M instruments for alpha monitoring shall be discontinued, except as noted below. A preliminary investigation has indicated that the pancake probe is incapable of detecting less than about 1000 dpm of Pu alpha. This preliminary investigation has shown that the net cpm (gross cpm - bkg cpm) must be multiplied by a factor from 10 to 20 to convert to "dpm" for Pu alpha. No officially accepted value has been established for converting readings on Ludlum Model 14's with a mR/hr meter reading. Until further notice, use only alpha monitoring instruments (PeeWee's, PAC-7, PAC-1SAGA, Ludlum 139, Ludlum 11, Ludlum 12) for all alpha monitoring.

Littlejohn, G. J., Letter to Photodosimetry Evaluation Book, dated October 30, 1979, entitled “The Use of “Visitor” Dosimeter Badges at the Los Alamos Scientific Laboratory,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

This is an historical analysis of visitor badge use. At LASL, a "visitor" badge is a badge temporarily issued to an individual who does not have a "permanent" or regularly assigned badge.

Film badges, used as a means to measure personnel exposures to radiation, were first issued by the Health Group on 2/19/45. Prior to and after the Trinity Test on 7/16/45, it is not possible to classify a particular badge as being either a visitor badge or a permanent badge. At that time, badges .were given to various operating personnel for distribution and no attempt was made to record the person's employment status or parent organization. The first record of a visitor badge appears in LA Notebook 11304, where a badge was worn at Pajarito Site on 12/9/46. After that date, almost all of the Notebooks have separate entries for visitor, permanent, and planted badges. Information as to the wearer's name, film badge number, and dates worn, were recorded on "Visitor Register Forms", then given to the Health Group for entry in the LA Notebooks. After film processing and dosage evaluation, exposure reports were prepared in inter-office memorandum form. Reports were distributed to the leader of the Health Group, involved supervisory personnel, and the Hematology Lab.

This document is much longer with examples of various records.

<u>1980</u>

Storm, E., Letter to Photodosimetry Evaluation Book, dated January 6, 1980, entitled “Error in Dose Evaluations (Neutron Evaluation Program),” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

In March 1979, an error was found in the computer program which resulted in the incorrect neutron evaluations of certain TLD badges. The badges affected were Types 5 (light yellow), and 6 (light blue), which were worn during the months of September 1978 through February 1979. For these months, neutron exposures were reported low by a factor of 6, since a correction factor of 0.5 had been used instead of a factor of 3.0. Except for the Form 630 exposure reports, which had already been circulated, corrections were made to all other dosimeter 1istings and computer entries. The computer program was also corrected.

Anonymous, LANL Record dated January 23, 1980, entitled “Employee Health Physics Checklist,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 110058]

This reference contains numerous LANL forms of routine monitoring activities. One of the forms (HS&E 5-1A) is titled “Employee Health Physics Checklist” and involves a review of potential workplace exposure scenarios. The external section includes checklists as follows:

- Pu x-rays
- Machine x-rays
- Neutrons, less than 2 MeV
- Neutrons, over 2 MeV

This information is apparently used to determine which types of dosimeters to be assigned such as a Personal Neutron Dosimeter (PND) and finger rings.

Gutierrez, J., Memorandum dated February 6, 1980 to R. R. Showalter, entitled “TLD Survey, SM-316,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109556]

This reference appears to be a routine report of TLD measurements at selected locations. Three of the 34 TLD packets showed positive results described as follows:

a) Target room, in line with the beam: total dose = 1.12 rem, average dose per shot = 25 mrem
b) In the Maze: total dose = 0.02 rem, average dose per shot = 0.4 mrem.
c) Perimeter fence, adjacent to SW corner of SM-316: total dose = 0.01 rem, average dose per shot = 002 mrem.

There are 42 TLDs strategically placed within and throughout (sic without) SM-316. Special dosimeters (10 each) are in place around the facility for neutron dosimetry. For the December 1979 dosimetry records, no personnel in the group in question showed a positive recorded neutron dose.

Buchanan, R., Memorandum dated February 10, 1980 to File, entitled “Average neutron Energy and Dose Rate Measurements in Counting Houses in Area A,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109559]

This reference concerns results of a special radiation survey performed on February 12, 1980 of the counting houses in Area A to determine the average neutron energy. A moderated BF3 and a proton recoil counter were used. The beam parameters were: 800 MeV, 560 µA at A-1, 120 PPS, and 550 µsec. The results are:

Location	**Flux, (n/cm^2-sec)**	**± 2σ**	**Average E, (KeV/n)**	**± 2σ**	**Dose Rate**	
					Neutron (mrem/h)	Gamma (mR/h)
Trlr. 433	0.32	2.7%	1030	13%	0.04	0.05
LEP ct. h.	7.33	1.7%	894	8.8%	0.81	0.22
SMC ct. h.	9.50	1.9%	342	16%	0.53	0.19
P^3 ct. h.	3.17	3.3%	482	24%	0.23	0.10
EPICS ct. h.	6.89	2.3%	453	17%	0.46	0.16
Area A floor*	7.44	2.2%	191	24%	0.25	0.5
* by Remote Handling Trlr.						

Dosimetry and Records Section, Office Memorandum, dated March 21, 1980, entitled “New Personnel Monitoring (Body) Totals Form,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

The reporting form for personnel monitoring results has been redesigned 1) to conform to the current trend in dosimetry measurements of describing exposures in terms of penetrating and non-penetrating doses and 2) to more accurately express the measurements made with the new TLD badge system.

Except for the removal of birth year, the identification information on the old and new forms has been retained. Missing from the new forms are the columns entitled:
beta-rad, gamma-r, gamma-rem, thermal neutron-rem and fast neutron-rem.

The new form heading "Non-penetrating Rad" is intended to indicate the total skin dose from external ionizing radiation. It is equivalent to the old beta-rad plus gamma-.rem, or the old gamma-r doses. The new form heading "Penetrating-rem" is intended to indicate the total whole body dose from external ionizing radiation. It is equivalent to the old gamma-rem dose.

The new form contains only a single "neutron-rem" heading. The exposures indicated in this column are primarily the albedo (body scattered) neutron dose as measured by the TLD badge. However, for those few cases where a "piggy-back" NTA film is part of the badge, the fast neutron dose recorded by the NTA film is added to the albedo neutron dose, and an entry "NTA" is included under the REMARKS column.

The exposures recorded under the heading "Tritium-rem" is the whole body dose due to tritium in the body. It is calculated from the tritium urine assay results. Under the heading "Total-rem" is tabulated the sum of the "penetrating-rem," "neutron-rem," and "tritium-rem," similar to the procedure used on the old forms.

Under "REMARKS," in addition to the "NTA" indication, are three other possible entries: "LATE" to indicate TLD badge results from badges issued prior to the month being reported; "NTS" to indicate exposures reported by the Nevada Test Site; and "AWAY" to indicate exposures reported from other installations visited by LASL staff. Also indicated is the latest date for which "NTS" and "AWAY" exposures apply.

The new forms are preprinted with the' Privacy Act marking "PERSONAL INFORMATION." PERSONAL INFORMATION designates information of a privileged nature, relating to the Federal Privacy Act of 1974.

Littlejohn, G. J., Letter to Dosimetry Personnel and Evaluation Book, dated June 6, 1980, entitled “TLD Audit Program,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8206]

The audit program monitors the accuracy of reported personnel exposures as measured by the TLD dosimeter badges. This program is similar to the one used with film badges during the years 1973 through 1979.

<u>Audit Procedures</u>
Each month 12 badges are taken, at random, from the supply of temporary badges prepared for use in the field - these serve as audit badges. Ten of the badges are exposed to a ^{60}Co source and receive exposures ranging from 10 mR to 1000 mR. Changes are made in the delivered exposures each month. The remaining 2 badges receive no exposure. Following exposure, the badges and identification cards are returned to the appropriate technician for processing. Audit badges are included with the personnel badges, and after processing the reported exposures are compared to the delivered exposures.

Blackstock, A. W., Letter to J. N. P. Lawrence dated November 25, 1980, entitled “TLD Badge Neutron Correction Factors at LAMPF,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

The TLD albedo badge neutron response varies by three orders of magnitude over the energy range 50 keV to 14 MeV. Therefore, appropriate correction factors must be determined for each area where personnel neutron exposures can occur. Such factors have been measured in a number of locations at LAMPF and the results are summarized below for the noncadmium badge on a polyethylene slab.

Area	Neutron Correction Factor (N rem/60Co R)
WNR Experimental Room #1	0.27
Catwalk, near EPICS Pumphouse	0.082
Mezzanine, Top of South Stairs	0.087
LEP Counting House	0.13
South catwalk near Beam-on Light	0.16
Test Channel	0.15
Test Channel Instr. Rack Area	0.29

A. J. Miller stated that the WNR area is the only area at LAMPF where the personnel assigned work exclusively in that area. None of the other personnel work only in one area. Also, relatively few people work in the Test Channel Instrument Rack area at any time, and the crews change with changing experiments during an operating cycle.

We have been using a neutron correction factor of 1.0 for all TLD badges worn at LAMPF, which are the cadmium type. It is now recommended that the noncadmium badge be worn at LAMPF and that a neutron correction factor of 0.20 be used for all areas at LAMPF.

Lawrence, J. N. P., Letter to R. Stafford, dated December 1, 1980, entitled “Evaluation of TA-55 Neutron Exposures,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

This reference concerns minutes of a Personnel Dosimetry staff meeting to discuss the Blackstock letter of 11/25/1980 containing measurements of the required neutron correction factors at TA-55. This data was examined, along with the September 1980 and the January through September 1980 exposure information for TA-55 workers. Conclusions of the meeting included:

1. To improve the accuracy of neutron exposures recorded for TA-55 workers, it was decided to use 3 pairs of TLD badges at TA-55, with 3 different neutron correction factors. Three different operational activities at TA-55 were defined:
   a. Glove box workers using boxes with hydrogenous' shielding who spend 60% or more time working-,n-these glove boxes. Neutron correction factor 0.1. Light brown and dark brown badges to be issued.

b. Glove box workers using boxes without hydrogenous shielding who spend 60% or more time working in these glove boxes. (Possible inclusion of persons working with PuBe sources in boxes with hydrogenous shielding; data being developed this week.) Neutron correction factor 1.0. Light purple and dark purple badges to be issued.
c. All other TA-55 workers, including persons working in the general PF-4 area, supervisors, HP surveyors, vault workers, process coordinators, CMB-11 count room workers, and persons who divide their time approximately equally between glove boxes with and without hydrogenous shielding. Neutron correction factor 0.5 (this is the same as has been used throughout 1980 at TA-55 for all workers). Yellow and aqua badges to be issued.

2. For this system to work, the H-1 TA-55 Section must supply the Dosimetry Section with the names and Z-numbers of the persons in each of the 3 categories by the 15th of the month preceding the TLD badge issue. This time frame is necessary for the Dosimetry Section to prepare the next month's TLD badges in the proper color (and with the proper coding). I suggest that after the procedure is established, the changes from the previous month be identified by "*"s.

3. In addition, the H-1 TA-55 Section must supply the Dosimetry Section with any corrections to the original color (and coding) when the TLD badges are returned for processing. Hopefully, these changes will not exceed 10 per month or the system will not be functionally operative from the Dosimetry Section's point of view (due to the necessity of correcting the computer data bank).

4. The Dosimetry Section will be ordering the new badges this week. Depending on the delivery time and the time to add the filters and labels to the badges, the system cannot be instituted before February 1981, or more probably March 1981. I suggest that the H-1 TA-55 Section initiate and operate their notification phase of the operation as soon as possible in order to discover and correct their difficulties before the system becomes effective.

Lawrence, J. N. P., Letter to E. Storm, dated December 3, 1980, entitled "TLD Badge Neutron Correction Factors at LAMPF," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8206]

I concur with A. W. Blackstock's recommendation that noncadmium TLD badges be issued at LAMPF, using a neutron correction factor of 0.2 for all LAMPF areas (see 12/1/80 Letter above). From our discussions, I understand that H-1 will prepare light green and dark green badges for LAMPF, starting by the February 1981 issue (since LAMPF does not anticipate any neutron exposure in January 1981). Using the noncadmium badge with the 0.2 neutron correction factor is approximately equivalent to using the cadmium badge with a correction factor of 1.0 and should not result in any significant change for large exposures (>100 mrem). However, the noncadmium badge will give a factor of 5 increase in sensitivity, enhancing the reliability of low exposures

1981

Storm, E., P. L. Buslee, A. W. Blackstock, G. J. Littlejohn, J. R. Cortez, R. V. Fultyn and J. N. P. Lawrence, 1981, *The Los Alamos Thermoluminescence Dosemeter Badge*, *Rad Prot Dosi*, Vol. 1, No. 3 p 209-219, [SRDB Ref ID: 27290]

The Los Alamos thermoluminescence dosimeter (TL.D) provides an accurate and versatile instrument for the measurement of ionizing radiation and is capable of passing the Health Physics Society Standard, -Criteria for Testing Personnel Dosimetry Performance" For photons above 100 keV in energy, the badge can measure dose without the need of correction factors. However, below 100 keV correction factors are necessary but the badge can be used as a crude spectrometer to estimate the photon energy and thus the appropriate correction factors. For a mixture of low and high energy photons, an average energy is obtained that varies with the mixture. Low energy photons can be distinguished from beta rays. For a mixture of ^{90}Sr beta and ^{60}Co gamma radiation, the fraction of each component can be determined and appropriate correction factors applied. To evaluate neutron doses, the badge reading must be supplemented with a knowledge of the source and moderating material, or on-site determination of correction factors.

Umbarger, J. Letter to J. N. P. Lawrence, dated June 4, 1981 entitled "Use of NTA Film for Personnel Neutron Dose Measurements at Los Alamos," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8209]

Until recently, the TLD cadmium badge has been issued to personnel at LAMPF. The response of the cadmium badge to neutrons, over a range of 0.05 to 14 MeV, decreases with increasing energy by three orders of magnitude and is relatively insensitive to fast neutrons. For example, assuming 10 mrem is the minimum detectable dose when the neutron correction factor equals unity, the minimum detectable doses at 1, 5 and 14 MeV are 100, 400 and 500 mrem, respectively. Because early measurements at LAMPF indicated the presence of fast neutrons in certain areas, the TLD badge is supplemented by the Kodak NTA film, which is placed in a Cycolac "piggy-back" holder attached to the TLD badge. The NTA film records proton recoil tracks over a range of approximately 0.7 to 14 MeV; below 0.7 MeV the tracks are too short to be distinguished. Three tracks are considered background and a dose of 24 mrem is assigned to each track above background. To obtain the total neutron dose, the TLD and NTA film doses are summed.

The number of gross tracks recorded each month on the NTA film during the period of June 1979 through March 1981 is shown below:

DISTRIBUTION OF GROSS TRACKS ON PERSONNEL NTA FILM

Gross	**1979**							**1980**			
Tracks	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr

0	65	63	59	54	24	17	14	36	42	23	28
1	12	11	11	16	15	12	10	7	0	12	11
2	2	3	3	6	5	6	10	0	0	6	3
3	0	0	1	2	0	5	2	0	0	3	1
**** Greater than background counts below****											
4	0	0	0	0	0	0	1	0	0	1	0
5	0	0	0	0	0	1	0	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0	0

Gross Tracks	**1980**								**1981**		
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
0	33	31	31	34	22	31	27	(a)	(a)	16	17
1	9	9	8	4	9	8	10			9	13
2	2	1	3	3	7	2	23			7	6
3	0	1	1	0	1	0	0			1	1
**** Greater than background counts below****											
4	0	0	0	0	0	0	0			0	0
5	0	0	0	0	0	0	0			0	0
10	0	0	0	0	0	0	0			0	0
a. No film issued. LAMPF shut down.											

For the 964 films issued during this period, only 4 gave a positive reading. The positive NTA film readings, along with the net number of tracks, film dose, and corresponding TLD dose, are summarized in the following:

POSITIVE NTA FILM READINGS

Month	**Net tracks**	**NTA (rem)**	**TLD (rem)**
Nov 79	2	0.05	0.00
Dec 79	1	0.02	0.00
Dec 79	7	0.17	0.53
Mar 80	1	0.02	0.36

Of the 4 positive readings, 3 recorded only 1 or 2 tracks above background. Although the film recording 7 net tracks appears to have received a valid fast neutron exposure, the TLD dose exceeds the film dose by a factor of 3, indicating lower energy neutrons predominate.

Of the 964 TLD badges containing film, 205 gave positive TLD readings, indicating the presence of low energy neutrons. The doses tend to be low, only 5 exceeding or equal to 0.1 rem as shown, along with the corresponding NTA film dose, in the following:

TLD DOSES ≥ 0.1 rem

Month	TLD (rem)	NTA (rem)
Jun 79	0.13	0.00
Dec 79	0.53	0.17
Mar 80	0.36	0.02
Mar 81	0.10	0
Mar 81	0.17	0

The NTA film readings indicate negligible dose even for the larger TLD doses with only one exception (Dec 79).

Lawrence, J. N. P., Letter to J. Umbarger, dated June 11, 1981, entitled "Discontinuation of NTA Film for Personnel Dosimetry," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8209]

This reference expresses agreement with the previous letter from J. Umbarger (dated June 4, 1981). It does state that the regular issue of NTA film for LAMPF personnel should be discontinued as of the July 1981 dosimeter issue. It also suggests another possibility which is to assign NTA film to only a few selected workers based on trend in TLD measured doses rather than simply assigning 40 combination TLD/NTA film dosimeters each month.

Gutierrez, J., Memorandum dated July 9, 1981 to J. Gallimore, entitled "Radiation Survey Results," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109553]

This reference appears to be a report of special Li-6 TLD measurements at selected personnel desk locations. The Li-6 chips were used in a H2O moderator with the expressed purpose of the survey to monitor for neutrons which could possibly be generated from the east bay of SM-40, AT-1's, 20 MeV Linac Injector Gun. Maximum beam parameters during the period were specified in the report. Survey results for 4 personnel desk locations were presented ranging from 3.5 to 5 mrem during the 34 day period from June 4 through July 8, 1981.

Lawrence, J. N. P., 1981, "Dosimetry Records and Radiation Hazards Questionnaire," Los Alamos National Laboratory, Los Alamos, NM, September 19, [SRDB Ref ID: 8209]

The LANL input to this questionnaire identifies several reference documents as follows:

LAM-620	Los Alamos Health Group Film Badge Techniques, C. Buckland, 1974
LA-1107	A Method for Monitoring X-rays Using Eastman Type K Film, E. Storm & E. Bemis, 1950
LA-1220	The Response of Film to X-Radiation of Energy Up to 10 MeV, E. Storm, 1951
LA-1284	The Response of Sensitive 552 DuPont Film to Beta Radiation, E. Storm,

	1951.
LA-1923	A Film-Badge Method of Differential Measurement of Combined Thermal-Neutron and Gamma-Radiation Exposures, F. Kalil, 1955
LA-2494	Photodosimetry Procedures at Los Alamos, G. J. Littlejohn, 1960
LA-3001	The Development of Film Badges Containing Multi-element Filters to Reduce the X-Ray Energy Dependence of Photographic Film, E. Storm & S. Shlaer, 1961.
LAUR-81-1799	The Los Alamos Thermoluminescent Dosimeter Badge, E. Storm, etc., to be published in 1982 in Radiation Protection Dosimetry.

1982

Littlejohn, G. J., Letter dated March 4, 1982, entitled "Change in Neutron Correction Factor for OWR Personnel," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8209]

A review of the neutron correction factor being used at the Omega West Reactor for CNC-5 personnel TLD badges was completed on 2/19/82. Neutron measurements were made with a 9" diameter polyethylene sphere, RM-16 rate meter, and an Ortec scaler. TLD badges, mounted on a 1.5" polyethylene slab, were exposed beside the sphere. Two exposures runs were made: 1) The first from 2/1/82 to 2/10/82, and the 2) from 2/11/82 to 2/19/82. The detectors, badges, and sphere were placed near the north face of the reactor. This is an area where significant personnel exposures are most likely to occur. The results are:

Detector	**Run #1**		**Run #2**	
	Neutron, mrem	Ratio	Neutron, mrem	Ratio
9" Sphere	73.1	10.7	44.4	12.7
TLD Badge	761		564	

The results indicate that a correction factor of 0.1 should be applied to the neutron dose instead of the 0.5 in current use. It is recommended that this change be made in the evaluation procedures.

1983

Littlejohn, G. J., Memorandum dated April 25, 1983 entitled "Dosimeter Badges," Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8209]

This memorandum requests that the following message be placed in the NewBulletin.

DOSIMETER BADGES

Wear your dosimeter badge visibly exposed on the front of your person between the waist and the neck. It should be worn at all times when working or visiting in the Laboratory areas where badges are required. Since the purpose of the badge is to measure your occupational exposures, the badge should not be worn when receiving dental x-rays or medical treatments involving the use of radiation.

Mundis, R., and Larkin, J. E., Memorandum dated April 26, 1983 to A. J. Miller, entitled "WNR Facility SOP," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 55688]

This memorandum concerns editorial changes to the Weapons Neutron Research (WNR) facility Standard Operating Procedure (SOP). This document describes facility-specific survey, control and response activities. For example, a survey is required to verify that all areas where the radiation level is greater than 10 mrem/h and all beam paths are identified with a proper barrier." Also, for personnel entry into an area with a >10 mR/h field, pocket dosimeters are required. Another section concerns notification of the WNR RSO and the LAMPF H-1 office of all shipments of sources and radioactive materials (such as research sources and experimental apparatus) to WNR.

Mundis, R., Memorandum dated September 12, 1983 to R. Ryder, entitled "Neutron Measurements in Line D and ER-1, August 30, 1983," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 55686]

Reference describes results of measurements of neutron intensity in Experimental Room 1 (ER-1) while the beam was striking a tungsten beam block with a known beam intensity. Moderated indium foils that have a fairly uniform response to neutrons in the energy range from 0.02 to 20 MeV were used as the primary measuring device. These measurements showed that substantial neutron doses could occur in ER-1 if beam shutdown capabilities do not work as designed.

Larkin, J. E., LAMPF HSE-1, Memorandum dated November 4, 1983 to A. J. Miller, entitled "October Area A Balcony TLD Dosimetry Plants," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 55689]

This memorandum concerns results of TLD measured photon and neutron radiation exposure levels detected on the Area A balcony during October.

A. Badge 2136-on monitor stand gamma - 1.36 mR/h, beta - 0.26 mR/h, neutron - 1.2 mrem/h, Total penetrating radiation - 2.56 mrem/h
B. Badge 2137 - on work table, gamma - 0.94 ~R/h, beta - 0.15 mR/h, neutron - 1.02 mrem/h, Total penetrating radiation - 1.96 mrem/h

1984

Mundis, R and J. Miller, Memorandum dated January 10, 1984 to R. Woods, entitled "WNR Blue Room High Current Run Radiation Surveys," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109441]

Reference contains results of radiation surveys on and around the shielding berm over the Blue Room conducted on December 22, 1983 by members of the LAMPF Health Physics staff. Gamma and neutron dose rates were measured at several locations. The data also showed that significant neutron activation of the walls and structure of the Blue Room may occur at high beam currents.

McAtee J. L., Memorandum to R. Stafford, dated February 6, 1984, entitled “TA-55 Neutron Dosimetry Factor Re-Evaluation,” “Photodosimetry Evaluation Book "Bible" Volume VI Procedures 1980-1989,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 27288, 8209]

This reference contains the final report for the neutron dosimetry factor re-evaluation at TA-55. Correction factor measurements were made at numerous locations throughout PF-4 by comparing the time-integrated response of a 9 inch spherical neutron rem meter to the response of TLD badges mounted upon the face of a 40 x 40 x 15 centimeter Lucite phantom slab. The correction factor is the ratio of the rem meter reading to the response of the TLD badge. A summary of the measured neutron correction factors follows:

Work Area	Average Correction Factor
100 Area	0.79
206/207	0.29
208	0.72
209	0.85
319	0.65
327	0.52
401	0.75
409	0.71
420	0.76
429	0.56
Vault	0.63

Miller, A. J., Memorandum dated April 9, 1984 to D. G. Vasilik, entitled “TLD Badge Neutron Correction Factor at LAMPF,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109565]

This reference concerns a meeting among health physics and operational staff regarding the appropriate correction factor to be used for LAMPF neutron personnel dosimetry evaluations. Based upon considerations of measured neutron spectral and dose equivalent data, it was agreed that the LANL noncadmium badge should remain in use at the LAMPF, and that a 0.2 neutron correction factor continue to be used. A table of neutron rem measurement comparisons is provided between TLD and 9” rem-meter measurements showing minimum and maximum correction factors of 0.02 and 0.4, respectively.

Hankins, D. E., 1984, *Beta- and Gamma-Dose Measurements of the Godiva IV Critical Assembly,* Health Physics Journal, Vol. 46, No. 3, pp 561-579, [SRDB Ref ID: 35110]

The beta and gamma dose rates from the los Alamos national Laboratory Godiva IV Critical Assembly were measured at numerous distances from the assembly four and twelve days following a burst. Information was obtained on the beta-particle spectra using absorption curve studies. The beta/gamma dose-rate ratio as a function of distance from the assembly was determined. Shielding provided by various metals, gloves and clothing was measured. The beta- and gamma-ray doses measured were compared with a film packet used in the past at the Nevada Test Site with two types of current TLD personnel badges. Measurements made with a commercial thin-window ion chamber instrument are compared with the dose rates obtained using other dosimeters.

LANL Bulletin, 1984, “Los Alamos Thermoluminescent Dosimeter Badge,” Los Alamos National Laboratory, Los Alamos, NM, December, [SRDB Ref ID: 8209]

This bulletin describes the components, operation, and limitations of the thermoluminescent dosimeter (TLD) Los Alamos badges used for personnel radiation exposure monitoring. It also describes the procedures for reading the badges, recording dose information, and distributing dose reports. A number of recommendations are included for those who wear TLD badges.

Lawrence, J. N. P. Letter to T. F. Gesell, DOELAP Testing Administrator date December 14, 1984 concerning “Completed Questionnaire to Participate in DOELAP Pilot Performance Testing,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8209]

The completed DOELAP Pilot testing program application requires information regarding the categories selected for testing. The LANL application states that accreditation is not sought for Category VB (Beta, uranium), nor for the low energy component of Category VA (Beta). It is stated that while LANL testing indicates that routine evaluation procedures would evaluate beta doses from contact with uranium adequately, the calibration method is not consistent with the geometry under which most beta doses are received. No person is believed to be currently working with and receiving beta exposures from ^{204}Tl. If (and when) such work is undertaken, it will be necessary to modify our standard evaluation procedures for the identified TLD badges used for that work because LANL standard evaluation procedure can not identify ^{204}Tl betas. .

<u>1985</u>

McAtee, L, Memorandum to B. McKerley, dated April 16, 1985, entitled “Dose Rate Measurements,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 54539]

Per your request, dose-rates were evaluated in Room 409 and in the Room 522 (the mezzanine above Room 409). Both gamma and neutron measurements were made at two locations in each area as shown in Attachments #1 and #2. Direct readings of gamma dose-rates were measured on the morning of March 25 using an Eberline RO-3C while neutron doses were integrated for several hours using an Eberline PRS-2/NRD instrument arrangement. Additionally, ^{7}Li thermoluminescent dosimeters were used to integrate gamma doses at the same locations for the time period of March 25 through April 1. Table 1 below shows the results of these measurements. As calculated from the tabled values, the total room average penetrating radiation dose-rates (gamma plus neutron) are 0.84 mrem/hr for Room 409 and 0.26 mrem/hr for Room 522.

Table 1

Location	Description	Gamma Dose Rate		Neutron Dose Rate	Total Dose Rate
		mR/hr		mrem/hr	
		(a)	(b)	(c)	(b + c)
A	Room *409* West Wall	0.3	0.34	0.23	0.57
B	Room 409 South Wall	0.4	0.26	0.86	1.12
C	Room 522 South End	0.1	0.13	0.18	0.31
D	Room 522 North End	0.1	0.11	0.10	0.20
(a) Direct readings with RO-3C ion chamber instrument. (b) Average dose-rates 3/25 - 4/1 using Li TLD's. (c) Average dose-rates at two hour intervals on 3/25.					

Stafford, R. G., Memorandum to J. N. P, Lawrence, dated April 18, 1985, entitled "Extremity Exposures," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 54538]

This memorandum states "It has been brought to my attention that Group HSE-10 extremity reports since June, 1983 do not identify where neutron factors were applied to extremity dose. Please note that all individuals who are identified as working with Pu-238, Pu-242 and PuBe had neutron components added to their reported extremity exposure from June, 1983 to present. We will identify those who had neutrons added to their exposure in future reports."

McAtee, L, Memorandum to J. Cortez, dated May 8, 1985, entitled "Room 429 Neutron Factor Re-evaluation," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 8209]

During 1983, a complete re-evaluation of the TA-55 neutron dosimetry factor was made (ref: HSE-1-PF-84-13). Since that time, material processing, and thus radiation exposures, has steadily increased for the Metal Preparation Line (MPL) in Room 429. Consequently, in early 1985, substantial additions in neutron shielding in the form of both Lucite and borated water shields were made around the MPL. This, in turn, affected the neutron dosimetry factor and led to the decision to re-evaluate the Room 429 factor during March and April, 1985. The results of this study are included in this reference. A summary of the 1983 and 1985 Factors follows;

1985 Location No.	1983	1985
1	0.40	0.38
2	0.56	0.65
5	0.57	0.61
6	0.83	0.49
9	0.58	0.48
10	0.69	0.62
Average	0.60	0.54

Aragon, J., Letter dated June 7, 1985 to A. Gallegos, concerning information requested by E. J. Vallario in his May 2, 1985 memorandum concerning “Radiation Exposures at Department of Energy (DOE) accelerators,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID:109569]

This reference contains an overview of LAMPF personnel exposures during the period of 1981 through 1984, the workplace activities that caused these exposures, and an assessment by LAMPF health physics staff of necessary radiation protection technology upgrades. Three technology upgrades were identified as follows:

1. A general need for improved instrumentation and dosimetric techniques to measure and evaluate neutron fields with a greater sensitivity than currently available particularly in view of the potential at that time of an increase in the Quality Factor of neutron radiation.
2. A need at the LAMPF a capability to measure biologically important pure beta emitters in gaseous effluent in the presence of mixed gamma, positron, and beta emitters.
3. A need at the LAMPF to determine the molecular form of LAMPF’s principal radioactive stack emissions: carbon, oxygen and nitrogen.

1986

Lawrence, J. N. P. Letter dated February 14, 1986 to Dosimetry Evaluation Book concerning “LANL Results of Participation in DOELAP Pilot Performance Testing,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 8209]

Positive bias exhibited by the LANL TLD badges in the DOELAP pilot testing has been identified as the result of backscatter from the Lucite calibration phantoms. Backscatter radiation increases the badge response by about 10% for ^{137}Cs gammas, and more than 10% in the photon energy range from 40 to 150 keV. Thus, for TLD badges calibrated in free air, the exposure evaluation for badges exposed on a Lucite phantom (i.e., according to DOELAP procedures) will be high by at least 10%. Lacking the time and manpower resources to re-evaluate the response of the LANL TLD badge over the full range of photon and beta energies and the total fading response, the interim correction will be to remove 10% fading correction for photons and beta dose evaluations, since the two effects compensate. The 10% fading correction will be retained for neutron exposure evaluation, because the neutron calibration factors were established using a Lucite phantom. These changes will be made operational for the January 1986 badges.

Coulson, L., V., A. J. Elwyn, and W. S. Freeman, 1986, Draft of DOE Program entitled "Accelerator Health Physics Characterization Report of DOE Laboratories," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109575]

This reference is an early draft of an effort undertaken by the DOE designated lead laboratory (Fermi National Accelerator Laboratory) in conjunction with the other DOE accelerator facilities to develop a guidance document of good practices. The document contains an assessment of current status of accelerator facilities at several DOE sites including LANL. A general description of the LANL accelerator facilities is provided. An overview of radiation fields from these accelerator facilities is also provided.

1987

Mundis, R. L., and M. L. Howe, Memorandum to Distribution dated September 4, 1987, entitled "Neutron Spectrum Measurements in ER-1, July 22, 1987," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 27270]

This memorandum contains a summary of an experiment performed to measure the neutron energy spectrum in ER-1 with the proton beam being stopped in the carbon beam block in Line D directly downstream of the IR bender. The purpose of this measurement was to determine the neutron energy spectrum and dose rate that is in ER-l under these conditions of beam spill and to determine the relative sensitivity of the Albatross-IV neutron survey instrument and the sensitivity of the LANL personnel TLD that is currently worn by TA-53 personnel and a Nuclear Track Emulsion Film, Type A (NTA) that was previously worn. The dosimeters were placed on phantoms for these measurements and the responses were interpreted as if they were ordinary dosimeters being worn by personnel, with the calibrations based respectively using ^{252}Cf and PuBe.

The detectors used to determine the energy spectrum included a set of six polyethylene moderator spheres with TLD 600 and TLD 700 LiF detectors in the center, an unmoderated set of TLD detectors, a cadmium covered set of unmoderated TLD detectors, a p1astic scintillator, C(n,2n} threshold activation detector, and a large bismuth fission counter. Each of these ten detectors has a unique sensitivity for neutron detection as a function of neutron energy. Computer codes are used to unfold the neutron energy spectrum that gives a match to the input data from the ten detectors. The unfolding codes yield a spectrum that covers the energy range from 0.01 eV to 400 MeV.

The upper limit is determined by the limits on the known response functions of the detectors. The C(n,2n) reaction has an energy threshold of 20 MeV, and the bismuth fission counter has a 50 MeV threshold energy.

The reference illustrates the importance of selecting the correct technology and matching the calibration neutron spectra with the workplace measurements. The results with explanations noted in quotations (“) not entirely contained in this reference include:

- The Albatross-IV neutron survey instrument underestimated the dose rate by approximately 50% for this neutron spectrum. This is not unexpected because the response of the Albatross falls off at neutron energies > 20 MeV.
- The TLD under-responded by factors of 5-7 “which is not surprising given the large difference between the neutron spectra of ^{252}Cf used to calibrate the dosimeter and the measured neutron spectra,” and also the known decrease in response of TLDs at neutron energies greater than a few MeV.
- The NTA under-responded but only by about 20% “which is likely associated with the difference between the PuBe calibration spectra and the measured spectra. The generally flat energy response of NTA film to higher neutron energies resulted in reasonable agreement. These results also illustrate that there were comparatively few lower energy neutrons in the measured spectra.”

<u>1988</u>

Mundis, R. L., Memorandum dated January 21, 1988 to J. M. Puckett, entitled “Accelerator Health Protection Quarterly Progress Report for the Fourth Quarter 1987,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 45487]

The memorandum is a routine health protection report for the 4th quarter1987 that includes summary information for several health physics topics such as exposure overview, incidents, surveys, standards, training, special studies, etc. The special studies section describes information of interest as follows:

A. LANSCE/WNR Neutron Measurements for Shield Evaluation. Neutron measurements using activation detectors and portable survey instruments continued in the LANSCE Experiment Room 1 (ER-1). Stray radiation in ER-1 was measured for a variety of beam spill points in the Line D beam channel located directly overhead of the west half of ER-1. Measurements were also made during normal WNR and LANSCE operation. A separate study was conducted where measurements were made as successive layers of neutron shielding were added.

B. Neutron Spectrum Unfolding. Data has been collected in various locations in the Area A experimental hall during normal operating conditions of the LAMPF beam. The bismuth .fission counter was used in conjunction with the multi-sphere set of detectors to extend the useful information to the neutron energy region above 50 MeV. The TLD detectors from the sphere set located at the guard tower on East Road were changed out at the end of the LAMPF operating period. The preliminary data reduction completed so far indicates that there is no significant neutron dose due to the operation of LAMPF at that location. A second measurement is in progress to measure the background when the accelerator is off.

C. Meetings were held to discuss TA-53 stack effluent levels and the resulting radiation doses expected at the East Road boundary of the Laboratory. It appears that the effluent total for the year will be of such a magnitude that the 12.5 mrem/y level will be exceeded by a small amount, thus necessitating the notification of DOE.

In September 1988, LANL evaluated changing from monthly to monthly/quarterly badge issue (LANL 1989). The HSE-1 section leader recommended against changing to monthly/quarterly issuance, stating that problems with fading supported continuation of monthly exchange. Monthly exchange continued to be the most common.

Mundis, R. L., Memorandum dated April 14, 1988 to J. M. Puckett, entitled "Accelerator Health Protection Quarterly Progress Report for the First Quarter 1988," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 45486]

The memorandum is a routine health protection report for the 1st quarter 1988. Summary information of interest includes:

A. The following table gives the radiation exposure experience for the TA-53 site for 1987 compared with calendar year 1986.

Group	Average Badges/Month		Cumulative Person-Rem		Exposure Percent Change
	1986	1987	1986	1987	
AT	307	318	5.28	1.13	-77.70
MP	385	410	62.59	54.86	-12.40
P	32	35	1.12	0.90	-19.60
INC	14	14	7.60	6.96	-8.40
HSE-11	21	21	17.63	13.98	-20.70
Pan Am	74	92	4.36	6.00	+37.60
Visitor	7	8	0.88	0.28	-68.18
TA-53	859	915	99.50	83.62	-16.00

The only significant increase in personnel exposure is in the Pan Am work force. The increase is due almost entirely to work on the transfer of radioactive waste from the storage pools to TA-54. All other divisions and groups have shown a significant decrease in exposure in 1987.

B. Neutron Measurements Around SM-16. HSE-11 personnel participated in a neutron measurement and characterization study in the areas surrounding the Van de Graff (Ion Beam Facility), TA-3, SM-16. The Van de Graff was operated in two different modes with a deuteron beam accelerated onto a thick beryllium target to produce 'a known high intensity source of neutrons. HSE-11 personnel made measurements with a high sensitivity BF_3/polyethylene lined counter system at many locations in the surrounding areas and also made measurements with the multi-sphere neutron energy spectrometer system at four selected locations. A monitor system with a chart recorder was also set up in the vicinity of the .production target to provide a method for normalizing survey readings taken at different times during the survey.

1989

1990

Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume VII Procedures 1990-1995,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 27273]

This reference contains many letters, memorandum and reports regarding Los Alamos personnel dosimetry system design, calibration, use, and dose assessment.

Inkret, W. C., Memorandum to Distribution date January 1990 concerning “Health Physics Checklist Form Update,” Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 110061]

This reference concerns direction to Health Physics staff concerning the effort to update the Health Physics Checklist Form information for LANL work areas. The form is prepared by the line manager and the local health physics technician. Several areas of potential radiation exposures are included in the respective forms. For external dosimetry the form includes criteria as follows:

- Visitor Dosimetry Badge Required?: Yes No
- Permanent Dosimetry Badge Required?: Yes No
- Personal Neutron Dosimeter Required?: Yes No
    - a) CR-39?: Yes No
    - b) NTA film?: Yes No
- Personal Nuclear Accident Dosimeter Required?: Yes No
- Finger Ring Required?: Yes No

Mundis, R. L., Memorandum dated January 19, 1990 to J. M. Puckett, entitled "Accelerator Health Protection Quarterly Progress Report for the Fourth Quarter of 1989," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 45824]

This memorandum is a routine health protection report for the 4th quarter1989. The following table gives the radiation exposure experience for the TA-53 site for the first ten months of 1989 compared with the same period of 1988.

Group	Average Badges/Month		Cumulative Person-Rem		Exposure Percent Change
	1988	1989	1988	1989	
AT	273	276	0.52	0.60	+15.38
MP	401	413	47.32	54.17	+14.48
P	38	77	1.97	2.68	+36.04
INC	14	14	5.61	4.04	-27.99
HSE-11	22	23	11.14	15.78	+41.65
PAW	87	115	3.17	3.90	+23.03
TA-53	852	935	69.79	81.30	+16.50

Mallett, M. W., D. G. Vasilik, G. J. Littlejohn, and J. R. Cortez, 1990, *High-Energy Neutron Dosimetry at the Clinton P. Andersen Meson Physics Facility*, LA-11740-MS, Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 912]

This reference describes neutron energy spectrum measurements performed at the Clinton P. Anderson Los Alamos Meson Physics Facility (LAMPF). Unique experimental environments at LAMPF required the development of a dosimeter to effectively measure the dose component due to high energy neutrons (> 10 MeV). The measurements indicated potential areas for high energy neutron exposure to personnel. The low sensitivity of the Los Alamos thermoluminescent dosimeter (TLD) to high energy neutrons warranted issuing a NTA dosimeter in addition to the TLD badge to employees entering these areas. The dosimeter consists of a plastic holder surrounding NTA film that has been desiccated and sealed in a dry nitrogen environment. A study of the fading of latent images in NTA film demonstrated the success of this packaging method to control the phenomenon. The double badging (e.g., TLD and NTA) is maintained throughout the operating period of the LAMPF accelerator and its associated experimental areas and facilities.

This document also discusses the 1987 report of neutron dose measurements (Mundis and Howe, SRDB 27270). The 1987 neutron energy spectrum measurements were made at a potentially high neutron-energy location at LAMPF. Neutron survey instruments along with personnel dosimeters were placed in the ER-I experimental area with the proton beam being stopped in a carbon block in an adjacent beam line. The experiment was performed to evaluate the neutron energy spectrum and dose equivalent rate under conditions of controlled beam spill and to assess the relative sensitivity of each neutron measuring device. Computer codes unfolded data from various detectors which included moderated, unmoderated, and cadmium covered TLD 600 and TLD 700 LiF chips. In addition, a plastic scintillator threshold activation detector, C(n, 2n), and a bismuth fission chamber were used. The unfolding codes revealed that more than 90% of the neutron dose equivalent was due to neutrons of energy greater than 1 MeV, and 70% due to neutrons of energy greater than 10 MeV.

The experiment further showed that the Los Alamos TLD badge under responded by a factor of 5 to 7 for this particular neutron spectrum. NTA film under responded but only by about 20%. However, the sum of the two dosimeters was in good agreement with the spectrum unfolding results, as would be anticipated based on their sensitivity ranges. In 1988, employees at LAMPF who entered ER-1 were issued a separate NTA badge in addition to the regular TLD badge. The NTA film was placed inside a cadmium covered Cycolac plastic TLD badge holder. The double badging system continued throughout LAMPF's 1988 operating period. High relative humidity from extensive rainfall during this period prompted a concern for fading. A fading study was subsequently initiated to recharacterize the NTA dosimeter. Badges irradiated to 500 mrem (PuBe-238 or Cf-252) were developed throughout a 2-month period. More than 50% fading was observed in the first 20 days since irradiation and no tracks were present at 60 days.

Los Alamos implemented changes to reduce the rate of fading involving the NTA film being desiccated in a glove box and sealed in a ultra-high purity nitrogen gas (minimum purity 99.999%) with less than 3 ppm moisture. A desiccating jar filled with Drierite indicating desiccant is used to dry the film for 64 hours inside this nitrogen environment. The dosimeter assembly and plastic pouch sealing are then completed within the glove box.

The Los Alamos NTA dosimeter is issued for a I-month period. The dosimeter is produced less than 1 week prior to being issued. The badges are exchanged and developed within 10 days following the end of the I-month consignment period. Hence, the maximum time between exposure and development is about 50 days. The plastic badge holders are color coded by the issue month in order to distinguish between permanent personnel and temporary employees or visitors. In the event that the seal of the dosimeter is breached, the badge is returned for early development and the employee reissued a temporary NTA dosimeter.

NTA film has frequently been calibrated at Los Alamos using a PuBe-238 or a bare Cf-252 source having an average neutron energy of 4.5 MeV or 2.3 MeV, respectively. The film is irradiated in the Cycolac plastic holder using an NBS slab phantom (40 x 40 x 15 cm methyl methacrylate slab) backing. Due to the neutron energy spectrum measurements conducted at LAMPF during 1987 and the sensitive energy range of NTA film, it was concluded that the NTA dosimeter primarily measures exposure to neutrons from approximately 10-60 MeV. A response factor of 4 mrem/track/mm^2 was conservatively chosen based on this energy spectrum study, film response characterization experiments performed at Los Alamos, and a general consensus of the available literature. A background factor of 3 tracks/mm^2 was selected based on a 99% confidence level.

In conclusion, this report states that the Los Alamos NTA dosimeter adequately satisfies high energy neutron dosimetry requirements at LAMPF. Sealing the film overcame the problem of severe latent image fading. Desiccating and sealing NTA film in a dry nitrogen environment essentially eliminates fading over the ~1-month issue period of the dosimeter. The presence of indicating silica gel crystals in the packet provides acceptable assurance of the integrity of the seal. The summation of the TLD and NTA dosimeter responses agrees with spectrum unfolding code predictions. Thus, the combination of the two dosimeters effectively covers the broad neutron energy range existing at LAMPF.

Anonymous, Survey logs from August 13, 1991, concerning workplace measurements at the ER-1 area," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109577]
This reference is a tabulation of ER-1 workplace surveys that include neutron and gamma dose measurements.

1991

Anonymous, Survey logs from 1991, concerning workplace measurements at Area-A East Run Survey," Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref. ID: 109579]

This reference is a tabulation of Area-A East Run workplace surveys that include neutron and gamma dose measurements.

1992

1993

Harvey, W. F., and F. Hajnal, 1993, Multisphere Neutron Spectroscopy Measurements at the Los Alamos National Laboratory Plutonium Facility, LA-12538-MS, Los Alamos National Laboratory, Los Alamos, NM, June, [SRDB Ref ID: 27250]

Multisphere neutron spectroscopy methods are applied to measure representative working fields within the Los Alamos National Laboratory (LANL) Plutonium Facility. This facility hosts dynamic processes, which include the fabrication of Pu heat sources for radioisotope generators used to power space equipment and a variety of plutonium research programs that involve recovery, hydrofluorination, and metal production. Neutron fluence per unit lethargy, as a function of neutron energy measured for locations throughout this facility, are described Dosimeter/remmeter response functions [e.g., determined for a 22.8-em-diameter neutron rem detector (NRD), an Anderson/Braun-type neutron "Snoopy" monitor, track-etch CR-39, BDI·100 bubble detectors, and Kodak type A nuclear track emulsion film, (NTA)] are folded into these spectra to calculate absolute response values of counts, tracks, or bubbles per unit-dose equivalent. The relative response values per unit- dose equivalent for bare and albedo ^{6}LiF-based thermoluminescent dosimeters (TLDs) are also calculated to estimate response scenarios encountered with use of the LANL-TLD. These results are further compared to more conventional methods of estimating neutron spectral energies such as the "9-to-3 ratio" method.

The conclusions of this study are summarized as follows:

i. The average Plutonium Facility quotient of neutron to gamma- and x-ray-dose equivalent was measured to be 2.5 while photon dose equivalent rates were measured to have a range in hall and storage areas of 3.84 to 80.0 µSv/h (0.384 to 8.00 mrem/h, respectively.
ii. reference neutron dosimetry methods used for calibration result in an average 20% over-response (i.e., values ranging from 6% to 30%) of the Eberline 22.9-cm NRD when used in the Plutonium Facility;
iii. when the response functions of BDI-100, CR-39, and NTA film are rolled into the measured Plutonium Facility neutron spectra, these dosimeters are calculated to under-respond (i.e., relative to their measured response values for bare ^{252}Cf by values of 9.5%, 14%, and 30%, respectively:
iv. when the relative response values for bare and albedo ^{6}LiiF TLDs are folded into the measured Plutonium Facility neutron spectra, the inherent thermal and epithermal sensitivities of these dosimeters result in significant changes in response values representative of highly moderated and dynamic processes;
v. due to the dynamic and significant presence of thermal and epithermal neutrons encountered at specific locations in the Plutonium Facility, applied TLD neutron correction factors arc valid primarily for static, site-specific processes; and
vi. properly calibrated BDII-l00 and CR-39 dosimeters are calculated to be more accurate than the currently used LANL-TLD system for quantifying neutron-dose equivalents encountered in the Plutonium Facility.

Unless valid and site-specific neutron correction factors are applied to all encountered fields, the currently used LANL TLD-based dosimeter will not measure neutron-dose equivalents to a high degree of accuracy for individuals who oversee many operations and processes within this facility. The inherent nature of properly calibrated bubble and CR-39 dosimeters renders them less sensitive when compared to TLDs in changing thermal/epithermal neutron fields. This fact, combined with calculated spectral response values, demonstrates that both BDI-100 and CR-39 dosimeters are more accurate than the currently used LANL-TLD system in measuring neutron-dose equivalents imparted for dynamic and highly moderated neutron processes encountered in the LANL Plutonium Facility.

1994

Mallett, M. W., J. M. Hoffman, and D. G. Vasilik, 1994, *Los Alamos National Laboratory Environment, Safety and Health Division Personnel Dosimetry Operations External Dosimetry Technical Basis Document*, ESH-4-PDO-94:005, Los Alamos National Laboratory, Los Alamos, NM, February 8, [SRDB Ref ID: 27265]

The measurement and interpretation of external radiation exposure to employees and visitors of the laboratory is the responsibility of the Personnel Dosimetry Operations section of the Health Physics Measurement group under the direction of the Environment, Safety and Health Division. This manual constitutes the technical basis document for the measurement and interpretation of external radiation exposure at the Los Alamos National Laboratory.

The Los Alamos TLD badge is an accurate and versatile dosimeter recording both penetrating and nonpenetrating ionizing radiation. Given no more than the three TLD-700 readings, a computer program has been written that can evaluate without corrections gamma and high energy x rays, estimate the energy of low energy (<100 keV) x rays and apply empirically derived correction factors, obtain an approximate effective energy and correction factor for a mixture of low energy x rays and ^{60}Co gamma rays, distinguish between low energy x rays and ^{90}Sr beta rays, estimate the beta only dose, and determine the fraction of beta rays in a mixture of gamma and beta rays and apply suitable correction factors. Although no additional information is required, a Health Physicist is requested to verify periodically that a badge wearer indeed works with or is exposed to the photon and beta radiation attributed to him by the computer program.

To evaluate neutron doses, supplemental information is required. The TLD-600 minus the TLD-700 reading is not sufficient to determine the dose, because the badge response is strongly dependent on energy, necessitating on-site periodic determinations of correction factors at each location where neutrons occur. At some facilities, such as LAMPF, the neutron spectrum may be relatively constant throughout the accelerator area, and a single correction factor for the entire facility will suffice. At other facilities, such as the Plutonium Facility, the neutron spectrum varies markedly, depending on the work performed, and three different correction factors are required in different parts of the facility.

<u>1995</u>
Track-etch dosimeters (TEDs) have been used for evaluation of fast neutron doses since 1995. TEDs were exchanged quarterly.

<u>1996</u>
Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume VIII Procedures 1996-2001,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 27292]

This reference contains many letters, memorandum and reports regarding Los Alamos personnel dosimetry system design, calibration, use, and dose assessment.

<u>1998</u>
Implementation of the Harshaw Model 8823 TLD badge in 1998, the following dose quantities have been evaluated and recorded (Hoffman and Mallett 1999a, b):

- Beta shallow DE (mrem)
- Beta eye DE (mrem)
- Gamma shallow DE (mrem)
- Gamma deep DE (mrem)
- Gamma eye DE (mrem)

- Neutron deep DE (mrem)
- Total shallow DE (mrem)
- Total deep DE (mrem)
- Total eye DE (mrem)
- Total deep neutron DE (mrem)

Shallow doses, which are reported to a tissue depth of 7 mg/cm^2, correspond to the old nonpenetrating doses.

1999

Hoffman, J. M., and M.W. Mallett, 1999, The LANL Model 8823 Whole-Body TLD and Associated Dose Algorithm, LA-UR-99-2327 (ESH4-PDO-TBD-02, R1), Los Alamos National Laboratory, Los Alamos, NM [SRDB Ref ID: 27256]

Hoffman, J. M., and M.W. Mallett, 1999, The LANL Model 8823 Whole-Body TLD and Associated Dose Algorithm, Health Physics, Vol. 77, No. 5, Supplement, pp. S96-S103.

This document describes operational characteristics of the LANL Model 8823 Personnel Dosimetry system which was DOELAP accredited during 1977. The use of a supplemental track-etch dosimetry (TED) capability is also described.

2002

Los Alamos Dosimetry, “Photodosimetry Evaluation Book "Bible" Volume IX Procedures 2002-2003,” Los Alamos National Laboratory, Los Alamos, NM, [SRDB Ref ID: 27301]

This reference contains many letters, memorandum and reports regarding Los Alamos personnel dosimetry system design, calibration, use, and dose assessment.

As of February 2002, quarterly periods were used for about 40% of dosimeter issues (LANL 2003).

2009

ORAUT, “Analysis of LANL Reported Annual Doses 1944-2008,” Oak Ridge Associated Universities Team, [SRDB ref. ID: 27261]

This reference contains LANL annual recorded shallow, deep (photon) and neutron doses for each monitored worker with a positive recorded dose for any dose component. The reference also provides the annual collective dose for all years from 1944-2008.

2011

ORAUT, "Analysis of LANL Reported Annual Doses 1944-2008," Oak Ridge Associated Universities Team, [SRDB ref. ID: 104692]

This reference contains analyses of the neutron-to-photon dose ratio for each year for annual neutron and deep (photon) doses that equal or exceed 50 mrem