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Preliminary Results of the 1975 International Personnel Monitoring Survey

Klaus Becker

OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

About 70 detailed questions have been answered in mid-1975 by 83 personnel monitoring services in 33 countries, representing almost half a million, or ∿28%, of the world's total radiation workers, as well as by 11 customers of U.S. commercial services. Extensive data are given on many questions regarding the current system in use, future plans, and experiences, for example on the type(s) of TLD, film and readout instrumentation; monitoring period; applications for extremity and environmental monitoring; advantages and disadvantages of various systems; R&D projects; experience with beta and neutron dosimetry; intentional "fake" exposures; lower and upper dose limits; recordkeeping; and reporting of the results. Some of the more important results are:

1. The larger services in the advanced countries lead in the transition from film to TLD. More than half of the radiation workers already wear TLDs, or will do so within about two years.
2. Important unsolved problems are fast neutron monitoring and the low information content and high initial cost of TLD.
3. The trend is towards large, centralized, automatic services and recordkeeping, with extensive computer use for evaluation and data handling.
4. There is a need for better performance standards and testing, and more information exchange and cooperation between services.

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1. Introduction

Health physicists in charge of personnel monitoring (P.M.) services, researchers, and administrators in this field have, like those in other areas of specialization, always been interested in the philosophies, techniques, experiences and future plans of their colleagues in other institutions and other countries. They have tried to communicate through correspondence, topical meetings, etc., and there is no lack of "this-is-the-way-we-do-it" descriptions of procedures, or statistical reports of P.M. results of various services in the literature. There are, however, numerous new or small services, in particular in less developed countries, who are not part of this "invisible college" of communication, and even some colleagues in large institutions often have only a rather superficial picture of the current situation and development trends. Clearly, a more comprehensive analysis was needed of who is doing what, where, and why, and what his experiences and plans for the future are.

As far as could be determined, none of the relevant international organizations such as International Atomic Energy Agency, World Health Organization, or Nuclear Energy Agency has yet undertaken such a survey on a world-wide scale, or plans to do so in the near future. Apparently, not even up-to-date lists of P.M. services are available. The first, and so far only, attempt to survey the situation in P.M. was made early in 1971 by F. H. Attix within the framework of a symposium on the Future of Personnel Monitoring, organized by the author during the 1971 Health Physics Society Meeting in New York (Becker, 1972). The results involving 105 returned questionnaires (58 from the USA, 47 from 26 other countries) have been published (Attix 1972) and widely quoted.

Early in 1975, it was felt that another survey would be desirable, primarily because

1. the sampling of the first survey, which was based on a research interest in thermoluminescence dosimetry (TLD), may have introduced a pro-TLD bias into the results;
2. during the past ∿4.5 y, the philosophy, scope, and size of many P.M. services underwent substantial changes, and several new services started operations;
3. the Attix-survey was essentially limited to an assessment of the role of TLD in P.M., while this current survey covers a much wider range of questions; and, perhaps most importantly,
4. a large percentage of the institutions involved in the 1971 survey did not actually provide a P.M. service, but were users of other commercial or government services, thus causing an overlap in the answers provided by services and users.

Consequently, a direct comparison of this survey with the 1971 one is only possible to a very limited extent.

The original mailing list provided by F. H. Attix was carefully revised. More than half of the addresses were replaced by new ones in an attempt to cover every institution known to the author which operates a genuine P.M. service. Friends in various countries provided valuable aid in this first, difficult phase of the project, and helped to establish new contacts. Efforts have also been made to get responses from the services in developing countries and Eastern Europe, unfortunately with limited success.

The six-page questionnaire was developed in discussions with several colleagues and dealt in detail (almost 70 questions and sub-questions) with the ten subject categories identification; type of service provided; techniques of monitoring; evaluation and record-keeping; other applications of the system; problem and development areas; intercomparisons; experiences; legal aspects; and miscellaneous. The same form was used for all services which implied questions irrelevant for some services. Most questions, however, were considered relevant and answered by most of the participants.

Some changes are anticipated if the survey is to be repeated, as desired by a majority of participants, in about 3-5 years. In particular, the forms will be made shorter by omission of a number of less important questions, mainly on experiences and legal aspects; a few new questions (e.g. on costs/prices; mail loss; calibration procedures; required government approval for the operation of the service; staff requirement per 1000 annual readings; damage rates; filter for penetrating radiation measurement; etc.) may be added; and more use will be made of multiple-choice answers in order to permit partial replacement of the present time-consuming hand evaluation of the about 5000 largely verbal answers by computer evaluation.

About 180 forms were air-mailed with an explanatory cover letter during May, 1975. To most addresses on the original mailing list who had not responded by mid-July, a reminder was sent. By August 26, the cut-off date for this report, filled-out forms were received from 94 institutions in 33 countries. A large percentage of the U.S. participants expressed a desire for confidentiality of the data. Many results of the survey, therefore, had to be presented in such a way that identification of the service providing the answers was impossible.

This report, whose circulation is essentially restricted to the participants, should be considered preliminary because:

1. the efforts to collect additional information continue, and forms from several more countries such as Iran, Israel, Mexico, and Spain are expected to be returned and included into a final version (all readers are encouraged to supply the addresses of additional services in their country or region!);
2. the participants should be given an opportunity to comment on this report and point out possible errors or deficiencies before a condensed version can be published in the open literature; and
3. it may be possible to extract additional valuable information from the returned questionnaires which is not yet included in this report.

2. Participants

Of the 92 forms received so far, 83 turned out to be from actual P.M. services as listed in Table 1 (U. S. services) and Table 2 (international services). The remaining 11 (Table 3) were U.S. users of commercial services. Their answers were of interest in some instances because the user's point of view may differ from that of the supplier. It is indicated in the results whenever these responses are included in the total numbers or percentages. A few hybrid institutions with partly in-house, partly out-house service have been classified according to which part appeared to be dominating.

The *organizational structure* of the P.M. services differs basically between the U.S. and the rest of the world. In the U.S., the services with a few exceptions, are either purely commercial or belong to semiprivate contractors of government agencies, mostly ERDA. In most other countries, the services are more or less directly operated by government institutions. Frequently, there are separate services for radiation workers in the nuclear field under the supervision of the atomic energy authorities and for the medical radiation workers with the ministry of public health, or national environmental protection agencies in charge. No data are included on the large area of strictly military "radiation workers", under the jurisdiction of the defense authorities, such as the $\gtrsim 10^5$ persons associated with the nuclear navy in the U.S.

The *number of users* of the surveyed services varied between less than 100 and 60000 (in one large commercial U. S. service which did not supply this information it may exceed 10^5). If they are classified according to their size, about 21% are large (>10,000 users); 30% medium 3000-10000 users); 24% small (1000-3000 users); and 25% very small (<1000). The average user number is about 6600. The P.M. services included in this survey can be estimated to monitor about 400,000 persons.

With an estimated total of about two million *radiation workers in the world* (Becker, to be published) of which only 60-80% may be monitored, it can be estimated that the survey includes ~30% of the world's total regularly monitored persons. Although certainly not comprehensive, largely due to the lack of information from most socialist and some large Third World countries, the sample size seems certainly large enough to be representative. If there is a slight bias, it may be towards the more industrialized Western countries which have been usually trend-setting in this field. Consequently, the results are not likely to be "wrong", but perhaps slightly ahead of time if seen on a global scale.

3. Choice of System(s)

The relative merits of the photographic film and TLD and their future roles in P.M. have been the subject of much discussion in recent years.* Of those 32 services and users who answered the question "If you have experience with both film and TLD, which would you consider the most important *advantage of the film?*", the most frequent answers (multiple answers permitted) were

1.	Permanent record, re-evaluation	62%
2.	Radiation Energy analysis	42%
3.	"Image" having high additional information content (detection of contamination, deliberate exposures, etc.)	32%
4.	Low costs	10%

Also mentioned in a few responses was the possible fast screening of large numbers, insensitivity to dirt, simplicity, and commercial availability as a one-way packet.

The main disadvantages of film were ranked by the same group as follows:

1.	Sensitivity to other agents and disturbing environmental factors	30%
2.	Poor stability (fading, fogging)	28%
3.	Poor accuracy, in particular in mixed fields and for low-energy X-rays	24%
4.	Time-consuming, complicated darkroom-processing	24%
5.	Poor sensitivity	10%

*For a recent review, see Becker 1973.

Also listed in several answers were limited dynamic range, pronounced energy response, lack of response to intermediate energy neutrons, and difficulties in automating the evaluation.

As chief *advantages of TLD* the following were listed most frequently:

1.	Easier, faster evaluation which can easily be automated	52%
2.	Essentially tissue-equivalent energy response	27%
3.	Higher sensitivity	18%
4.	Higher accuracy	15%
5.	Smaller size	15%
6.	Re-usability	15%

Also listed by 10% each were higher fading stability and physical robustness, generally higher reliability, and flexibility in special applications such as extremity monitoring.

As the primary *disadvantages of TLD* were listed

1.	Information destroyed by read-out, no permanent record	28%
2.	Low information content (no energy analysis, contamination detection, etc.)	25%
3.	Higher cost	19%
4.	Spurious reading due to dust, UV light, etc.	16%

Also listed in several responses were non-uniformity of the commercially available TLD chips, difficulties in fast screening of large detector numbers, poor reliability, and mechanical damage.

More to the point was another question which was answered by 61 services: "If more than one dosimeter type is used, e.g. film and TLD, which would you consider the *more reliable* one? Accomplished or imminent full conversion from film to TLD was considered a vote for TLD. More than half (53%) named TLD as more reliable; only one quarter (24%) film; 3% radiophotoluminescent glass; and 20% made qualifying statements such as "depends" or "about equal". There was no obvious difference in the response pattern if U.S. and other countries, large and small services, or developed and developing countries were compared.

This pro-TLD vote is adequately reflected in the actual numbers in the U.S. Of the services which provided user numbers, more than half (64,900 out of 114,400, or 57%) already use TLD exclusively and intend to continue to do so; another 15% presently use film, frequently supplemented by TLD, primarily for extremity (finger, hand) monitoring, but plan to switch soon to the exclusive use of TLD; only 20% use only film and have no plans for change, and the rest did not indicate future plans. This picture would change somewhat towards film if one would add a commercial service with an unknown number of users (Landauer), but it might also change into the pro-TLD direction if one adds the large number of TLDs with which the U.S. Navy is presently being supplied.

Internationally, the picture is similar. 56% of the services having 67% of the users presently employ film, frequently supplemented by some TLD, but plan to switch completely, or to a large extent to TLD within the next few years; only two services, each representing a total of 2.5% of the users, already switched completely to glass and TLD; 23% of the services (25% of the users) are presently working with film and TLD, also mostly for extremity monitoring, with no plans for change in the near future; and 12% of services with 5% of the users (which implies mostly smaller services) use presently only film, and plan to use it exclusively in the future.

Some of the more important international services in which the switch from film to solid-state detectors has already been carried out or is imminent, are the following:

1. Atomic Energy of Canada Ltd., Chalk River, recently implemented a self-developed, sophisticated fully automatic TLD system for 3000 persons;
2. Radiation Protection Bureau, Ontario, Canada, will switch to a modified version of the Chalk River system for ∿35,000 persons within a few months;
3. Czechoslovakian National Personnel Dosimetry Laboratory will supply, in 1976, about 5000 persons with a self-developed glass-TLD system;
4. Danish AEC, Risö, replaced film completely with a self-developed, sophisticated TLD system based on $Li_2B_4O_7$:Mn,Si sintered pellets for its 1200 employees;
5. French CEA will change within 2 y from film to self-developed LiF:Mg,Na for a substantial part of a large (30,000 persons) service;
6. Two West German laboratories, GFK Karlsruhe and GKSS Geesthacht, have used radiophotoluminescent glasses exclusively for ∿4300 persons for several years with satisfactory results;
7. Division of Radiological Protection, BARC, Bombay/India, will switch for about 8000 users to a self-developed, semi-automatic TLD system ($CaSO_4$:Dy in Teflon) within 1 y;
8. TNO Arnheim, Netherland, will switch a large service (11,500 users) fully to self-developed automatic TLD system;

9. AB Atomenergi, Nyköping, Sweden, plans to introduce the Risö system for its 5,000 employees within a few months;

10. CERN, Geneva/Switzerland, will employ a multifilter TLD system for 3,400 people;

11. Radiation Protection Section, Swiss Federal Health Office, plans to use exclusively a commercial TLD system (LiF-Teflon) for ∿13,000 people within 2 y;

12. Spanish authorities recently purchased 18 fully automatic commercial TLD systems (LiF-Teflon) for exclusive use in this country;

13. E.I.R. Würenlingen, Switzerland, will abandon film completely next year and employ a commercial TLD system (LiF chips) for ∿3000 people;

14. National Radiological Protection Board in the United Kingdom will switch part of a large national system to LiF-Teflon within 1-2 y. This step can be expected to have an impact also on a number of other countries presently using the British film badge.

In the U.S., some of the more important examples are:

1. Argonne National Laboratory will use TLD to a large extent within 2 y;

2. Battelle Northwest, Hanford, has been using a self-developed TLD system exclusively for several years;

3. Eberline, a large commercial service, will start a TLD albedo system for neutron dosimetry soon;

4. Lawrence Livermore Laboratory is using exclusively a self-developed automatic TLD system for 6600 employees and 24,000 visitors each year;

5. Los Alamos Scientific Laboratory will use exclusively an expensive ($>10^5\$$) system employing four LiF:Mg,Ti chips (including albedo capability) within 2 y;
6. National Reactor Testing Station, Idaho Falls, has been using a commercial (LiF:Mg,Ti chips) system for some time for its 6,000 employees;
7. Naval Research Laboratory will switch to TLD (a commercial automatic system) exclusively within a few months;
8. Naval Shipyards are beginning to use a specially developed system based on CaF_2:Mn in glass bulbs on a very large scale;
9. Oak Ridge National Laboratory started early in 1975 a new system in which the routine monitoring is carried out with a manual commercial TLD system, but films remain in the badge as a back-up system to be read in cases of special interest only;
10. Rockwell International is using a commercial TLD system for 3,000 employees; and
11. Teledyne/Isotopes, a large (15,000 users) commercial service uses its own automatic TLD system.

4. <u>Information Concerning the Current System</u>

In addition to the questions already discussed above, there are several points dealing more specifically with the current system. The *time between evaluations*, for example, varies between one week and one year. One month (or four weeks) is by far (63% of all services) the most common; 15% of the services issue dosimeters for different time intervals depending on the type of radiation workers involved, a large percentage of these dosimeters are also worn for one month; 14% have longer monitoring periods, mostly between 1.5 and 3 months; and only 8%

use periods of years.

When asked the question "Based on your experiences, which *organizational arrangements* would you favor for personnel monitoring services?", two-thirds (66%) of the 62 services and users who answered this question prefer highly centralized services and recordkeeping; 18% prefer a decentralized system for the services, but centralized recordkeeping, and 16% decentralized services and recordkeeping. Another question "Is a *computer program* used in your data analysis, or for recordkeeping?" was answered by 78 services and users. Of those, 62% answered "yes", and 38% "no". Somewhat unexpectedly, some of the smaller services employ computers in their data handling, while some rather big ones do not.

Asked in which units they *report the results* to the users, by far the most (84% of all services) said that they report in rem or mrem, 11% in R or in mR, and 5% in rad or mrad. Some film-badge services also provide additional information on effective energy, contamination, suspected intentional exposure, etc., either routinely or only in cases of special interest such as high exposures.

Fifty services responded to a question concerning the *type of TLD reader* which they use. The Harshaw 2000 system was mentioned most frequently (36%), followed by one or the other of the Teledyne/Isotopes readers (25%). Self-developed, mostly fully or semi-automatic readers were used by 18%, Victoreen instruments by 9%, Eberline by 7%, and MBLE, Pitman, etc. by the remaining 5%. Several services employed more than one reader from different sources. With regard to the *TLD phosphors*, 25 out of 48 services (52%) which answered this question use the Harshaw LiF chips; 25% the Teledyne/Isotopes Teflon compounds; 10% various self-developed systems based on BeO, Al_2O_3, $CaSO_4$:Dy in Teflon, sintered $Li_2B_4O_7$:Mn, sintered LiF, etc.; and 13% miscellaneous other commercial or unspecified systems.

In the field of *conventional films* for X-and gamma radiation, the various products of Kodak in the U.S., Great Britain and France clearly dominate the scene. Of 56 services specifying the films they are using, 48 (86%) named Kodak RM2, PM3, or the French Kodak-Pathé material; 9% used Agfa-Gevaert products; and one each ORWO (East Germany), Fuji (Japan), and Minimax. Kodak NTA film is used in 32 (94%) of the 36 services which provide fast neutron monitoring. Two others use the Ilford K1 emulsion, and two track etching detectors.

Many different types of *densitometers* are in use for the film readings. The three most frequently named are the various types of Macbeth (28% of the 53 answers), Baldwin (19%), and Photovolt (9%), all of them manual. Other manual readers in use include those made by Welch, Electronic Systems, U. S. Testing, Astronix, Defa, Photolog, Universal, van Briesen, Digitalog, and Nuclear Enterprises. Only 19% of all services employ fully or semi-automatic systems, mostly (11%) self-developed ones.

Although other answers indicate that most film badge services are aware of the problems of fading, only three indicated that they routinely seal their films into an additional *protective cover*. Another 12 services sometimes seal films to be used under severe climatic conditions and/or nuclear track emulsions into plastic-metal foil compounds.

The *design of the film badge* varies widely. In many cases such as some developing countries or some commercial services, they are very simple with one or two metal filters only. Others such as the Los Alamos one employ extremely complex multi-element filters. A few examples are listed in Table 4. Frequently, several services use the same badge.

One of the most successful is the British AERE/NRPB badge, which is being used, for example, in Australia, Hong Kong, New Zealand, Norway, Netherlands, South Africa, and Sweden, as well as in various institutions in Switzerland (E.I.R.) and Belgium (University of Liége).

All services which are using, or have used, film extensively in the past were asked "If "permanently" recording detectors are used, are they actually kept after readout as an exposure record, and if so, for how long?" Of the 54 services which answered, apparently all stored the processed films for a variable period of time. Short *storage* (5 y or less) was reported by 26%, long-term but limited storage (6 to 30 y) by 43% of all services, and very long storage (typical answers: "indefinitely", "permanently", "semi-permanent", "30 y after leaving company") by 31%. Several services however, are beginning to have some doubts about the wisdom of keeping films for very long periods. One typical answer in this category was "We consider to throw them away".

Of the 70 services which answered the question "Do you regularly *test the performance* of your system under conditions which approximate those encountered during its actual use?", only 80% answered with "yes", which implies that one out of five services does not do such basic performance testing. Only two out of three (67%) of the services ever participated in national or international performance tests, and 78% expressed an interest in participating in planned tests of this nature at ORNL.

Services and users were asked if they also use their P.M. system to any extent for *other applications*. *Extremity monitoring* was so widespread that it can be considered almost a standard part of a modern P.M. service. It was named by 90% of the responding services. According to this survey, at least 30,000 people, or 7.7% of all monitored persons, are supplied with hand/finger detectors. The second most frequent additional application is *environmental monitoring* (68). Based on the interest expressed in the survey, it can be expected that about 90-100 participants from over 20 countries will participate in our next international intercomparison for environmental dosimeters scheduled for early in 1976, as compared to 41 laboratories from 11 countries in the 1974 study (Gesell, Burke and Becker 1975). Research and development work was named by half (49%), medical dosimetry by only 21%. Other applications named by one to three services each are the calibration or intercomparison of radiation sources; screening of diagnostic X-ray equipment or of TV sets; beam monitoring at accelerators or reactors; X-ray diffraction work; and underwater P.M.

5. Experiences

The possibility has been considered to weight the answers in this category according, for example, to the size of a service. However, as health physics expertize is not closely correlated with size, only the answers from a few very small services were not considered. For example, there has been much disagreement about the lower and upper *limits of reasonably precise dose measurements*. Therefore, the question was asked: "What are the lowest and the highest gamma radiation doses, or exposures which you feel you can report with an accuracy of about ± 30%?" Only the answers of the services are reported here, assuming that they know their system better than the users. It should be noted, however, that the opinions of service and user do not always agree. A big commercial U.S. service gives, for example, 25 mR as the lower limit, but one of its larger users reports 10 mR!

For the 53 film services which answered, the estimates for the *lowest measurable dose* varied between 5 and 150 mrem. One quarter (25%) felt they could measure doses of 5-10 mrem; 34% 15-40 mrem; 39% 50-100 mrem; and 2% more than 100 mrem. The world-wide average was 40 mrem, with no significant differences between services, countries, and film types. For the 14 TLD services, the estimates varied between 5 and 100 mrem, with an average of 22 mrem, which is clearly below that of film. For the *upper limit*, the estimates of the film services varied between 1 and 1500 rem, with 16% in the < 10 rem category; 22% between 10 and 100 rem; 49% between 110 and 1000 rem, and 13% above 1000 rem. The guesses for the upper limits of the TLD systems were between 5 and 10^6 rem, but usually in the 1000-2000 rem range.

Nevertheless, most services and users expressed substantial confidence in the reliability of their results. When asked, "Do you feel that the overall accuracy and reliability of your dosimeters and evaluation procedures justifies *administrative or legal action* against individuals or organizations if certain limits are exceeded?", 50 out of 67 answers (75%) were an unqualified "yes", only 10% a simple "No", and 15% expressed qualified opinions between, of which a few examples are given as follows: "This is a loaded question"; "administrative action yes, legal action no"; "must determine if individual, not only badge, was exposed"; "accuracy and reliability are technical questions which are not understood by lawyers"; and "yes, provided accuracy limits are recognized".

Most frequently, the feeling was expressed that the dosimeter is only one of many factors to be considered in determining a personnel exposure, and has to be supplemented by additional measurements, an inquiry, or investigation. This feeling was also expressed in the answer to a question whether the reading of the P.M. device was ever found important for medical, legal, or public relations reasons. About half answered "yes", the other half "no", frequently with qualifying statements.

Seventy-two services and users answered the question "Do you feel that in your country the *efforts in personnel radiation protection* are adequate, insufficient, or excessive compared with protection against other risks?" Two-thirds (65%) answered "adequate"; 21% (mostly in developing countries such as Colombia, Ecuador, Hong Kong, Chile, and Bangladesh) "insufficient"; and 14% "excessive".

The question "Would you consider the monitoring of *beta radiation* from radioisotopes an important part of your monitoring program?" was answered by most services, in the majority of cases (58%) with "yes", but frequently stating that it is usually only a small percentage of their users for which it is quite important; 30% replied "no", and 12% attached only "minor", "rare", or "small" importance to beta monitoring. Of seventy services and users who answered the question "Would you consider the *speed* with which dosimeters can be read an important factor?" 63% gave an unqualified "yes", 20% an unqualified "no", and 17% felt that sometimes, for example in accidents or emergencies, it was an important factor.

When asked in their opinion, how important is the information to be gained from the dosimeter on *additional exposure parameters*, 77% of 52 services and users considered the determination of the *effective radiation energy* important, and 23% unimportant or of minor importance.

Next in importance is the detection of *contamination.* Of 40 services, 95% considered this an important, only 5% a less important feature. Of 35 answers, 60% considered the determination of the *angle of incidence* important, 40% not, and 16 thought it would be desirable to obtain additional information on the time, or time distribution of exposure. A frequent comment to these questions was "important only for the investigation of high exposures, or in other special situations". Not surprisingly, essentially all the services considering the additional information important were using primarily film, while most of the TLD services put much less weight on such data.

There was also a question about the reliability of higher dose readings: "How frequently are, in your experience, substantial dosimeter readings ($\gtrsim$ 1 rem) in fact due to *intentional* exposures, or to *malfunctions* in the dosimeter or errors in the readout procedure?" The answers were, as expected, difficult to quantify, and included many statements such as "don't know", "not the faintest idea", "frequently", and "sometimes". Regarding the occurrence of intentional ("fake") badge exposures, the spectrum reached from "none" to "100%". About one-third felt that a large fraction (>50%) of all high readings were intentional; another third that the rate is in the 1-50% range; and the remaining third that faked exposures are "rare", "seldom", "a few cases every year", "infrequent", or even "never". Understandibly, the occurrence of simulated exposures increases whenever special benefits such as longer vacations or higher pay might be gained.

The estimates for high apparent dosimeter readings being actually due to a malfunction of dosimeter and/or evaluation process range from "never" to 10%. Never, or almost never, are claimed by 26% of the services; rarely, infrequently, seldom, or sometimes, it happens in another 26%, and fairly frequently, around one percent and more, in almost half of all services.

Multiple answers were permitted for the question "If you feel that it would be desirable to improve your present system(s), which aspects would you consider most important?" Of 68 answers received, *improved methods* for measuring fast neutrons received the highest priority (68%), followed by higher precision and reliability (57%), and reduced cost (25%). There was relative little concern for increased sensitivity (18%), which is apparently considered satisfactory by most services and users. The high priority of fast neutron monitoring is also reflected in the 42 answers to the following questions: "If you do *research and development* work, what are your primary objectives?" In 36% of all cases, improvement of fast neutron measurements, replacement of the NTA film by track etching detectors, development of albedo systems, etc. were named.

With 26%, improvement of the overall system accuracy, reliability, and data handling capacity was second. New or improved TLD phosphors were named by 14%; improved beta dosimetry and environmental monitoring by 7% each; and development of TLD holders for extremity monitoring and work on better calibration and standardization techniques by 5% each. Also listed as goals were cost reduction, radon daughter dosimetry, and (by one service) reduction of the film fading. Generally, the film seems to be considered--probably correctly so--exhausted as a topic for research and development, and the main emphasis is clearly on TLD.

From the results of this survey, it can be estimated that about 15% of all monitored persons are also supplied with a neutron detector, which is still in most cases an NTA film and/or a "thermal neutron film dosimeter" based on the (n,γ) reaction in cadmium. The results of this big effort have been very disappointing, partly due to the absence of thermal neutrons, which very rarely contribute significantly to the total personnel exposure, and partly due to the well-known severe limitations in the reliability of the NTA film.

Of the 40 services with *thermal neutron* capability, the question "How frequently have you detected a significant percentage of a person's total exposure to be thermal neutrons?" was answered in 20% of the cases with "never"; and 80% made statements such as "very rarely", "insignificant", "very infrequently", "extremely rare", "hardly ever", "minimal", "very seldom", "once every 5 years", "known to be negligible", etc. Obviously, the results of thermal neutron monitoring do not justify the efforts.

The same question for *fast neutrons* was answered by 38 services. Fast neutrons have never been detected by 27%; "very rarely", "negligible", "minimal", "insignificant", "∿0.005%", "extremely rare", etc., in 49% of the services; and "occassionally", "quite a few", "frequently", etc., by 24%. One service, Los Alamos, reports "up to 10%". This service also reports a substantial contribution of intermediate neutrons (∿10%), which are not detectable in practically all other existing systems. At Brookhaven National Laboratory, about 1.5% of all radiation workers with total penetrating radiation exposures above 1 rem, receive more than 20% of their total exposure from fast neutrons.

6. General Comments and Conclusions

The reader will probably draw his own conclusions from the data and will be delighted if they confirm his opinions or experiences. As many of the additional comments which were received, and which added valuable information to the picture, could not be discussed in the text, it may be useful to add a few more general comments to those already made above.

1. If one estimates the total number of radiation workers in the world to be currently slightly above two million (Becker, to be published) and the average number of users to be $\sim$6600 for each P.M. service, it can be guessed that there are about 300 P.M. services in the world today, of which $\sim$28% participated in this study.
2. Most of the health physicists involved welcomed this survey, and would like to see it repeated in about four years. They also would be interested in a more intense exchange of information through other channels such as relevant articles in the Health Physics Journal, and topical international meetings.
3. TLD replaces the film dosimeter slowly but surely, with the larger services in the advanced countries leading in the transition. The majority of services consider TLD more reliable than film. A shrinking number of "hard-core" supporters of the film, however, continues to emphasize its chief merits, which are its document-character and high information content, in comparison with the easy automatibility and tissue-equivalence of TLD. Although it has been shown in installations such as Lawrence Livermore Laboratory and GFK Karlsruhe that the operation of a solid-state dosimetry service can be made less costly than a service based on film because of re-usability of the detectors and longer monitoring periods, the higher

initial price of TLD remains an important factor for many institutions. TLD is already firmly established in several special applications such as extremity monitoring and environmental dosimetry.

4. The adequate dosimetry of fast neutrons remains one of the central unsolved problems in P.M., and the replacement of the NTA film by a better device occupies a central role in the research and development efforts. Monitoring of thermal neutrons, on the other hand, should be abolished and there appears to be no strong desire to increase detector sensitivity.
5. Two-thirds of all services are in favor of central P.M. services and central recordkeeping, another sixth prefer decentralized services and central recordkeeping. The trend towards centralization, automatization, and the use of computers for evaluation and recordkeeping is obvious.
6. The need for higher performance standards and more frequent, more realistic performance tests and/or intercalibrations is now widely recognized.

Acknowledgments

Obviously, this study would have been impossible without the help of about one hundred colleagues in 33 countries who cooperated in the survey, frequently supplying valuable additional information in explanatory letters, added statistical compilations, etc. Several colleagues including F. H. Attix, M. Ehrlich, G. Hanson, and J. Mehl made contributions to the questionnaire, or address lists. Their assistance is appreciated.

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Table I. Compilation of Participating Services (excluding USA)

Country	Institution	Address	Person in Charge	Approx. Users	Monitor Period (months)
Australia	Australian AEC Res. Establ.	Southerland, N.S. Wales	J.C.E. Button	950	1
	State X-Ray Lab.	Shenton Park, W. Austr.	B. E. King	2,500	1-3
	Div. Occup. Health Rad. Control	Lidcombe, NSW.	E. Cardew	3,800	2
Bangladesh	AEC Health Physics Div.	Ramna, Dacca	R. Molla	400	2-3
Belgium	Cath. Univ. Radiat. Protect. Serv.	Louvain-la-Neuve	R. Gillet	800	0.75
	Zentralbüro Kernmess.	Geel	E.M.M. de Ras	100	1
	Univ. Radiat. Contr. Serv.	Liége	J. L. Garson	2,000	0.5
	SCK/CEN	Mol	L. Ghoos	5,200	0.5
Brazil	Inst. Rad. Protect. Dosimetry	Rio de Janeiro	J. L. B. Leao	3,000	1
Canada	Atomic En. of Canada	Chalk River, Ont.	A. R. Jones	3,000	0.5
	Radiat. Protect. Bureau	Ottawa, Ont.	D. Grogan	60,000	0.5-2
	Ontario Hyro	Toronto, Ont.	M. C. Walsh	4,000	0.5
Chile	Inst. Hig. Trabajo	Santiago	F. Vega	1,300	1
China, Rep.	Inst. Nucl. Res.	Lung-Tang	Y. Y. Chou	600	1
	Nat. Tsing-Hua Univ.	Hsinchu	P. S. Weng	3,500	1
Colombia	Inst. Nat. de Salud	Bogota	A. Santana	1,200	1
Costa Rica	Nat. Radiat. Protect. Serv.	San José	J. F. C. Solera	1,500	1
Czechoslovakia	Nat. Pers. Dosimetry Lab	Prague	J. Trousil	12,000	1-2
Denmark	AEC Res. Establishm.	Risö, Roskilde	P. Christensen	1,200	1-3
	State Inst. Rad. Hygiene	Copenhagen	B. Vig	6,000	1
Ecuador	Nat. Inst. Hygiene	Guayaqual	F. P. Gil	500	1

Table I. Compilation of Participating Services (excluding USA) (cont.)

Country	Institution	Address	Person in Charge	Approx. Users	Monitor Period (months)
Egypt	Nuc. Res. Centre	Cairo	M. A. Gomaa	1,000	1-3
Finland	Inst. Radiat. Protect.	Helsinki	M. J. Toivonen	7,500	3
France	CEA/STEPPA	Fontenay-aux Roses	G. Portal	30,000	1
Germany, Fed. Rep.	Ges. Strahlenforsch.	Neuherberg	F. Wachsmann	30,000	1
	Ges. Kernforsch.	Karlsruhe	E. Piesch	4,000	1-6
	Landesanst. Asbeitsschuk	Karlsruhe	Schelikes	18,000	1
	Staatl. Nat. prief. amt.	Dortmund	Ritzenhoff	45,000	1
	GKSS	Geesthacht	Krupke	260	1
	DESY	Hamburg	Tesch	650	1
Hong Kong	M.&.H.D. Inst. Raclid.	Kowloon	G. Mauldon	1,000	0.5
India	Div. Radiolog. Protect, BARC	Bombay 85	K. G. Vohra	16,000	0.5
Italy	Lab. Fis. Saint., CNEN	Bologuo	G. Busuoli	6,000	1.5-3
	CESNEF, Politecizico	Milano	S. Kaffal	4,000	1
	Nat. Concer Inst., Health Physics	Milano	A. Sichirollo	15,000	1
Japan	JHERI	Tokai-mura, Ibarakiken	T. Nishi	1,800	3
Korea, Rep.	KAERI	Seoul	H. D. Lee	250	3
Netherlands	Radiolog. Dienst TNO	Arnhem	H. W. Julius	11,500	0.5-3
New Zealand	Nat. Radiat. Lab.	Christchurch	A. C. McEwan	4,000	1
Norway	Inst. Atom. En.	Kjeller	T. Gravdahl	500	1
	Stat. Inst. Radiat. Hyg.	Osteraas	K. Koren	6,000	1
Philippines	At. En. Com.	Diliman, Quezon	E. Valdezco	1,500	1
Poland	Centr. Lab. Radiat. Protect.	Warsaw	J. Wysopolski	6,000	1

Table I. Compilation of Participating Services (excluding USA) (cont.)

Country	Institution	Address	Person in Charge	Approx. Users	Monitor Period (months)
	Inst. Nucl. Phys.	Krakow	E. Ryba	180	
Saudi Arabia	Direct. Mineral Resources	Jeddah	M. A. Al-Tasan	200	1
South Africa	Nat. Nucl. Res. Centre	Pelindaba, Pretoria	A. Selzer	430	0.5-3
Sweden	AB Atomenergi	Studsvik	C. O. Widell	5,000	1
	Nat. Inst. Radiat. Protect.	Stockholm	J. O. Snihs	8,600	1
Switzerland	CERN	Geneva	J. Dutrannois	3,400	1
	Sekt. Strahlenschuk	Bern	W. Moos	13,000	1
	EIR	Würenlingen	C. Wernli	3,000	3-6
Thailand	Office At. En. for Peace	Bangkhen, Bangkok	S. Ratsvanich	200	3
United Kingdom	Nat. Radiat. Protect. Board	Harwell	H. J. Dunster	35,000	0.5-1
	AERE	Harwell	J. W. Smith	14,500	1
	Central Electric. Gen. Board	Berkeley	M. J. Hill	5,000	1

Table 2. Compilation of Participating U. S. Services

Name, address	Person in Charge
Argonne Nat. Lab., Argonne, Ill.	W. L. Bleiler
Battelle Pac. Northwest, Lab., Richland, Wash.	K. R. Heid
Baylor Univ. Medical Center, Dallas, Texas	H. Barnes
Brookhaven Nat. Lab., Upton, N.Y.	L. F. Phillips
Dep. of the Army, Sacramento Army Depot, Calif.	
Eberline Instr. Co., West Chicago, Ill.	M. Trautman
Eberline Instr. Co., Santa Fe, N.M.	E. L. Geiger
EPA, Las Vegas, Nev.	P. C. Nyberg
Exxon Nuclear Co., Richland, Wash.	M. L. Smith
General Electric Morris Operat., Morris, Ill.	K. J. Eger
Goodyear Atom. Co., Piketon, Ohio	S. H. Hulett
Harvard Univ., Env. Health & Safety, Cambridge, Mass.	R. U. Johnson
Landauer, Glenwood, Ill.	R. V. Wheeler
Lawrence Berkeley Lab., Berkeley, Calif.	L. W. Stephere
Lawrence Livermore Lab., Livermore, Calif.	B. Samardzich
Lexington Blue Grass Army Dep., Lexington, Kentucky	A. E. Abney
Los Alamos Scient. Lab., Los Alamos, N.M.	E. Storm
Monsanto Res. Corp., Miamisburg, Ohio	W. A. Bigler
N. H. Radiat. Contr. Agency, Concord, N.H.	J. R. Stanton
Nurnberger Radiat. Protect., Germantown, Tenn.	C. E. Nurnberger
Rockwell Internat., Golden, Col.	C. R. Lagerquist
St. Francis Hosp., Bleechgrove, Ind.	N. Perry
Teledyne/Isotopes, Westwood, N.J.	Ch. Rau
TVA, Muscle Shoals, Ala.	J. Lobdell
Univ. of Utah, Salt Lake City, Utah	R. C. Pendleton
U.S. ERDA Health Serv. Lab., Idaho Falls, Idaho	J. P. Cusimano
U. S. Naval Res. Lab., Washington, D.C.	R. B. Luersen

Table 3: Compilation of Participating U.S. Users of Commercial Services

Name, address	Person in Charge	Service
Calif. Inst. Techn., Pasadena, Calif.	W. F. Wegst, Jr.	Radiat. Detect. Co.
DHEW-FDA Bureau Rad. Health, Rockville, Md.	C. B. Kincaid	Teledyne/Isotopes
Emory University, Atlanta, Ga.	H. C. Karp	Landauer
Nat. Bureau Standards, Wash., D.C.	T. G. Hibbs	Lexington Army Blue Grass Depot
Nat. Inst. Health, Bethesda, Md.	M. B. Dickinson	Rad. Detect. Comp.
NUS Corp., Rockville, Md.	J. Andrews	Eberline
Temple Univ., Philadelphia, Pa.	R. E. Zelac	Landauer
Univ. of Pennsylvania, Philadelphia, PA	J. W. Thomas	Landauer
Univ. of Pittsburgh, Pittsburgh, PA.	E. D. Durkosh	Landauer
Yale Univ., New Haven, Conn.		Landauer
Yankee Atomic Electric Co., Westboro, Mass.	J. A. MacDonald	Landauer

Table 4. Examples of Filter Combinations in the Badges of Some of the Larger Film Services

Country	Institution	Filter (thickness in mm unless otherwise indicated) #1	#2	#3	#4	#5	#6	#7
Canada	Health & Welfare	0.125 Cu	0.75 Cu	0.5 Pb				
Czechoslovakia	Nat. Pers. Dos. Lab.	150 mg/cm^2 plastic	0.05 Cu	0.5 Cu	1.6 Cu	0.5 Pb	open window	
Finland	Inst. Radiat. Protect.	1 plastic	1 Al	1 Pb/Sn mixt.				
France	CEA Fontenay-aux-Roses	3 plastic	1.5 Al	0.2 Cu	0.6 Cu	0.4 Pb + 1 Sn	0.4 Pb + 0.6 Sn + 0.4 Cd	
Germany (West)	GSF Neuherberg	0.05 Cu	0.3 Cu	1.2 Cu	0.8 Pb	0.12 Al	0.9 Sn	1.0 Cd
India	BARC, Trombay	1 plastic	1 Cu	1 Cd	1 Pb	open		
Italy	CNEN Bologna	0.4 Pb +0.5 Sn	0.5 Pb + 0.8 Cd					
	Serv. Fis. Saint. Milano	0.05 Cu	0.3 Cu	1.2 Cu	0.8 Pb			
Korea	KAERI	0.02 Al	0.05 Cu	0.5 Cu	1.5 Cu	1.0 Cd	1.0 brass	
Poland	Centr. Lab. Radiolog. Protect.	0.05 Cu	0.5 Cu	1.5 Cu	0.6 Sn + 0.3 Pb	0.5 Cd + +0.3 Pb	50 mg/cm^2 plastic	300 mg/cm^2 plastic
Switzerland	Sekt. Strahlenschutz, Bern	plastic	0.05 Cu	0.5 Cu	1.0 Cu			
United Kingdom	CERE/NRPB	50 mg/cm^2 polyprop.	300 mg/cm^2 polyprop.	1 Al	0.7 Sn + 0.3 Pb	0.7 Cd + 0.3 Pb		
United States	Argonne Nat. Lab.	0.48 Al	0.125 Ag.	1 Cd				
	Landauer	0.32 cycolac	1 Al + 0.75 cycolac	1.5 Sn-Pb (40:60)	1.5 Cd-Pb (40:60)	open windows		
	U. S. Army, Lexington	1 Al	1 Cu	0.25 W + 0.75 Cd	open			