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A Survey of International Personnel Radiation Dosimetry Programs

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A SURVEY OF INTERNATIONAL PERSONNEL RADIATION DOSIMETRY PROGRAMS

R. E. Swaja

Highlights

In September of 1983, a mail survey was conducted to determine the status of external personnel gamma and neutron radiation dosimetry programs at international agencies. A total of 130 agencies participated in this study including military, regulatory, university, hospital, laboratory, and utility facilities. Information concerning basic dosimeter types, calibration sources, calibration phantoms, corrections to dosimeter responses, evaluating agencies, dose equivalent reporting conventions, ranges of typical or expected dose equivalents, and degree of satisfaction with existing systems was obtained for the gamma and neutron personnel monitoring programs at responding agencies. Results of this survey indicate that to provide the best possible occupational radiation monitoring programs and to improve dosimetry accuracy in performance studies, facility dosimetrists, regulatory and standards agencies, and research laboratories must act within their areas of responsibility to become familiar with their radiation monitoring systems, establish common reporting guidelines and performance standards, and provide opportunities for dosimetry testing and evaluation.

INTRODUCTION

In September of 1983, a survey was conducted by the staff of the Dosimetry Applications Research Facility at Oak Ridge National Laboratory to determine the status of external personnel gamma and neutron radiation dosimetry at international facilities. This study consisted of mailing two-page questionnaires to 185 agencies and evaluating the responses of the 130 organizations which replied. With regard to gamma dosimetry, the survey form requested information concerning basic dosimeter types, calibration sources, calibration phantoms, corrections to dosimeter responses for mixed-field monitoring, evaluating agencies (vendor or in-house), monitoring periods, and ranges of typical or expected dose equivalents. Requested neutron dosimetry data included the same information as for gamma monitoring plus dose equivalent reporting convention, knowledge of incident spectra, basis of system selection, and degree of satisfaction with the monitoring program. Results of this survey are presented and discussed in the following text.

PARTICIPATION

Table 1 summarizes information concerning the responding agencies including general facility types and locations, total number of institutions responding, number of agencies doing personnel gamma and neutron dosimetry, number of monitored workers, and number of agencies doing beta dosimetry. Of the 130 responding facilities, 102 were from the United States (US) and 28 were from other countries. Types of participating US agencies included military, regulatory, hospitals, universities, laboratories (national laboratories, industrial research

facilities, and fuel processing plants), and nuclear utilities. Foreign facilities, which will be considered as one facility type in this report, included laboratories, universities, regulatory agencies, and utilities.

With regard to dosimetry programs, all responding organizations are or will be performing personnel gamma monitoring. About 81% of the participants also conduct or will be conducting neutron personnel monitoring. A total of 83% of the responding facilities also conduct or will conduct beta dosimetry programs. The gamma monitoring involves about 500,000 radiation workers while the neutron monitoring affects about 72,000 people. Laboratories, utilities, and military facilities account for about 90% of all radiation workers monitored for gamma and neutron radiation. Considering only the US agencies, personnel radiation monitoring programs are regulated by the Nuclear Regulatory Commission for about 49% of the facilities (mostly utilities), various state governments for 29% of the facilities (mostly hospitals and universities), the Department of Energy for 20% of the facilities (laboratories), and the Department of Defense for the remaining 2% of the responding agencies (military).

SURVEY RESULTS

The following text presents and discusses results of this survey. To preserve anonymity of the participants, results are presented for the collection of all responding agencies, for the collection of US and foreign participants, and by facility type for the US participants. Unless otherwise indicated, data given in the summary tables represents the percent of all responses for each facility type. While conclusions obtained from these results may not characterize a particular

institution, they do indicate trends in personnel radiation monitoring at the responding facilities.

PERSONNEL GAMMA DOSIMETRY

Information requested on the survey forms for gamma monitoring included basic dosimeter types, calibration sources and phantoms, corrections to dosimeter responses, evaluating agencies, monitoring periods, and ranges of typical or expected gamma dose equivalents. Kinds of gamma dosimeters used at the responding agencies are summarized in Table 2. Basic dosimeter types considered in this study include thermoluminescent (TLD), film, and radiophotoluminescent (RPL). Some percent responses given in the table for particular facilities total more than 100% because several agencies use more than one basic type of gamma dosimeter for personnel monitoring.

Overall, TLD systems are the most popular gamma monitors at the responding agencies. These systems are about twice as popular as film with about 77% of all agencies using TLD's for gamma monitoring. For the US agencies, TLD's were about 2.5 times as popular as film systems and were used by almost all utilities. At foreign facilities, thermoluminescent gamma dosimeters were used by only about 25% more agencies than used film. The RPL systems were used by only 2% of the responding agencies - all at foreign laboratories.

Table 2 also shows the types of TL phosphors used for gamma monitoring at various agencies. Considering all facilities, TLD-700 (^7LiF material) is the most popular for gamma monitoring. About 2.5 times as many agencies use TLD-700 as use the second most popular phosphor CaSO_4 (or CaSO_4 used in combination with another material). Natural LiF (TLD-100) is used for gamma monitoring by about 13% of all agencies

employing TLD's. Composite responses from foreign and US agencies showed similar trends with regard to TL phosphors in that TLD-700 material is about 2.5 times as popular as CaSO_4 with TLD-100 phosphor being least popular. All responding utilities use either TLD-700 or CaSO_4 for gamma monitoring while TLD-100 is used mostly at hospitals and universities.

Evaluating agencies and ranges of actual or expected annual gamma dose equivalents are shown in Table 3 for the responding facilities. Overall, about twice as many facilities do their own gamma personnel monitoring as use vendor services. Responses from US facilities indicate that only 12% more agencies maintain in-house programs than use vendors. More than 75% of the responding US military agencies, laboratories, and utilities do gamma monitoring in-house while vendor services are used by more than half of the regulatory agencies, hospitals and universities. Responses from foreign facilities indicate that almost 90% of the gamma monitoring is done using in-house programs.

Ranges of actual or expected gamma dose equivalents shown in Table 3 indicate that about 62% of all responding agencies report values less than 5 mSv per year, 15% report values less than 10 mSv per year, and the remaining 23% report values less than 50 mSv per year. No responding agency indicated maximum annual gamma dose equivalents greater than 50 mSv for routine monitoring. These percentages are similar for all US and foreign responding facilities. For routine monitoring, about 83% of all responding agencies used monthly monitoring periods, 9% used quarterly monitoring periods, and the remaining 8% used some other period (weekly, bi-weekly, or every six weeks). These percentages were typical of participating US and foreign agencies.

Characteristics of gamma dosimeter calibration are shown in Table 4. Results shown in this table summarize types of sources and the use of phantoms for gamma dosimeter calibration. Considering all responding facilities, Cs-137 is the most popular gamma calibration source and is used by over half (55%) of all agencies. About 18% of the responding facilities use Co-60 as the primary calibration source while about 12% use some other single source or multiple calibration sources. The Cs-137 sources are most popular among US facilities (used by 63% of all responding US agencies) with Co-60 the second most widely used source (12% of all US facilities). Most (about 42%) foreign agencies use Co-60 as a gamma calibration source with Cs-137 and other single or multiple sources each used by 29% of the responding foreign facilities. Approximately 15% of all responding agencies do not know what source is used to calibrate their gamma dosimeters. All of these facilities are in the United States and all use vendor services.

Table 4 also shows that over half (51%) of all responding agencies do not use phantoms to calibrate their gamma personnel dosimeters. Phantoms are used by 29% of all responding facilities. Foreign facilities not using phantoms outnumbered those who do by almost 4 to 1 while only 1.3 times as many US facilities do not use phantoms compared to those who do. A total of 20% of all responding facilities do not know whether or not phantoms are used to calibrate their gamma dosimeters. All of these are in the United States and all use vendor services.

Of the 130 responding agencies doing routine personnel gamma dosimetry, 105 (81%) are performing this monitoring in mixed neutron and gamma radiation fields. The presence of neutrons can affect measured gamma dose equivalents depending on the basic type of gamma dosimeter

and radiation field characteristics (1,2,3). This survey indicated that 45% of all responding agencies who perform gamma dosimetry in mixed radiation fields consider possible effects of neutrons on the responses of their gamma dosimeters and, if necessary, make some correction to account for these effects. More than half (57%) of the foreign agencies consider or account for possible neutron effects on their gamma dosimeters while only 39% of the US facilities doing mixed-field gamma monitoring consider or account for neutron effects.

PERSONNEL NEUTRON DOSIMETRY

Information requested on the survey forms for neutron monitoring included the same data as for gamma monitoring plus dose equivalent reporting convention, knowledge of the incident spectrum, basis of system selection, and degree of satisfaction with the monitoring program. Table 5 summarizes the types of sources producing occupational neutron exposure at the responding facilities. Data shown in the table total more than 100% for each facility type since some agencies have more than one source of neutron exposure. Considering all responding agencies, isotopic sources produce neutron exposure at the most facilities (87% of all agencies, 80% of all US agencies, and 92% of all foreign facilities). Reactors are the second largest source of neutrons for occupational exposure with 58% of all responding agencies possessing this source. More than half (54%) of the reporting US facilities and about 60% of the responding foreign facilities have some type of reactor which can produce occupational neutron exposure. Most of these agencies are utilities, laboratories, and universities. Accelerators provide the third largest source of neutrons for occupational exposure (about 33% of all responding agencies). About 29% of the US facilities (mostly

hospitals, universities, and laboratories) and about 48% of all foreign agencies have accelerators of some type. Nuclear fuel provides a source of neutron exposure in about 21% of all agencies including 18% of the US facilities and 32% of all foreign agencies.

Types of neutron personnel dosimeters used at the responding agencies are shown in Table 6. Basic neutron dosimeter types considered in this study include TLD-albedo, NTA film, recoil track (mostly CR-39), combination albedo-track, TLD, and fission track (4,5). Considering all responding agencies, TLD-albedo systems are the most popular for neutron personnel monitoring being used by about one-third (35%) of all facilities. Film dosimeters are second in popularity and are used by about one-fifth (21%) of all facilities. Recoil track and combination albedo-track systems are each used by 14% of the responding agencies and are third in popularity for neutron personnel monitoring. Direct interaction TLD's and fission track (Th-232 radiator) dosimeters are used by less than 10% of all agencies. About 7% of all facilities use some other neutron monitoring system (primarily stay time times dose equivalent rate measured using a remmeter).

Among the US facilities, albedo dosimeters (36%) are used by twice as many responding agencies as film (18%) which is the second most popular type. Recoil track and combination albedo-track systems are each used by about 15% of the US facilities while direct interaction TLD's are used by 7% of all US agencies. No responding US facility uses a fission track dosimeter for routine personnel monitoring. Albedo systems are used by more than half of the US military, laboratory, and utility agencies and are least popular with hospitals. Film systems are used by about half of the responding hospitals and almost no utilities.

Nuclear utilities are the only US organizations using stay times and remmeters to determine occupational neutron dose equivalents. Universities show no strong preference for any of the basic types of neutron dosimeters.

Responses from foreign agencies indicated that film (47%) is about twice as popular as albedo systems (21%) for neutron monitoring. Recoil track (11%) and fission track (8%) monitors are third and fourth in popularity among foreign agencies. Combination albedo-track systems, stay time times dose equivalent rate, and direct interaction TLD's are used by less than 5% of all responding foreign facilities.

Table 7 shows evaluating agencies and ranges of actual or expected annual neutron dose equivalents for the responding agencies. Considering all facilities, about twice as many do their own neutron personnel monitoring (65%) as use vendor services (35%). Responses from US facilities indicate that only 12% more agencies maintain in-house programs than use vendors. More than 64% of the US utilities, laboratories, and military agencies do their own neutron dosimetry while vendor services are used by more than 55% of the responding hospitals, universities, and regulatory agencies. With regard to foreign agencies, more than 90% of the neutron personnel monitoring is done using in-house programs.

Ranges of actual or expected annual neutron dose equivalents shown in Table 7 indicate that about 69% of all responding agencies report values less than 1 mSv per year, 21% report results less than 5 mSv per year, 5% report results less than 10 mSv per year, and 5% report values less than 50 mSv per year. No responding agencies indicate maximum annual neutron dose equivalents greater than 50 mSv. These percentages are similar to results obtained for all responding US and foreign agencies.

In addition to data shown in Table 7, responding agencies indicated that the primary selection criterion for their neutron monitoring systems was response characteristics of the dosimeter (63% of all facilities). The second most important selection criterion was cost which was indicated by 48% of all responding facilities. Characteristics of the radiation environment and recommendations from other dosimetrists were two of the least important selection criteria (about 25% of all agencies).

Table 8 summarizes the types of sources and phantoms used for neutron dosimeter calibration at the responding facilities. Considering all responses, the most popular type of neutron calibration source (35% of all agencies) is an unmoderated encapsulated source such as PuBe, AmBe, or Cf. Neutron energy spectra available from these sources are much harder than those obtained from moderated sources or reactors (3). The next most popular calibration source is the 15-cm D₂O-moderated Cf source which is used by 18% of all participants and is recommended as a calibration source for utilities (6). Twenty-five percent of all agencies use other sources (reactors or accelerators) or multiple sources to calibrate their neutron dosimeters. About one-fifth (22%) of all responding agencies don't know what source is used for neutron calibration. All of these facilities use vendor services for neutron monitoring.

Among the US facilities, about 36% use unmoderated neutron sources for dosimeter calibration. These hard sources are the only ones used at responding hospitals and universities. About 20% of responding US agencies use D₂O-moderated Cf which is the most popular neutron calibration

source at utilities (44%). Other single or multiple sources are used at 14% of the US facilities and are the most popular at laboratories and military agencies. About one-third (30%) of the US facilities don't know what source is used to calibrate their neutron dosimeters. Foreign responses indicated that other or multiple calibration sources are the most popular (52%) followed by unmoderated encapsulated sources (37%) and D₂O-moderated Cf (8%). Only 8% of the responding foreign agencies don't know what type of source is used to calibrate their neutron dosimeters.

Table 8 also summarizes types of phantoms used for neutron dosimeter calibration. Phantoms are necessary to simulate body reflection and absorption characteristics which can significantly effect neutron dosimeter response (7). Considering all agencies, 40x40x15 cm blocks made of Lucite and other polymethylmethacrylates are the most popular single type of phantom being used by 28% of all responding facilities. This type of phantom is recommended for neutron dosimeter calibration by the United States National Bureau of Standards (8). Other phantom types such as water-filled elliptical bombs (2), cylindrical polyethylene bottles, and polyethylene slabs are used by 28% of all agencies. Fourteen percent of all responding facilities use no phantom for neutron dosimeter calibration, and 30% don't know what type of phantom is used. Among the US facilities, Lucite blocks are the most popular (30% overall) and are used by about half of the participating utilities. Approximately 13% of the US agencies do not use any phantom for neutron dosimeter calibration with most of these being from universities (40%). Approximately one-third (30%) of all US facilities don't know what type of phantom is used for neutron calibration. All of these use vendor

services. Foreign responses indicate that Lucite blocks (12%) are less popular than other types of phantoms (40%). About one-fourth (24%) of the foreign facilities don't use any phantoms, and about one-fourth (24%) don't know what type of phantom is used for neutron calibration.

Knowledge of the incident neutron energy spectrum is necessary to select a basic dosimeter type suitable for the monitored radiation field and to apply corrections to basic dosimeter response which account for energy sensitivity of the system and differences between incident and calibration spectra. Neutron energy spectra can be determined by spectrometer measurements, such as multispheres or He-3 spectrometers (9), or by calculations using various shielding or neutron transport computer codes. Table 9 summarizes the types of information that responding agencies have concerning their neutron spectra. Some of the percent responses for particular facilities total more than 100% because some agencies have both measurements and calculations of their incident spectra. Overall, about 83% of all agencies have some knowledge of the neutron energy distribution encountered at their facilities. About 76% of all agencies have made measurements (multispheres or other spectrometers) while about 34% have performed calculations to obtain spectral information. Of the US responses, 82% of all facilities have some knowledge of the neutron spectra-79% by measurements and 28% by calculations. More than 75% of responding hospitals, universities, and utilities have made neutron spectral measurements at their facilities. About 84% of all foreign agencies have some knowledge of their neutron spectra which includes 64% who have made measurements and 44% who have performed calculations.

Table 9 also summarizes types of corrections to basic neutron dosimeter responses which account for dosimeter energy sensitivity and differences between measured and calibration spectra. The types of corrections considered in the table include those based on integral detector response measurements, such as 9-to-3 inch polyethylene sphere response ratios and bare BF₃-to-3 inch response ratios (10), and other corrections, such as calibration factors and calculated corrections. Slightly more than half (51%) of all responding agencies apply no correction to the basic neutron dosimeter responses. Most of these agencies use vendor services. Of those who do apply some correction, 19% use factors based on integral detector measurements and 30% employ some other correction. Among the US facilities, 54% apply no corrections to basic dosimeter responses including well over half of the responding hospitals and universities and more than 35% of the utilities and laboratories. Integral detector measurements were used by 21% of the US facilities including 25% of the responding laboratories and 36% of the utilities. Other corrections are used by 25% of the remaining US facilities including about one-third of the responding hospitals (33%) and laboratories (36%). Of the foreign agencies, about 40% apply no corrections to their neutron dosimeter responses, about 12% use measured integral detector responses as the basis for a correction factor, and about 48% use some other correction factor.

Another important characteristic of neutron personnel monitoring systems is the convention used to report dose equivalents. Differences in neutron dose equivalent estimates due to differences in dose equivalent conventions can be substantial for certain incident spectra (11). Table 10 lists the most common conventions used to report neutron

dose equivalents at responding facilities. The primary conventions considered in the table include those recommended by the International Commission on Radiological Protection (ICRP) in their publication number 21 (12) the National Council on Radiation Protection and Measurements (NCRP) in their publication number 38 (13), and the volume element 57 dose equivalent as calculated for the cylindrical tissue-equivalent Snyder-Auxier phantom (14).

For all responding agencies, the ICRP convention is the most popular being used by about 36% of all facilities. The NCRP and element 57 conventions are used by about 11% and 12% of all facilities, respectively, and about 9% use some other convention. About one-third (32%) of all agencies do not know what convention is used to report their neutron dose equivalents. Among the US facilities, most responding agencies (41%) don't know what convention is used to report neutron dose equivalents including more than half of the hospitals and universities. Of the remaining US facilities, about 25% use ICRP, 12% use NCRP, and 12% use element 57. Laboratories and utilities exhibit no strong preference for any of the conventions. Responses from foreign agencies indicate that ICRP is by far the most popular convention for reporting neutron dose equivalents and is used by 68% of all facilities. The NCRP (4%) and element 57 (4%) conventions are not very popular among foreign agencies. Only 12% of the reporting foreign facilities do not know what dose equivalent convention is used to report their results.

Two other questions concerning neutron personnel dosimetry involved previous or planned participation in dosimetry performance testing or qualification programs and degree of satisfaction with the existing or proposed neutron monitoring program. Overall, 86% of all agencies have

participated or will participate in some performance testing program or intercomparison study. About 87% of the US facilities and about 84% of all foreign facilities responded affirmatively to this question. With regard to degree of satisfaction with the existing or proposed neutron monitoring program, only 38% of all responding agencies (42% US and 20% foreign) indicated that they were satisfied with their programs.

CONCLUSIONS

The following conclusions concerning gamma and neutron personnel monitoring are obtained from data presented in the preceding text:

1. About twice as many facilities maintain in-house gamma and neutron personnel monitoring programs as use vendor services. Vendor services are most popular with hospitals, universities, and regulatory agencies while in-house programs are maintained by the majority of laboratories, and utilities.
2. About 60% of the responding facilities report maximum annual gamma dose equivalents of less than 5 mSv. All agencies reported maximum gamma dose equivalents lower than 50 mSv.
3. The TLD systems are the most popular for routine gamma personnel dosimetry and are used by about 80% of the responding agencies. About 60% of all agencies use TL-700 material, the most popular phosphor, for gamma monitoring. Approximately 25% of all agencies use CaSO_4 , the second most popular phosphor, alone or in combination with another material for gamma monitoring.
4. About 15% of the dosimetrists at responding facilities are not familiar with all details of their gamma monitoring systems such as radiation sources and types of phantoms used for calibration. Most of these use vendor services.

5. More than half (55%) of the agencies doing gamma monitoring in mixed radiation fields do not consider possible effects of neutrons on the response of their gamma dosimeter and make no attempt to account for such effects.
6. Most (about 90%) occupational neutron exposure is due to isotopic sources at the responding agencies. Reactors (58%), accelerators (33%), and nuclear fuel (21%) account for most of the remaining neutron sources.
7. Approximately 70% of the maximum reported annual neutron dose equivalents at the responding facilities are less than 1 mSv with 90% being less than 5 mSv. All responding facilities reported maximum annual neutron dose equivalents less than 50 mSv.
8. The TLD-albedo systems are the most popular for neutron personnel monitoring with film second and recoil track and combination albedo-track third. Albedo dosimeters are most popular at utilities and laboratories while film and track (including combination albedo-track) systems are most popular at hospitals. Universities indicated no strong preference for any of the basic neutron dosimeter types.
9. About 25% of the dosimetrists at responding agencies are not familiar with details of their neutron monitoring systems including types of calibration sources, types of phantoms, and dose equivalent reporting conventions. Most of these use vendor services.
10. Approximately 20% of all agencies have no knowledge of their incident neutron energy spectra, and more than half of the responding facilities make no attempt to account for neutron dosimeter energy sensitivity and differences between incident and calibration spectra in the evaluation of their dosimeters.

11. The ICRP dose equivalent convention is the most popular among the responding agencies and is used by about 36% of all facilities. About 10% of all facilities use NCRP, element 57, or other conventions for reporting neutron dose equivalents. Approximately one-third of the responding agencies don't know what convention is used.
12. About 86% of all responding agencies have participated or will participate in some performance testing program or intercomparison study. This indicates that a large majority of dosimetrists are actively concerned with evaluating and improving their personnel monitoring systems.
13. Only 38% of all agencies are satisfied with their existing or proposed neutron monitoring programs.

RECOMMENDATIONS

Results of this survey indicate that a significant number of dosimetrists are not familiar with all components of their gamma and neutron personnel monitoring systems. This is especially true of those using vendor services. Most problems are exhibited in areas concerning dosimeter calibration, dosimeter response analysis, and dose equivalent reporting. These areas have been identified as major contributors to inaccuracies observed in international personnel dosimetry intercomparison and performance testing studies(2,3).

To provide the best possible occupational radiation monitoring programs and to improve dosimetry accuracy in performance studies, facility dosimetrists, regulatory and standards agencies, and research laboratories must act within their areas of responsibility. Dosimetrists maintaining in-house programs or using vendor services must become familiar with all phases of their personnel monitoring systems to ensure that detection methods, calibration procedures and equipment, and data evaluation and interpretation are correct for the radiation environments

at their facilities. Regulatory and international standards agencies must specify a common convention for reporting occupational dose equivalents at all facilities and common performance standards (accuracy and precision) for personnel dosimetry. In addition, research laboratories must continue to conduct and develop intercomparison and irradiation programs to afford applied dosimetrists an opportunity to evaluate and test the performance of their monitoring systems.

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Table 1. Characteristics of facilities responding to the 1983 personnel dosimetry survey^a

Type of facility	Total number responding	Gamma monitoring		Neutron monitoring		Beta monitoring agencies
		Agencies	Workers badged	Agencies	Workers badged	
Total US	102	102	176,823	80	45,422	85
Military	2	2	36,000	2	24,000	2
Regulatory	4	4	600	2	300	2
Hospitals	18	18	8,664	9	810	14
Universities	21	21	10,170	21	1,518	15
Laboratories ^b	21	21	63,441	16	13,439	16
Utilities	36	36	57,948	30	5,355	36
Total foreign ^c	28	28	323,844	25	26,585	23
Total all	130	130	500,667	105	72,007	108

^aResponding agencies are now or will be conducting personnel monitoring programs.

^bIncludes national laboratories, fuel manufacturing or processing facilities, and industrial research laboratories.

^cIncludes laboratories, universities, utilities, and regulatory agencies.

Table 2. Types of personnel gamma dosimeters used at responding facilities							
Type of facility	Personnel gamma dosimeter type ^a			TL Phosphor ^b			
	Film	TLD ^c	RPL ^d	TLD-700	TLD-100	CaSO ₄ ^e	Other
Total US	31	76	0	63	12	25	0
Military	50	100	0	100	0	0	0
Regulatory	50	50	0	100	0	0	0
Hospitals	50	89	0	62	38	0	0
Universities	43	57	0	58	17	25	0
Laboratories	38	62	0	62	8	30	0
Utilities	8	92	0	61	0	39	0
Total foreign	64	79	7	59	18	19	4
Total all	38	77	2	62	13	24	1

^aData given as percent of all responses for each type of facility.

^bData given as percent of all TL users for each type of facility.

^cThermoluminescent dosimeter.

^dRadiophotoluminescent dosimeter.

^eIncludes CaSO₄ used in combination with another phosphor such as Li₂B₄O₇.

Table 3. Evaluating agencies and annual gamma dose equivalents at responding facilities

Type of facility	Evaluating agency ^a		Range of annual gamma dose equivalents, mSv ^b		
	In-house	Vendor	<5	<10	<50
Total US	56	44	62	14	24
Military	100	0	100	0	0
Regulatory	0	100	100	0	0
Hospitals	22	78	66	17	17
Universities	43	57	81	5	14
Laboratories	76	24	48	29	24
Utilities	72	28	50	11	39
Total foreign	89	11	64	18	18
Total all	63	37	62	15	23

^aAgency evaluating gamma dosimeters and providing dose equivalent estimates. Data given as percent of all responses for each type of facility.

^bIncludes actual and expected annual gamma dose equivalents. Data given as percent of all responses for each type of facility.

Table 4. Sources and phantoms used for gamma dosimeter calibration at responding facilities

Type of facility	Gamma calibration source ^a				Phantom used for calibration ^a		
	¹³⁷ Cs	⁶⁰ Co	Other ^b	Don't know	No	Yes	Don't know
Total US	63	12	7	18	43	32	25
Military	100	0	0	0	0	100	0
Regulatory	25	25	0	50	0	50	50
Hospitals	39	11	11	39	50	17	33
Universities	57	14	0	29	43	29	28
Laboratories	57	14	10	19	48	29	23
Utilities	81	11	8	0	42	39	19
Total foreign	29	42	29	0	79	21	0
Total all	55	18	12	15	51	29	20

^aData given as percent of all responses for each type of facility.

^bIncludes multiple sources for gamma dosimeter calibration.

Table 5. Types of sources producing occupational neutron exposure at responding facilities.

Type of facility	Source of neutron exposure ^a				
	Isotopic sources	Reactors	Accelerators	Fuel	Other
Total US	80	54	29	18	4
Total foreign	92	60	48	32	4
Total all	87	58	33	21	4

^aData given as percent of all responses for each type of facility.

Table 6. Types of personnel neutron dosimeters used at responding facilities

Type of facility	Personnel neutron dosimeter type ^a						
	TLD-albedo	Film	R.Track ^b	Combination ^c	TLD	F.Track ^d	Other ^e
Total US	36	18	15	16	7	0	8
Military	100	0	0	0	0	0	0
Regulatory	50	0	50	0	0	0	0
Hospitals	5	50	11	34	0	0	0
Universities	20	20	25	30	5	0	0
Laboratories	50	30	12	8	0	0	0
Utilities	50	3	7	10	10	0	20
Total foreign	21	47	11	5	3	8	5
Total all	35	21	14	14	6	3	7

^aData given as percent of all responses for each type of facility.

^bRecoil track (mostly CR-39).

^cCombination TLD albedo-recoil track systems.

^dFission track (Th-232 radiator).

^eIncludes stay time times dose equivalent rate and special in-house systems.

Table 7. Evaluating agencies and annual neutron dose equivalents at responding facilities

Type of facility	Evaluating agency ^a		Range of annual neutron dose equivalents, mSv ^b			
	In-house	Vendor	<1	<5	<10	<50
Total US	56	44	67	21	6	6
Military	109	0	100	0	0	0
Regulatory	0	100	100	0	0	0
Hospitals	22	78	67	33	0	0
Universities	45	55	85	15	0	0
Laboratories	66	34	52	36	6	6
Utilities	64	36	67	21	6	6
Total foreign	92	8	76	16	4	4
Total all	65	35	69	21	5	5

^aAgency evaluating neutron dosimeter and providing dose equivalent estimates. Data given as percent of all responses for each type of facility.

^bIncludes actual and expected annual neutron dose equivalents. Data given as percent of all responses for each type of facility.

Table 8. Sources and phantoms used for neutron dosimeter calibration at responding facilities

Type of facility	Neutron calibration source ^a				Phantom used for calibration ^a			
	Unmoderated ^b	Cf-D ₂ O	Other ^c	Don't know	Lucite ^d	Other ^e	None	Don't know
Total US	36	20	14	30	30	27	13	30
Military	0	0	100	0	100	0	0	0
Regulatory	0	0	50	50	50	0	0	50
Hospitals	66	0	0	34	33	0	0	67
Universities	70	0	0	30	5	30	40	25
Laboratories	18	6	54	22	34	40	0	26
Utilities	24	44	6	26	50	24	4	22
Total foreign	32	8	52	8	12	40	24	24
Total all	35	18	25	22	28	28	14	30

^aData given as percent of all responses for each type of facility.

^bIncludes PuFe, AmBe, and unmoderated Cf.

^cReactors, accelerators, or several sources.

^dPolymethylmethacrylate slab of dimensions 40x40x15 cm.

^ePolyethylene bottle, bomb phantom, etc.

Table 9. Knowledge of incident neutron spectra and neutron dosimeter response corrections at responding facilities

Type of facility	Knowledge of neutron spectrum ^a			Corrections to neutron dosimeter response ^a		
	Measurements ^b	Calculations	None	Measurements ^c	Other ^d	None
Total US	79	28	18	21	25	54
Military	50	50	0	100	0	0
Regulatory	50	0	50	0	0	100
Hospitals	89	66	11	0	33	67
Universities	75	45	15	0	14	86
Laboratories	48	36	36	25	36	39
Utilities	88	7	10	36	28	36
Total foreign	64	44	16	12	48	40
Total all	76	34	17	19	30	51

^aData given as percent of all responses for each type of facility.

^bIncludes multispheres and other types of spectrometers.

^cIntegral detector response measurements such as 9-to-3 inch sphere ratios and bare BF₃-to-3 inch ratios.

^dCalibration factors based on differential energy spectra, calculated corrections, etc.

Table 10. Conventions used to report neutron dose equivalents at responding facilities

Type of facility	Neutron dose equivalent convention ^a				
	ICRP ^b	NCRP ^c	Element 57 ^d	Other	Don't know
Total US	25	12	12	10	41
Military	50	50	0	0	0
Regulatory	0	25	0	25	50
Hospitals	33	0	0	0	67
Universities	30	15	0	0	55
Laboratories	18	12	30	15	25
Utilities	22	14	18	14	32
Total foreign	68	4	8	8	12
Total all	36	11	12	9	32

^aData given as percent of all responses for each type of facility.

^bConvention given in ICRP publication 21.

^cConvention given in NCRP publication 38.

^dDose equivalent in volume element 57 of the cylindrical Snyder-Auxier phantom.

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