KERNFORSCHUNGSZENTRUM

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Abteilung Strahlenschutz und Dekontamination

The Accuracy of Personnel Dosimeter Readings - A Critical Review of Intercomparison Measurements

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- Strahlenmeßdienst -

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Abstract

The paper reviews the results of intercomparison test exposures with film, TLD and RPL dosimeters. To discuss the measuring accuracy attainable today by routine personnel dosimeters the measuring accuracy will be described exactly by the distribution curve of the dose reading deviations related to the actual dose. Instead of the term standard deviation normally used, two different values are ascertained here to compare the results of different test exposures:

- The relative number of exposures found within a dose reading deviation of ± 30 %,
- the dose reading deviation found for 85 % of all test irradiations (15 % outliers).

A careful examination of the results of 12 intercomparison test exposures so far published in the United States, the United Kingdom and Germany demonstrates that the film dosimeter - most frequently used in routine monitoring today - has a unfavourable measuring accuracy. Generally, it was found to be within ± 30 to 50 % in routine evaluation besides the fact that the measuring accuracy may depend on the type of dosimeter, the exposure and evaluation conditions as well as on the qualification of the measuring laboratory.

Above all, new TLD and RPL dosimeters have a measuring accuracy of almost ± 15 % because of their energy and direction independence and their stability against environmental influences.

1) Introduction

For the past 15 years especially the film dosimeter has been one of the most important dosimeters used in routine personnel monitoring. Although the personnel dosimeter is gaining more importance because of administrative regulations, the measuring accuracy of film dosimeters proves in many monitoring applications to be unsatisfactory. This is of no importance in the most cases of routine monitoring when only low exposures are encountered. An accurate dose reading, however, is desirable for persons routinely working in control areas or for unforeseen incidents where major exposures of the individual must be expected.

In view of the importance of routine personnel monitoring, the results of numerous calibration exposures performed in the US, the U.K. and the European EURATOM countries have been published in the past five years. To test and introduce new solid-state dosimeters for routine dosimetry most interesting intercomparison measurements with radiophotoluminescent (RPL) and thermoluminescent (TL) dosimeters have been performed in the past two years. It was tried to compare the results of the test exposures published till now.

In the conservative opinion of several health physicists the qualification of more recent dosimeters for routine personnel dosimetry can be judged only by comparison with the film dosimeter mostly used today. In addition to many other interesting characteristics and additional information provided by a personnel dosimeter, the accuracy of the dose reading is the most important factor, if it is primarily a problem of dosimetry.

Below, the results of intercomparison measurements performed with film, glass and TLD dosimeters are critically reviewed. These are results of calibration exposures as well as of routine evaluation performed by different laboratories. The indicated dose reading accuracy of various dosimeters does not necessarily decide which dosimeter or which type of dosimeter is better suited for routine personnel dosimetry. However, the reproducibility or the measuring accuracy of a dosimeter is one characteristic of interest and of most importance in personnel monitoring.

This review answers the question what measuring accuracy can be achieved today with a personnel dosimeter in routine personnel monitoring.

2) Methods of Intercomparison Measurements

The physical characteristics of the radiation detector determine the accuracy of the dose measurement. In addition to systematic calibration and evaluation errors of the dosimeter service. For instance, a specific type of film dosimeter is precisely defined by the film emulsion, the combination of filters in the film badge and by the analytical procedure of evaluation. Furthermore the accuracy of the dose measurement depends on additional influences and properties of the dosimeter, e.g.:

- when registering the measured value: Type of irradiation, i.e. influences of radiation energy, radiation incidence, the presence of mixed radiations (gamma rays of Co-60, Cs-137, X-rays of different tube voltages and filtrations, beta rays), as well as the amount of the exposure,
- when storing the measured value: If the dosimeters are evaluated as late as one week or one month after irradiation, environmental conditions will influence personnel dose reading,
- when reproducing the measured value: Error of evaluation and determination of the measured value, influences of the evaluation procedure and the experience or the quality of the evaluation laboratory are likewise responsible for the accuracy of the dosimeter.

Calibration exposures cannot simulate all these influences. To restrict the number of possible errors, most intercomparison measurements are performed under known environmental influences (e.g. under laboratory conditions) and on the basis of a routine evaluation technique. In practice, frontal radiation incidence with but one type of radiation energy in the lower dose range is preferably used to calibrate dosimeters under given irradiation conditions. On the other hand, intercomparison measurements with different types of dosimeters were performed within routine personnel dosimetry where the errors are higher and all irradiation conditions (carriage, direction of radiation incidence) are fulfilled. To estimate the measuring accuracy or the reproducibility of a dosimeter, two methods are used now:

- In case of calibration exposures, the dose reading is related to the precisely known exposure, e.g. in the relative deviation of the dose reading from the test exposure,
- in case of routine personnel monitoring, pairs of dosimeters may be worn by one person. The dose reading deviation of those pairs of dosimeters will be regarded as the reproducibility of the dose reading in case of a homogeneous irradiation of both dosimeters which were worn on adjacent parts of the surface of the body. Hence, the reproducibility can be indicated by the relative deviation between the readings from both dosimeters (e.g. D_{max} : D_{min}) or a plus-or-minus deviation of the dose reading. The result of such intercomparison measurement shows the reproducibility of dose measurement actually existing in routine personnel monitoring.

In routine personnel monitoring, but also in case of a test exposure, the errors of measurement or evaluation of the dosimeter will influence the dosimeter reading to the same extent. Therefore the reproducibility found in routine monitoring may be compared to the measuring accuracy found by test exposures. Obviously the reproducibility of one dosimeter system can be compared with the reproducibility of another dosimeter system only if pairs of dosimeters of both types were exposed simultaneously under the same conditions.

Besides these exact methods of intercomparison, the dose readings of two or more types of dosimeters can be compared directly when worn simultaneously by the same person in routine personnel monitoring and exposedd under identical conditions. Such comparisons are informative in cases when additional test exposures reveal that one of two types of dosimeters is more reliable or in case when an agreement is found in the dose readings of two or more types of dosimeters.

3) Experimental Results of Intercomparison Measurements

3.1 Test Exposures with Film Dosimeters

The results of a representative test exposure in the United States have been published by Gorson, Suntharalingam and Thosmas in 1965 (1). The test was carried out with 12 different types of dosimeter and different film badge services, respectively. For this experiment the deviation of the dose reading was reported tobe ± 50 % which were found in excess of 7 % to 50 % of all irradiations by the different evluation services.

The average deviation of dose reading from the actual exposure gained from all laboratories is shown in Fig. 1 for single exposures with Co-60 and Ra-226 and for all exposures performed (additional single exposures with X-rays of 120 kV and 250 kV tube voltage as well as with radiation mixtures). Almost 85 % of all irradiations were within a deviation of ± 50 % (single exposures with Co-60 and Ra-226 only) and within ± 75 %, respectively (all exposures).

The most complete review of the capabilities of United States film dosimeter processors was shown in a study for the U.S.A.E.C. intended to develop film dosimeter performance criteria. This study was based in part on experimental results of a film dosimeter test irradiation program with 35 film dosimeter processors (75 % of the commercial film processing companies in the United States, 70 % of the major AEC installations and several military bases) (2).
The corresponding test films and the type of each exposure were known to each film dosimeter service. A total of 218 personnel film badge dosimeter data coming from each processor were examinated by Battelle Northwest Laboratory.

The statistical evaluation of the experimental data was based on a theoretical formula which distinguished between systematic bias parameters a and b (errors resulting from calibration) and a random variable δ with a mean equal to zero and a variance σ^2 depending on the exposure level (statistical deviation given by the technical properties of the type of dosimeter) expressed here as the relative error RE at a 95 % confidence level, RE = $[2\sigma/D]$ x 100) . The ranges of a and b as well as RE for each test irradiation in different radiation categories are summarized in Table 1.

This study shows in detail that nearly 90 % of the processors were proved to have some systematic bias. The last column of the table indicates the range of the relative error values. At a specific dose level for each radiation category, at least,one processor is estimated to have no relative error (except for irradiation of fast neutrons). The maximum value of RE was found for irradiations in the intermediate photon energy range (X-rays $\sim$100 keV) and for neutron irradiations. The authors developed performance criteria to eliminate systematic bias and to control the variance of the film badge processors.

Another interesting calibration exposure was performed with the new Harwell film badge (4) in the United Kingdom. This dosimeter may be regarded as one of the best film dosimeters because of the favourable filter arrangement, the relatively

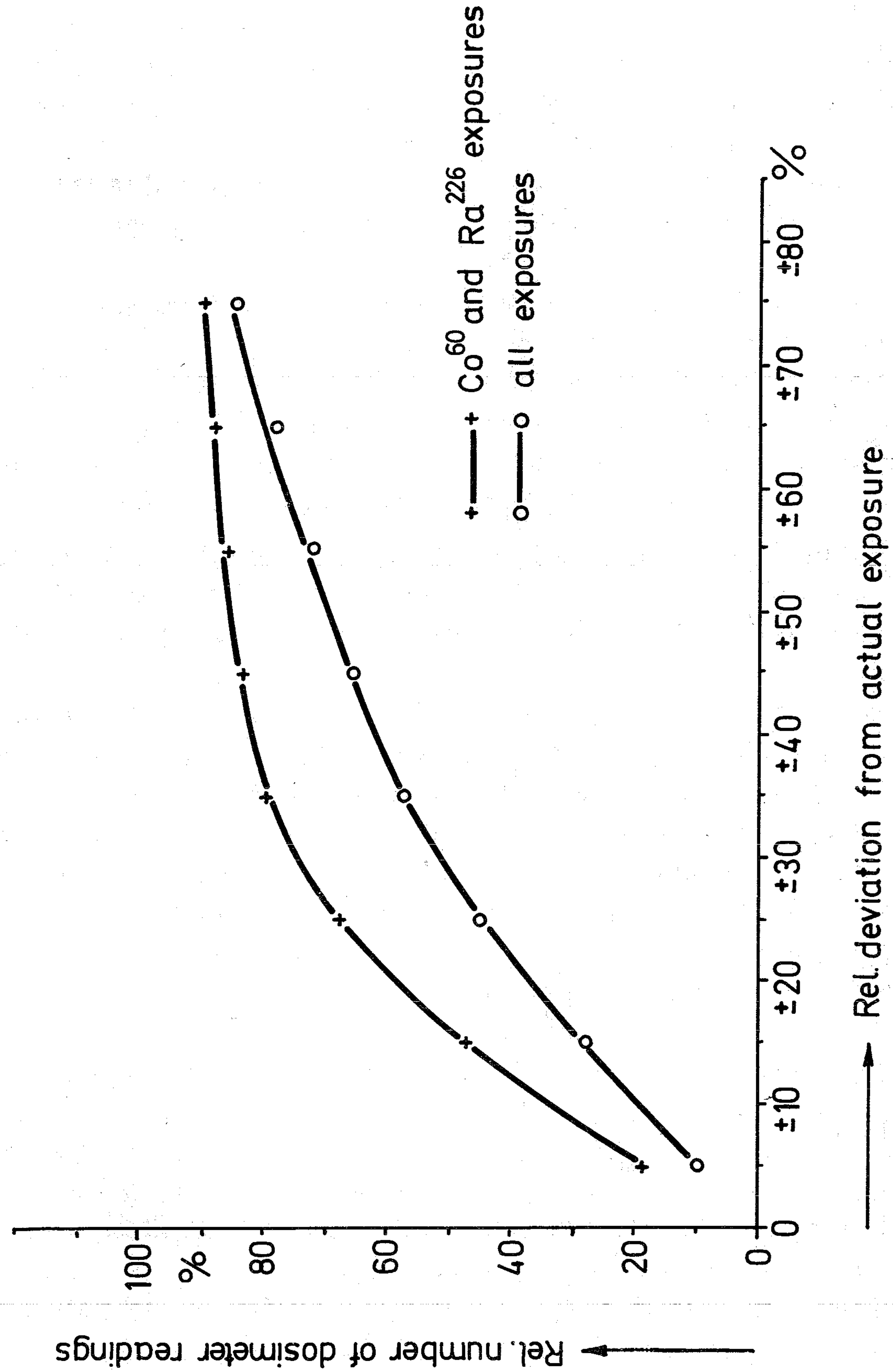

Co60 and Ra226 exposures
all exposures
Rel. deviation from actual exposure
±10 ±20 ±30 ±40 ±50 ±60 ±70 ±80 %
Rel. number of dosimeter readings
0 20 40 60 80 100 %

Fig. 1

Tab. 1: Experimental results of Hanford film badge dosimeter data for the past 14 years

Radiation Category	Dose Equivalent Range mrem	Number of Processors	Range of systematic Bias Parameters a Range (mrem)	b Range	Rel. Error $RE = \frac{2\sigma}{D} \cdot 100$ Range (%)
1) Photon					
High Energy	40 - 1 000	34	- 49 57	0.54 1.17	0 - 59
High Dose	20 000 - 800 000	33	- 19059 48476	0 1.48	0 - 110
Intermediate Energy	40 - 1 000	27	- 54 141	0.29 3.20	0 - 620
Low Energy	40 - 600	23	- 20 38	0.01 2.46	0 - 140
2) Beta	40 - 1 000	31	- 93 46	0.56 2.64	0 - 170
3) Neutrons					
Fast	200 - 1 000	27	- 139 552	0.03 2.59	1 - 450
Thermal	40 - 500	16	- 61 582	0.16 7.33	0 - 3 500
4) Mixtures					
Photons					
High Energy		17	- 77 42	0.73 1.92	0 - 94
Low Energy	40 - 1 000	13	- 138 119	0.15 12.39	0 - 270
Photons + Beta					
Photons High Energy		31	- 51 70	0.60 1.32	0 - 280
Beta	40 - 1 000	31	- 87 74	0.20 2.49	0 - 65

Statistical analysis of the experimental results: $D_e = a + b \cdot D_d + \delta$

D_e = Dose evaluated

D_d = Dose delivered

a, b = Systematic bias parameters

δ = random variable (zero to $\frac{2\sigma}{D} \cdot 100$)

energy-independent evaluation procedure and the extensive experimental testing.

The deviation of the film dosimeter reading from the actual dose is illustrated in Fig. 2. Approximately 85 % of all gamma exposures were found to be within a deviation of ± 35 %. Considering all exposures with additional beta radiation, 85 % of all irradiations were within a deviation of about ± 43 %.

In 1964 and 1965 four different intercomparison measurements with film dosimeters was organized by EURATOM including 7 laboratories from the EURATOM countries (France, Italy, Belgium, Netherlands)(4). The dosimeters were irradiated in the dose range up to 5 R by Physikalisch-Technische Bundesanstalt, Braunschweig/ Western Germany, using Co-60, Cs-137 and X-rays up to 300 kV tube voltage. Table 2 shows the relative number of dosimeters the readings of which were within a measuring error of ± 30 %. By the fourth run of exposures, a much better accuracy was found than by the first one.

The different accuracies encountered result from different types of dosimeter, different evaluation techniques, but apparently also from the different qualification of the evaluating laboratories. The European mean value covered almost 75 % of all irradiations within a measuring error of ± 30 %.

In Germany, the film dosimeter used from the governmental authorized film badge service showed similar deviations. These film dosimeters were evaluated by a filter analytical procedure. Between 1955 and 1964 the Physikalisch-Technische Bundesanstalt, Braunschweig, carried out test exposures employing Co-60, Cs-137 and X-rays. Fig. 2 reveals that almost 85 % of all measured values were within a measuring error of ± 50 % (5).

3.2 Intercomparison Measurements with Film and Solid-State Dosimeters

Testing new solid-state dosimeters in routine dosimetry showed that solid-state dosimeters have a better accuracy in dose reading than film dosimeters. Only few intercomparison measurements are presently available, however, The reported results were found experimentally over the past two years.

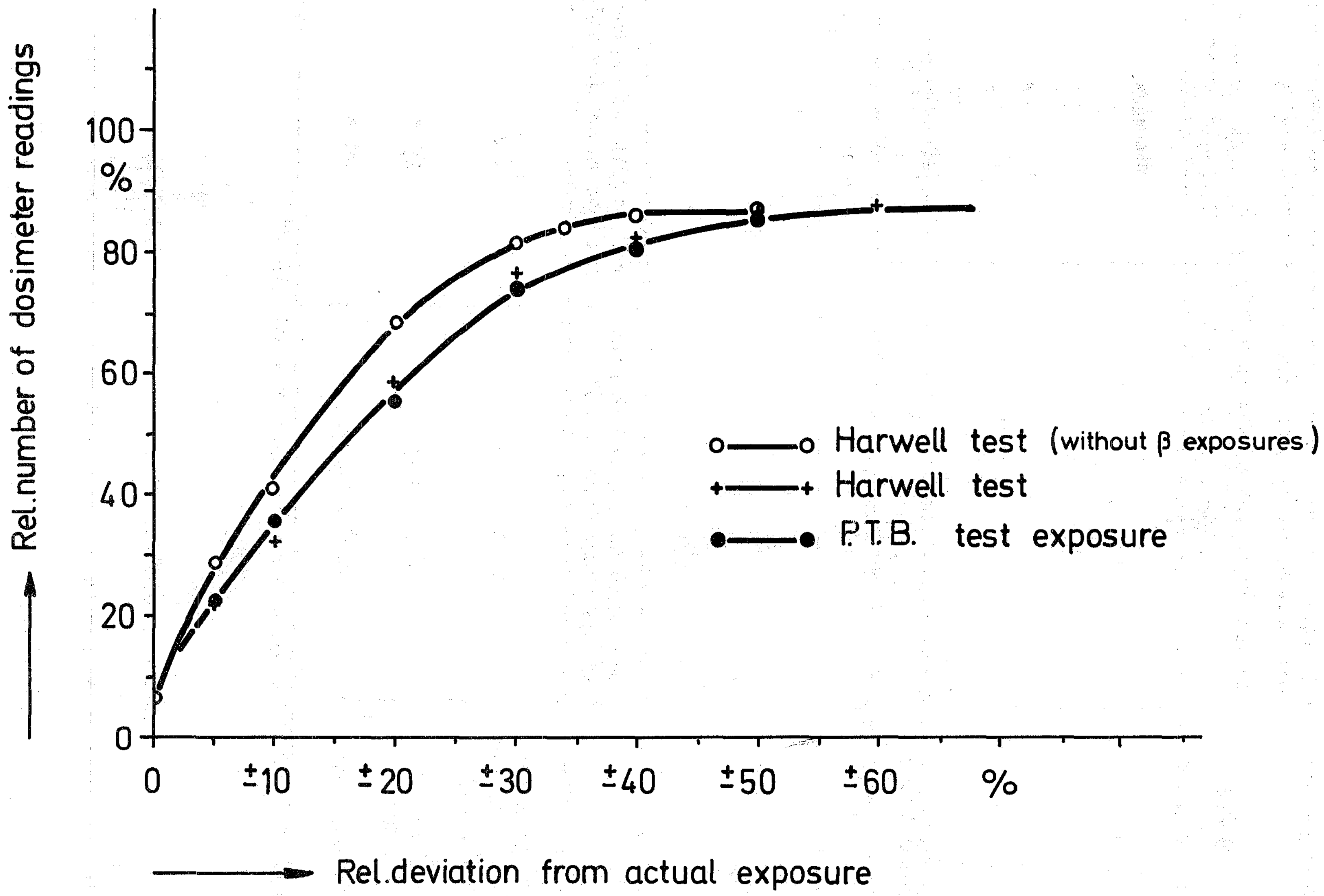

Rel.number of dosimeter readings
100
%
80
60
40
20
0
0
±10
±20
±30
±40
±50
±60
%
Rel.deviation from actual exposure
o——o Harwell test (without β exposures)
+——+ Harwell test
●——● P.T.B. test exposure

Fig. 2

Tab. 2

Laboratory	Rel. number of test exposures in % within a given deviation to the actual dose of ± 30 %	
	Exposures Series I	Exposure Series II
1	44	53
2	83	91
3	64	82
4	36	100
5	39	43
6	50	77
average value	53 %	74 %

Tab. 3

	Deviation to the TLD Reading of Dosimeter type DT-284	Rel. number of exposures besides given deviation
TLD Dosimeter (Manufacturer: M.B.L.E.)	10 % + 6 mR	0 %
Quarz fiber dosimeter	10 % + 6 mR	25 %
Film dosimeter+)	10 % + 50 mR	25 %

+) Result of 31 film dosimeters with dose reading ≥ 20 mR

3.2.1 Test Exposures with LiF Dosimeters

Test exposures of TLD dosimeters and film dosimeters were performed for the first time at the University of Wisconsin by Suntharalingam and Cameron (6). The TLD dosimeters consisted of LiF single crystals (TLD-100) of about 2 x 2 x 3 mm thickness in a plastic capsule of 1 mm thickness fastened to the commercial film badge.

The result of one test exposure performed by the National Sanitation Foundation Testing Laboratory at Ann Arbor, Mich., showed a deviation of ± 30 % relative to the actual dose in 84 % of all LiF dosimeter irradiations and in 63 % of all film dosimeter irradiations. 19 dosimeters of each type were exposed to Cs-137 and X-rays of 175 kV and 24 kV as well as mixed irradiations of Cs-137 and X-rays of 24 kV in the dose range between 0.1 and 1 R.

Johnson and Attix, United States Naval Research Laboratory, performed extensive intercomparison measurements with TLD dosimeters and film dosimeters in routine personnel monitoring under laboratory conditions (7). Two different CaF_2 dosimeters were worn in an additional filter-compensated capsule, i.e. the dosimeter DT/285 develped for the US Navy and the CaF_2 dosimeter of M.B.L.E. Additionally the NRL film badge and some quartz fibre pocket dosimeters were employed. First results proved that TLD dosimeters are capable of reproducibly detecting exposures below 10 mR (detection limit of the film dosimeter used: 20 mR). In Table 3 the results of the intercomparison run in the dose range between 1 and 90 mR are given. The dose deviation was related to the dose reading of the DT/284. Both TLD dosimeters exhibit an extremely good agreement of the dose readings.

The dose reproducibility of the film dosimeter was inferior by one order of magitude although only those film dosimeter exposures were compared which indicated a dose higher than 20 mR.

A comparison of LiF and film dosimeters in personnel monitoring was accomplished in plutonium processing areas at the Savannah River Plant in 1966 (8). LiF powder in a polyethylene capsule was inserted at the top of the film badge. The results of 324 test badges with LiF and 61 test badges with LiF behind a copper filter show the LiF dosimeter to indicate only half of the film badge reading. Similar differences between the LiF and the film dosimeter results were found by a calibration test exposure with X-rays (see Table 4). LiF results ranged within 20 % of the actual dose, the film dosimeter reading was high by

Tab. 4: Results from LiF and Film Test Exposures

X-rays Eff. Energy keV	Actual Exposure mR	Rel. deviation from actual dose+)		
		LiF	Film Badge Open Window	Film Badge Shield
48	95	+ 27 %	+ 113 %	- 65 %
	185	+ 28 %	+ 101 %	- 60 %
105	50	+ 10 %	+ 170 %	+ 90 %
	95	+ 11 %	+ 166 %	+ 93 %
	190	+ 19 %	+ 136 %	+ 93 %
154	190	+ 18 %	+ 30 %	+ 28 %

+) Average of 5 film or TLD results

a factor of 2 and 2.7 because of an energy dependence of the dose reading in the X-ray energy range.

Burton, Foster and Townsend (17) described operational trials with LiF dosimeters (sachets of LiF powder) attachted to film badges for personnel monitoring. The persons were working with varying amounts of gamma, X- and beta radiation. For exposures above 50 mR the correlation of both dosimeters was reasonably good. Test exposures of film badges and LiF powder in PVC sachets placed in the front and back surface of a man-equivalent thorax phantom show a very good agreement (± 10 %) for the LiF dosimeters using radiation sources of Au-198 and Co-60. Film dosimeters gave higher dose readings of about + 30 % for the 0.4 MeV gamma radiation.
R.L. Mather published results of an extensive statistical study involving 500 LiF dosimeters (LiF powder in sealed plastic capsule) which were exposed to precisely known Co-60 radiation by the US Naval Radiological Defense Laboratory of San Francisco and evaluated together with several thousand routine dosimeters by a commercial service (9). Table 5 shows the observed standard deviation of LiF at several exposure levels and under conditions of routine evaluation technique.

Tab. 5: The standard deviation of routine LiF thermoluminescent dosimetry for Co-60 calibration exposures

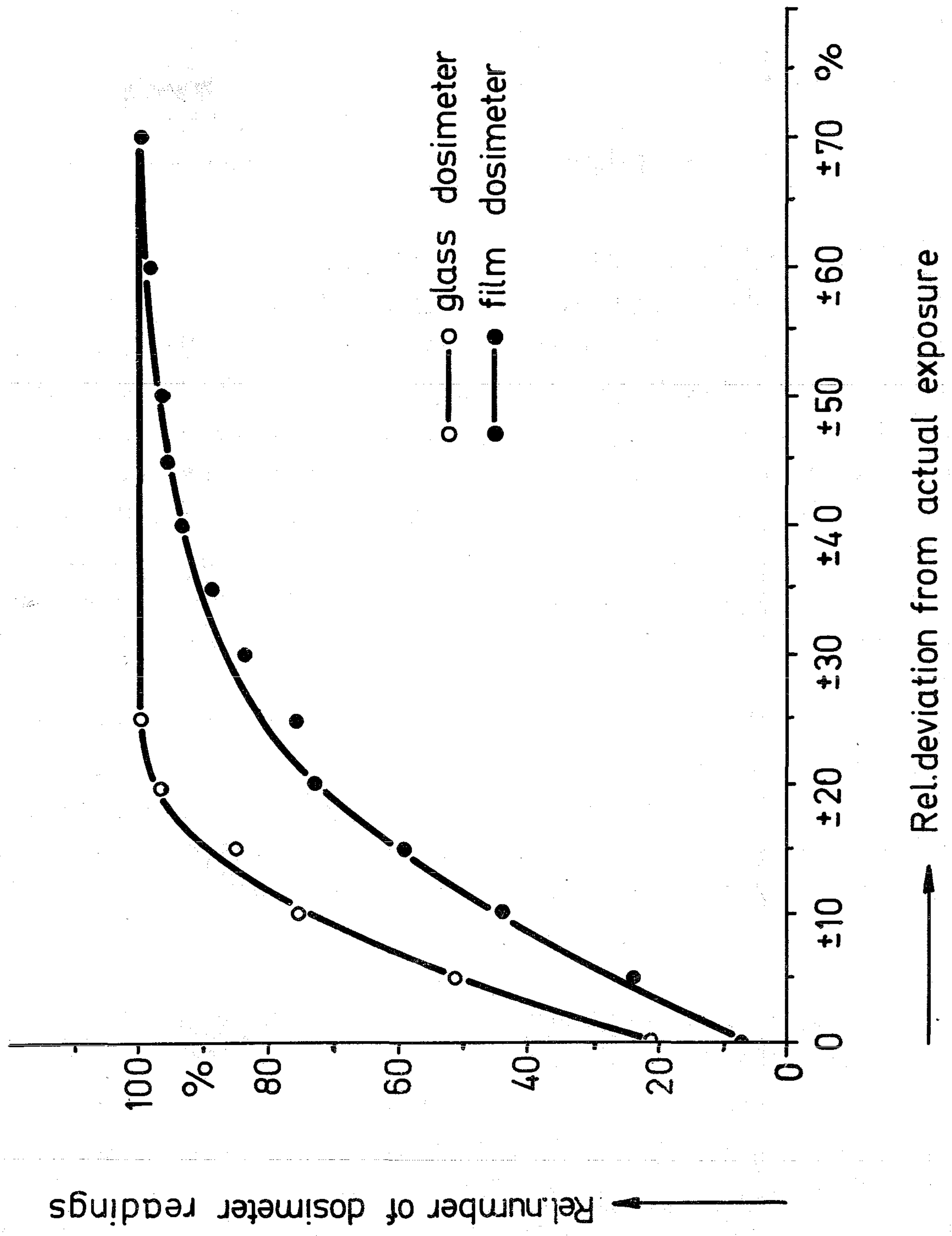
Exposure (mR)	Number of dosimeters	Standard Deviation
25	97	± 18 %
50	97	± 14 %
200	98	± 9 %
1000	48	± 9 %
5000	38	± 7 %

3.2.2 Test Exposures with Phosphate Glass Dosimeters

In Germany calibration test exposures of film and phosphate glass dosimeters were performed by Physikalisch-Technische Bundesanstalt, and the dose evaluation was carried out by the governmental measuring service at Karlsruhe (Landesinstitut für Arbeitsschutz und Arbeitsmedizin). The film dosimeter officially used by the government authorities requires a filter analytical evaluation technique. The phosphate glass dosimeter (Yokota glass, size 8 x 8 x 4.7 mm^3 in a special spherical tin capsule with conical holes) now used in routine personnel dosimetry for more than three years (10) is energy and direction dependent within ± 18 % in the energy range between 45 keV and 1.2 MeV for all radiation incidences.

The results of the PTB test exposure (11) performed with Co-60 and Cs-137 as well as X-rays of different qualities are given in Fig. 3. The deviation from the actual dose was ± 30 % for 85 % of all film dosimeters exposed. The same fraction of the glass dosimeter evaluations was found to be within a deviation of ± 15 %. The maximum deviation of the glass dosimeter was found to be within ± 25 %.

Similar intercomparison measurements between the film dosimeters officially used in Germany and glass dosimters in spherical capsule were performed at the Jülich Nuclear Research Establishment. However, dosimeters were stored under different climatic conditions during the monthly period of survey (20 to 35°C and 0 to 80 % relative air humidity). Test exposures of the front and back of the dosimeter were made in the energy range of 45 keV to 1250 keV with exposures between 60 mR and 870 R. The government authorized laboratory of Jülich evaluated the film dosimeters.



o——o glass dosimeter
●——● film dosimeter
Rel.deviation from actual exposure
0
±10
±20
±30
±40
±50
±60
±70
%
Rel.number of dosimeter readings
0
20
40
60
80
100
%

Fig. 3

Approximately 10 or 20 % of the film dosimeters and about 90 % of all glass dosimeter exposures were found to be within a deviation of ± 30 % (see Fig. 4). For exposures > 5 R, a deviation of ± 7 % was found for 85 % of 50 glass dosimeters.
Under practical conditions the measuring accuracy was tested with the same types of dosimeter (government authorized film dosimeter, phosphate glass dosimeter in spherical capsule and self-reading pocket dosimeter) in an intercomparison measurement which was performed by the Karlsruhe Nuclear Research Center in routine personnel monitoring in an isotope laboratory for 18 months (13).

Pairs of film and pairs of glass dosimeters worn simultaneously by the same person in adjoining places on the body and evaluated monthly showed the dose reading deviation indicated in Fig. 5. In the dose range between 40 mR and 1 R, a reproducibility of the dose reading within ± 30 % in 74 % of all film dosimeters and in 98 % of all glass dosimeters was encountered (only 1 outlier in 63 dosimeter pairs).

These results reveal a remarkable agreement with the measuring accuracy obtained in test exposures of Physikalisch-Technische Bundesanstalt (11), although glass and film dosimeters in that case were evaluated by another evaluation service.

Another interesting comparison of dose reading agreement between film and glass dosimeters and ionisation chamber dosimeters within routine personnel monitoring was derived. The persons worked in an isotope laboratory producing radioactive sources of Ra-226, Ir-192, Co-60 and Sr-90. Fig. 6 indicates the deviation of film and glass dosimeter readings from ionisation chamber dosimeter readings found in approximately 300 evaluations in the dose range of 40 mR to 1 R.

Monthly evaluation disclosed a relatively unfavourable dose agreement. When the monthly results for each person are added separately to the 13 weeks and annual doses, respectively, a glass dosimeter reveals a relatively favourable average of the dose reading deviation (see Table 6).
A comparison of the accumulated annual dose values of 10 persons performed with different types of dosimeter (values between 1.6 and 5.8 R) showed in this special case of routine monitoring that on the average the film dosimeter indicated 63 % of the pocket ionisation chamber dose and the glass dosimeter indicated 94 % of the pocket ionisation chamber dose.

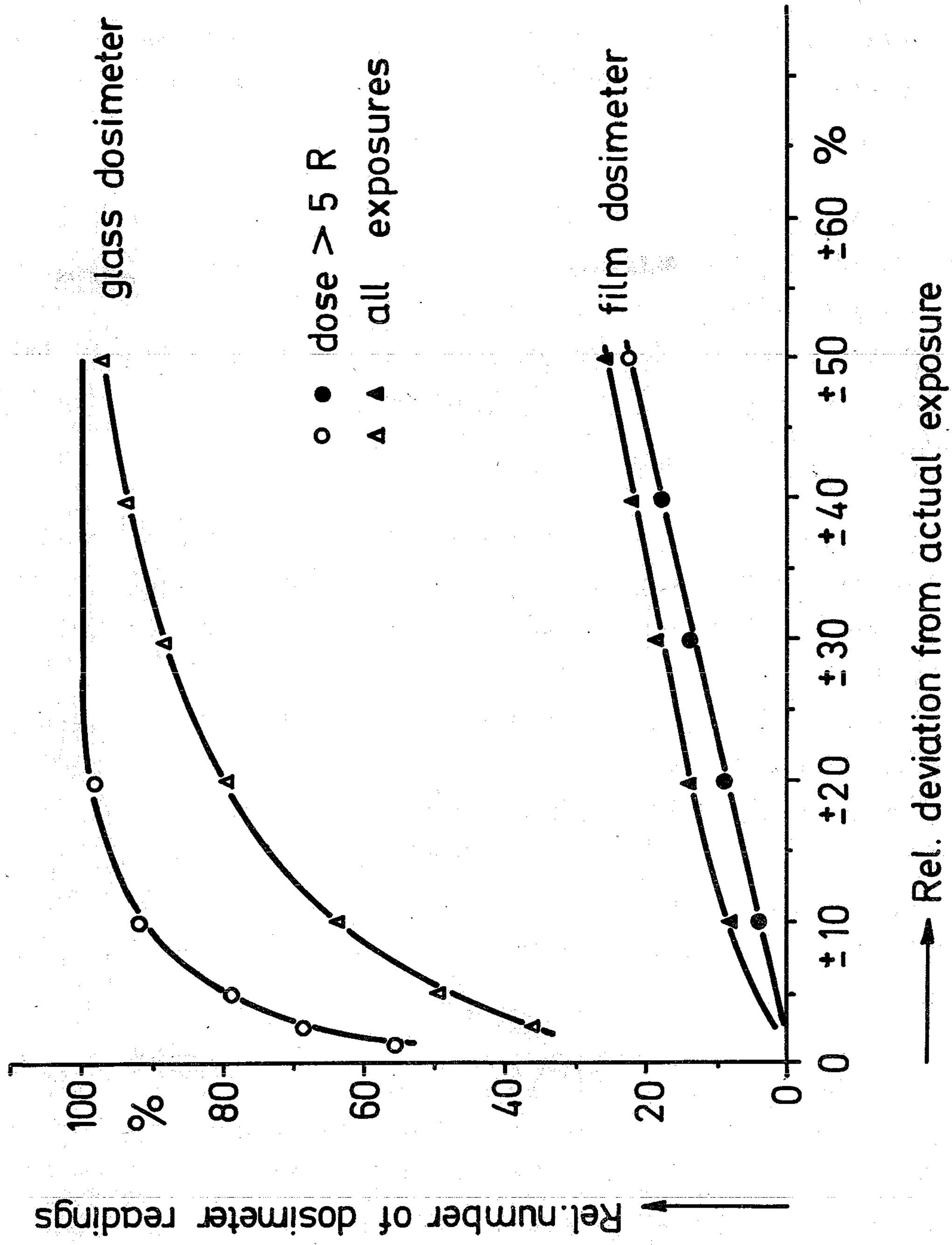

glass dosimeter
film dosimeter
○ ● dose > 5 R
△ ▲ all exposures
Rel. number of dosimeter readings
%
100
80
60
40
20
0
Rel. deviation from actual exposure
0
±10
±20
±30
±40
±50
±60
%

Fig. 4

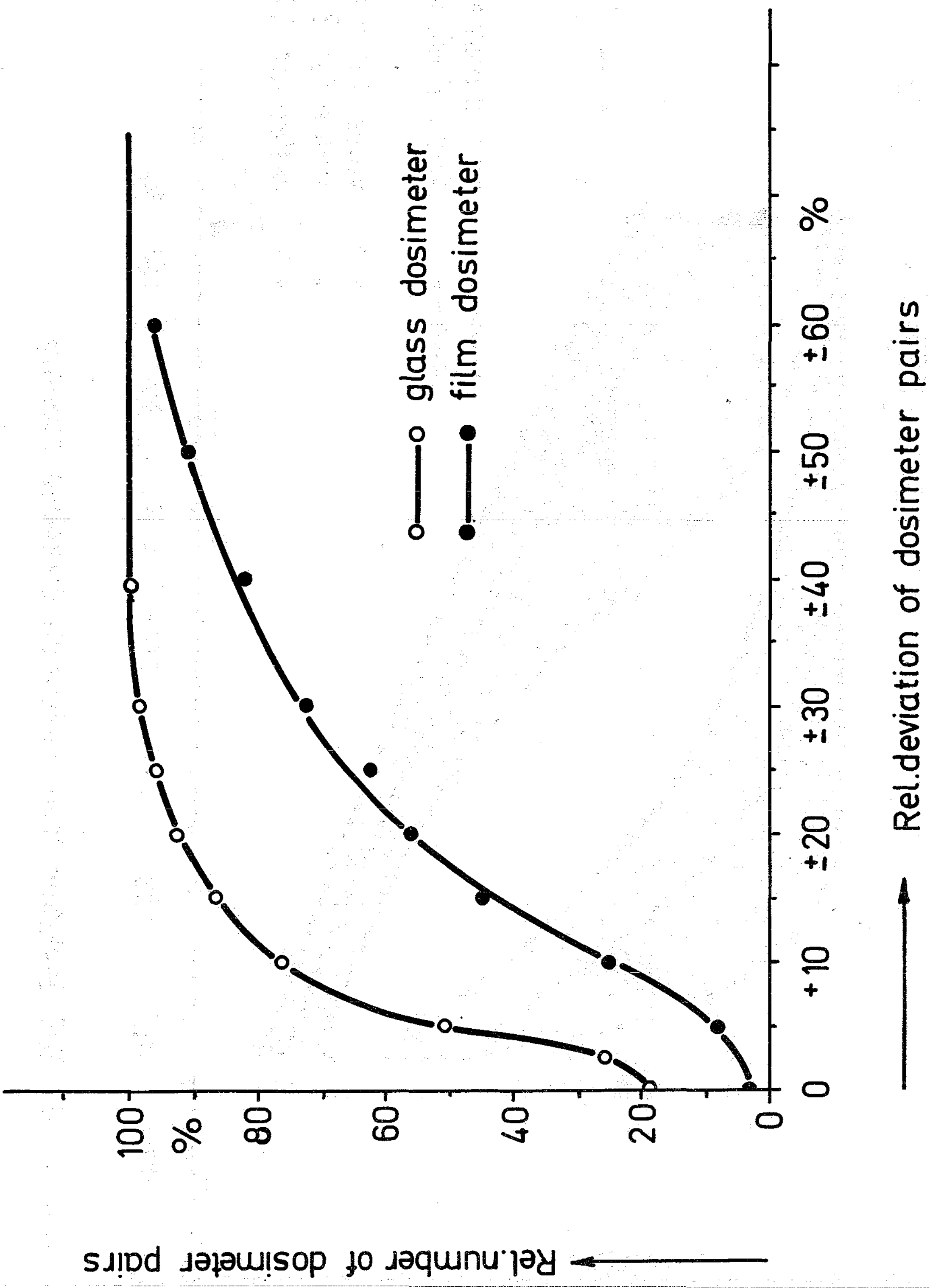

glass dosimeter
film dosimeter
Rel.number of dosimeter pairs
100
%
80
60
40
20
0
+10
±20
±30
±40
±50
±60
%
Rel.deviation of dosimeter pairs

Fig. 5

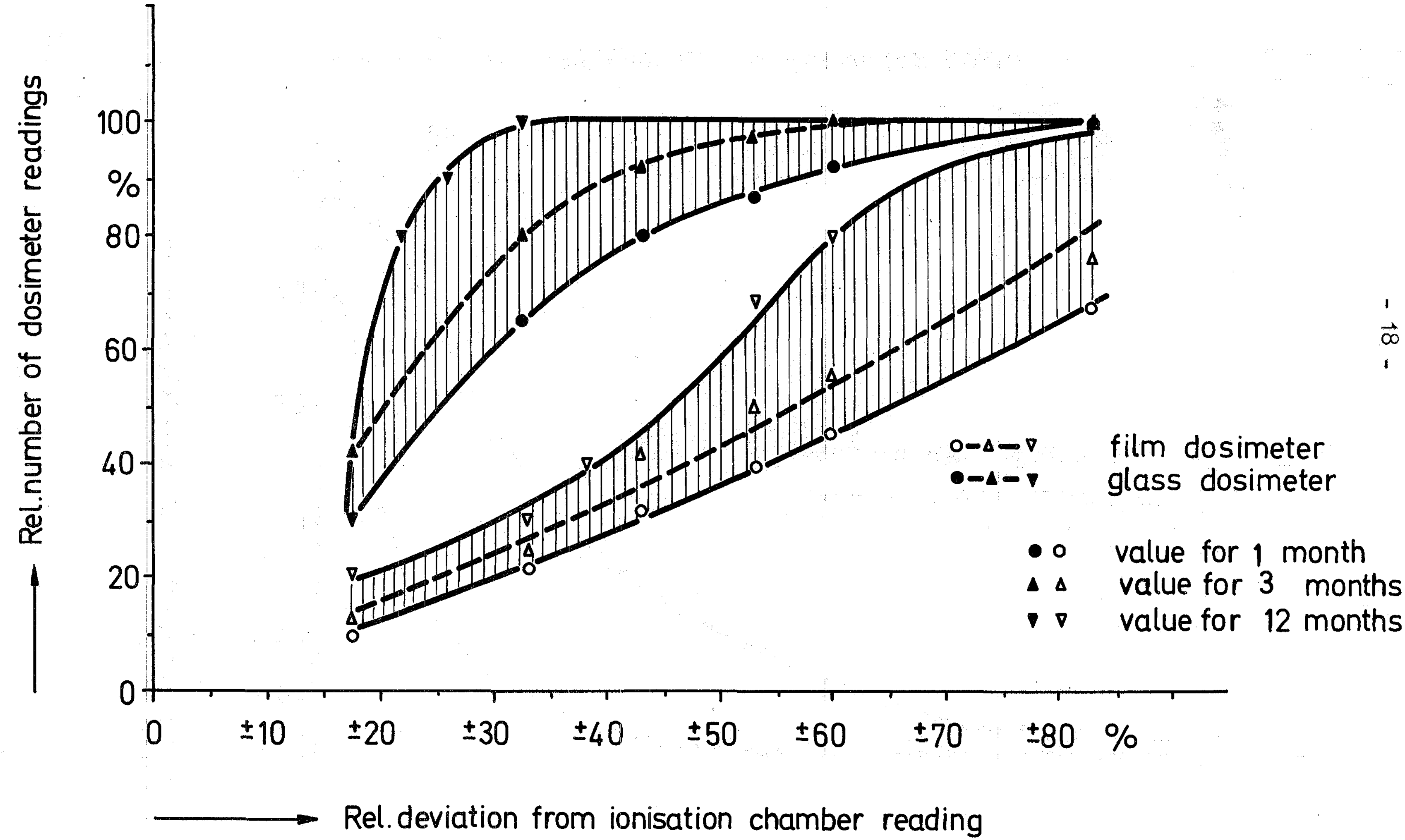

Rel. number of dosimeter readings
%
100
80
60
40
20
0
0
±10
±20
±30
±40
±50
±60
±70
±80
%
Rel. deviation from ionisation chamber reading
film dosimeter
glass dosimeter
value for 1 month
value for 3 months
value for 12 months

Fig. 6

Tab. 6: Agreement of the measuring values related to the pocket chamber dosimeter

Accumulated personnel dose		Dose within ± 30 % (Rel. number of dosimeters)	85 % of all dosimeters (within measuring value deviation)
Film/ Pocket	4 weeks dose	20 %	factor of 5
	13 weeks dose	24 %	factor of 4
	Annual dose	30 %	± 60 %
Glass/ Pocket	4 weeks dose	60 %	± 50 %
	13 weeks dose	75 %	± 35 %
	Annual dose	95 %	± 24 %

4) Comparison of the Dose Reading Accuracy of Different Types of Dosimeter and Intercomparison Measurements

In this paper it has been tried to derive equivalent statements on the measuring accuracy, the reproducibility, and the dose reading agreement for results published by various authors.
From the distribution of the dose reading deviation the following quantities may be determined to ascertain the measuring accuracy of a certain type of dosimeter:

- The relative number of exposures within a dose reading deviation of ± 30 %,
- the relative dose reading deviation found in 85 % of all irradiations in the intercomparison measurements (15 % outliers).

Both statements seem to be adequate to the distribution curves gained from all dose reading deviations and offer better possibilities of interpretation than the value of standard deviation. These values have been determined for test exposures and intercomparison measurements in Table 7. Table 8 shows the standard deviations found in the distribution curves of the intercomparison measurements.

The results of the intercomparison exposures are quite surprising. In spite of different types of dosimeter, different irradiation conditions (dose value, type of radiation) and different evaluation laboratories an almost comparable measuring accuracy is attained for the film dosimeter as long as there are test exposures.

For film dosimeters the dose reading deviation in the most favourable cases is within ± 30 %, but on the average it is within ± 50 % if outliers of 15 % are assumed. Adverse environmental conditions or less qualified evaluation laboratories can considerably impair this accuracy. Starting from various results, it is interesting to note that the different types of film dosimeter as used in the United States, the United Kingdom and the EURATOM countries show practically an almost similar measuring accuracy.

Generally an improved measuring accuracy is observed for TLD and RPL dosimeters. Here it is remarkable, too, that the same glass dosimeter provides comparable results despite different evaluation laboratories and independent of the fact whether test exposures, unfavourable environmental conditions, or results of routine personnel monitoring are concerned (see Fig. 7). Also in routine personnel monitoring, a dose reading deviation of about ± 15 % is encountered in 85 % of all the exposures.

Tab. 7 : Results of intercomparison measurements performed with film, TLD and RPL dosimeters

	Intercomparison measurements	Dose reading within $\pm$ 30 % (Rel. number of dosimeters)		85 % of dosimeters (within deviation)	
US	Calibration test exposure in 1963 (1)				
	12 commercial laboratories: gamma exposures only	F	75 %	F	$\pm$ 48 %
	all exposures	F	51 %	F	$\pm$ 75 %
	Calibration test exposure (6): X-rays and gamma exposures	T	84 %		
		F	63 %		
UK	Calibration test exposures (3): without beta exposures	F	82 %	F	$\pm$ 35 %
	all exposures	F	77 %	F	$\pm$ 45 %
Euratom	PTB calibration test exposure from 1964 to 1965 (4):				
	Series I — 6 laboratories	F	54 %		
	Series IV	F	75 %		
Germany	PTB calibration test exposure from 1955 to 1964 (5): Governmental film service I	F	74 %	F	$\pm$ 50 %
	PTB calibration test exposure from 1965 to 1967 (11):	G	100 %	G	$\pm$ 15 %
	Governmental film service II	F	84 %	F	$\pm$ 31 %
	Calibration test exposure in 1966 (12):	G	88 %	G	$\pm$ 25 %
	Governmental film service III	F	~20 %	F	>
	only exposures > 5 R	G	100 %	G	$\pm$ 7 %
	Intercomparison within personnel monitoring (13): from 1965 to 1967: pairs of dosimeters	G	98,5 %	G	$\pm$ 15 %
	Governmental film service IV	F	74 %	F	$\pm$ 42 %

F film dosimeter
T thermoluminescence dosimeter
G phosphate glass dosimeter
PTB Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Tab. 8: Standard deviation+) of personnel dosimeters

	Author	Irradiation	Exposure	Standard dev. %
Film	GORSON (1)	Test	16 mR - 8.2 R	
	all exposures			± 45
	only γ exposures			± 24
	WACHSMANN (5)	PTB test		± 25
	PIESCH (13)	Routine	40 mR - 1 R	± 25
	LANGMEAD, ADAMS (3)	Test	20 mR - 90 R	
	all exposures			± 23
	without ß exposures			± 19
	NARROG (11)	PTB test	100 mR - 14 R	± 18
Phosphate glass	BECKER (12)	Test	60 mR - 870 R	± 11
			5 R - 870 R	± 2,5
	NARROG (11)	PTB test	40 mR - 14 R	± 8
	PIESCH (13)	Routine	40 mR - 1 R	± 7
LiF	MATHER (9)	Test	50 mR	± 14
			200 mR	± 9
			5000 mR	± 7

+) These values were found by different kinds of comparison irradiations.

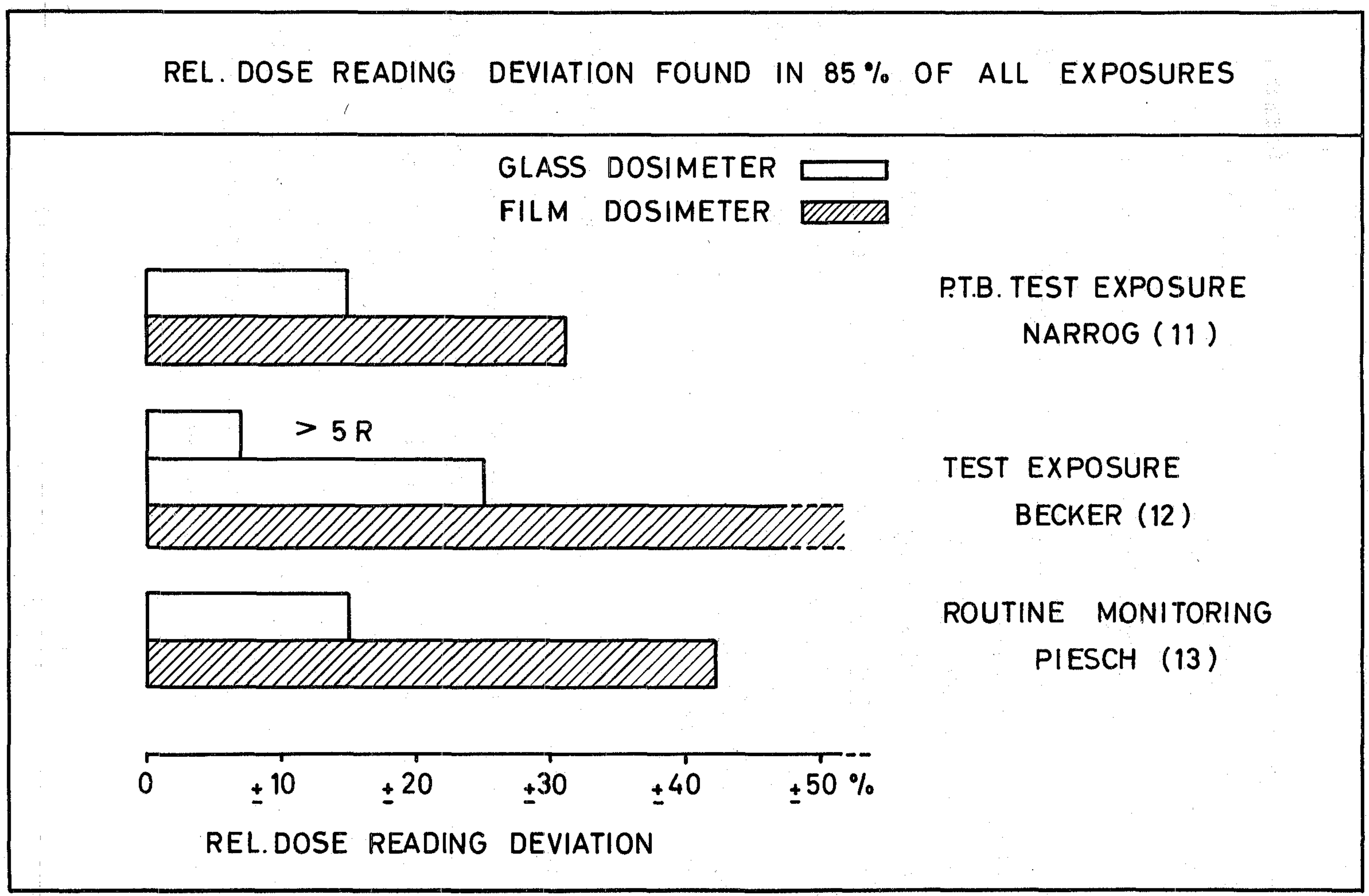


FIG. 7. RESULTS OF INTERCOMPARISON MEASUREMENTS

On the other hand, pocket ionisation chamber dosimeters show a better measuring accuracy than film dosimeters; it can be compared with that of solid-state dosimeters.
Hence, solid-state dosimeters in the future will replace film dosimeters in many cases of routine monitoring. This is especially true of cases where solid-state dosimeters are preferred also on account of their technical advantages:

- Insensitivity to radiation energy, radiation direction and environmental conditions,
- assessment of small doses which cannot always be detected with film dosimeters (e.g. natural radiation background),
- assessment of a long-term dose (annual dose) with a very low detection limit,
- assessment of high doses after accidents by employing a measuring accuracy and a measuring range which cannot be achieved by film dosimeters,
- assessment of the absorbed dose in the critical organ (such as gonads, bone marrow, gastrointestinal tract) corresponding to the conditions of routine and accidental dosimetry (14,15),
- assessment of the depth dose distribution (16) with phosphate glass dosimeters.

We hope that the work on intercomparison measurements and test irradiations will be continued in future, the results of which, however, should be reported in such an accurate way that a statistical quantitative interpretation of the accuracy or reproducibility of the dose reading can be obtained. The distribution curve gained from all dose reading deviations seems to yield the best quantity for the comparison of different dosimeters which were irradiated under the same conditions. The special method used in this paper to compare the results of different test irradiations should be understood only as an example that two different statements on the dose reading deviation can also be used as adequate values instead of the more accurate distribution curve.

References

1) R. O. Gorson, N. Suntharalingam, J.W. Thomas
Radiology 84, p. 333, 1965

2) C.M. Unruhr, H.V. Larson et al.
BNWL-542, 1967

3) W.A. Langmead, N. Adams
AHSB(RP) R 62, 1966

4) P. Recht, M. Collet
Proc. ENEA Symposium, Stockholm 1967, p. 209

5) F. Wachsmann
Proc. ENEA Symposium, Stockholm 1967, p. 188

6) N. Suntharalingam, J.R. Cameron
Health Physics 12, p. 1595, 1966

J.R. Cameron, N. Suntharalingam
Proc. 1st Intern. Congr. of Radiation Protection, Rome 1966, p. 451

7) T.L. Johnson, F.H. Attix
NRL Test and Evaluation Report 69, 1967

Proc. 1st Intern. Congr. of Radiation Protection, Rome 1966, p. 457

8) R.M. Hall, C.N. Wright
Health Physics 14, p. 37, 1968

9) R.L. Mather
Health Physics 14, p. 172, 1968

10) E. Piesch
DIRECT INFORMATION 17/64, 1964
R. Maushart, E. Piesch
Proc. Luminescence Dosimetry Symposium, Stanford 1965

11) J. Narrog
DIRECT INFORMATION, in: Atompraxis 7, 1967
Proc. ENEA Symposium, Stockholm 1967, p. 268

12) K. Becker
Health Physics 14, p. 17, 1968
Proc. ENEA Symposium, Stockholm 1967, p. 178

13) E. Piesch
Proc. ENEA Symposium, Stockholm 1967, p. 151

14) E. Piesch
Health Physics 15, p. 145, 1968, KFK-820 Gesell.f.Kernforschung, 1968

E. Piesch
2nd Congr. on Luminescence Dosimetry, Gatlinburg 1968

15) T. F. Johns
Proc. ENEA Symposium, Stockholm 1967

16) H. Kiefer, E. Piesch
DIRECT INFORMATION 10/67, 1967, in: Atompraxis 13, H. 11, 1967
H. Kiefer, E. Piesch
Atompraxis (to be published)

17) L. K. Burton, C.J. Foster, S. Townsend
Proc. 1st Intern. Congr. Radiation Protection, Rome 1966, p. 435

Fig. 1 — The relative number of film badge dosimeter readings within a given deviation from the actual exposure. Results of test exposures with Co-60 and Ra-226 and additionally X-rays found by 12 evaluation services in the United States under routine evaluation conditions according to (1)

Fig. 2 — The relative number of film badge dosimeter readings within a given deviation from the actual exposure. Results of a test exposure with the Harwell film badge dosimeter using X-rays and gamma radiation and beta radiation according to (3). Results of a test exposure with the German film badge dosimeter performed in 1955 till 1964 by the Physikalisch-Technische Bundesanstalt (PTB) using X-rays and gamma radiation according to (5).

Fig. 3 — The relative number of glass and film badge dosimeter readings within a given deviation from the actual exposure. Results of a test exposure with the German film badge dosimeter and the Karlsruhe spherical glass dosimeter performed in 1965 till 1967 by the Physikalisch-Technische Bundesanstalt (PTB) according to (11) with X-rays and gamma radiation.

Fig. 4 — The relative number of glass and film badge dosimeter readings within a given deviation from the actual exposure with X-rays and gamma radiation in the dose range of 0.06 to 870 R. Results of test exposures with the German film badge dosimeter and the Karlsruhe spherical glass dosimeter under simulated routine conditions performed by the Jülich Nuclear Research Center according to (12)

Fig. 5 — The relative number of glass and film badge dosimeter pairs within a given dose reading deviation of dosimeter pairs. Results of an intercomparison measurement within routine personnel monitoring in an isotope laboratory found for dosimeter pairs worn by the same person in the dose range of 0.04 to 1 R. Measurement was performed with the German film badge dosimeter and the Karlsruhe spherical glass dosimeter in 1965 till 1967 according to (13).

Fig. 6 — The relative number of dosimeter readings within a given deviation from the pocket ionisation chamber reading for the German film badge dosimeter and the Karlsruhe spherical glass dosimeter. Results of an intercomparison measurement within routine personnel monitoring in an isotope laboratory summarizing the individual dose reading of 1 person for 3 months and for 12 months (13).

Fig. 7 — Results of intercomparison measurements with film and glass dosimeters