KERNFORSCHUNGSZENTRUM

KARLSRUHE

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Abteilung Strahlenschutz und Dekontamination

Phosphate Glass Dosimeters for the Measurement of Organ Doses with Reduced Body Influence

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- Strahlenmeßdienst -

Phosphate Glass Dosimeters for the Measurement of Organ Doses with Reduced Body Influence+)

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Abstract

According to the ICRP recommendations, the hazard to a person depends primarily on the corresponding absorbed dose in the organ of interest. A personnel dosimeter calibrated for exposure will normally indicate the dose an the surface of the body.

The dose actually absorbed in an organ was measured by A.R.Jones in an Alderson phantom related to an exposure of 1 R as a function of quantum energy. Basing on this work, energy compensation filters for phosphate glasses were developed. The dose reading of such dosimeters shows the same energy dependence as the absorbed dose in the critical organ, as gonads, bone marrow, gastrointestinal tract, lenses of the eyes.

Different possibilities of organ dose indication at the front side of an Alderson phantom were realized:

- The dosimeter reading is energy independent, at least, for radiation incidence on the front side of the phantom,
- the dosimeter reading is energy independent for radiation incidence from the front and likewise from behind the phantom.

Phosphate glass dosimeters will be described indicating directly the absorbed dose in all interesting critical organs with reduced influence of body orientation to radiation incidence for quantum energies above 50 keV. The indication of the absorbed dose in the organ testes and gut mucosa is roughly independent of the direction of radiation incidence from the front or rear half space. For the other organs or for lower quantum energies, detailed statements about radiation quality and radiation incidence are required. Here, the depth dose distribution in phosphate glasses, which can be measured by employing a multiscanning technique, offers the additional advantage of indicating the dose actually absorbed in the body.

1) Introduction

The radiation hazard to a person is described in terms of the absorbed dose in the respective critical organ on the basis of the ICRP recommendations. In principle, it would be possible to measure the absorbed dose in the body or in the organ by means of the proper miniature dosimeter directly and independent of the orientation of the body relative to the radiation field. However, for obvious reasons such method of measurement has not been practically implemented as yet. Hence, routine personnel monitoring is restriced to wearing dosimeters on the surface of the body. On the basis of phantom measurements performed by A. R. Jones (1) the absorbed dose for an exposure of 1 R is known in various critical organs. If the radiation energy is taken into account, the absorbed dose in the organ of interest can be calculated from the dose reading (exposure) of a personnel dosimeter.

The idea of relating the dose reading to an absorbed dose in the critical organ was obvious when new dosimeters were introduced in routine personnel monitoring which showed a measuring accuracy better than 10 percent (see Table 1). In phosphate glass dosimeters, above all, it was relatively easy to calibrate the dose reading of an energy independent, non-directional spherical dosimeter to the absorbed dose in the critical organs. It has been shown that a direct indication of the organ dose on the surface of the body is possible for a frontal radiation incidence by changing the energy compensating filter (9, 10).

The type of organ dose measurement outlined here is described by these characteristics:

- Exposure of the personnel dosimeter on the surface of the body (dosimeter worn at chest level on the front of the body)
- Direct indication of the absorbed dose with an energy independent dosimeter without knowledge of the radiation energy
- Simultaneous indication in one dosimeter of the absorbed dose in different organs.

In continuance of this work it was tried to reduce the influence of the body orientation on the dosimeter reading by improving the dose reading in the case of radiation incidence from behind. The results outlined here indicate that this is possible for the phosphate glass dosimeter in a first approximation by an improvement of the energy compensating filter and by an improvement of the method of fluorescence measurement.

Table 1: Standard deviation of personnel dosimeters

	Author	Kind of irradiation	Exposure range	Standard deviation+) %
Film	GORSON (2)	Test	16 mR - 8.2 R	
	all exposures			± 45
	only γ exposures			± 24
	WACHSMANN (3)	PTB TEST		± 25
	PIESCH (7)	Routine	40 mR - 1 R	± 25
	LANGMEAD, ADAMS (4)	Test	20 mR - 90 R	
	all exposures			± 23
	without ß exposures			± 19
	NARROG (5)	PTB Test	100 mR - 14 R	± 18
Phosphate glass	BECKER (6)	Test	60 mR - 870 R	± 11
			5 R - 870 R	± 2,5
	NARROG (5)	PTB Test	40 mR - 14 R	± 8
	PIESCH (7)	Routine	40 mR - 1 R	± 7
LiF	MATHER (8)	Test	50 mR	± 14
			200 mR	± 9
			5000 mR	± 7

+) These values were found by different kinds of test exposures (deviation of the actual exposure) and by comparison irradiations within routine personnel monitoring (deviation of dosimeter pairs worn simultaneously by the same person)

2) Method of Organ Dose Calibration

The absorbed dose in the critical organ has been determined experimentally for various directions of radiation incidence on an Alderson phantom by A. R. Jones (1). The conversion factors rad/R found in these experiments (absorbed dose in the organ at an exposure of 1 R) are required for conversion of the dosimeter reading or for calibration of the dosimeter to an absorbed dose and are very strongly dependent on the direction of radiation incidence and the orientation of the phantom, respectively, relative to the radiation field. Hence, the dose reading of a personnel dosimeter can be referred to differently defined organ doses, depending upon the direction of radiation incidence. Below, three different definitions of the organ dose are used:

- The absorbed dose in the organ for uniform radiation incidence from all directions, achieved by exposure of the rotating phantom
- The absorbed dose in the organ for one direction of radiation incidence in which there is a maximum dose, i.e. a maximum personnel hazard, due to an irradiation of the phantom from behind (bone marrow) or from the front (all other critical organs of interest) (see Fig. 1)
- The absorbed dose in the organ for frontal direction of radiation incidence in case of frontal exposure of the phantom simultaneously with the absorbed dose in the organ for exposure from behind in case of an exposure from behind the phantom (see Fig. 2).

The personnel dosimeter is calibrated in the same way by an Alderson phantom; for this purpose the dosimeter was exposed at chest level in the front. A series of experiments with the spherical phosphate glass dosimeter varied the energy compensating filter in such a way that the dosimeter reading referred to 1 R was roughly proportional to the corresponding conversion factor rad/R for the absorbed dose in the respective critical organ. Fig. 3 indicates these calibration and detection conditions with respect to the orientation of the phantom relative to the direction of radiation incidence. The dose reading of dosimeters I and II in this case is proportioanal to the respective absorbed dose when the radiation is incident from the front half space and for dosimeter III when the radiation is incident from the front and the rear half spaces.

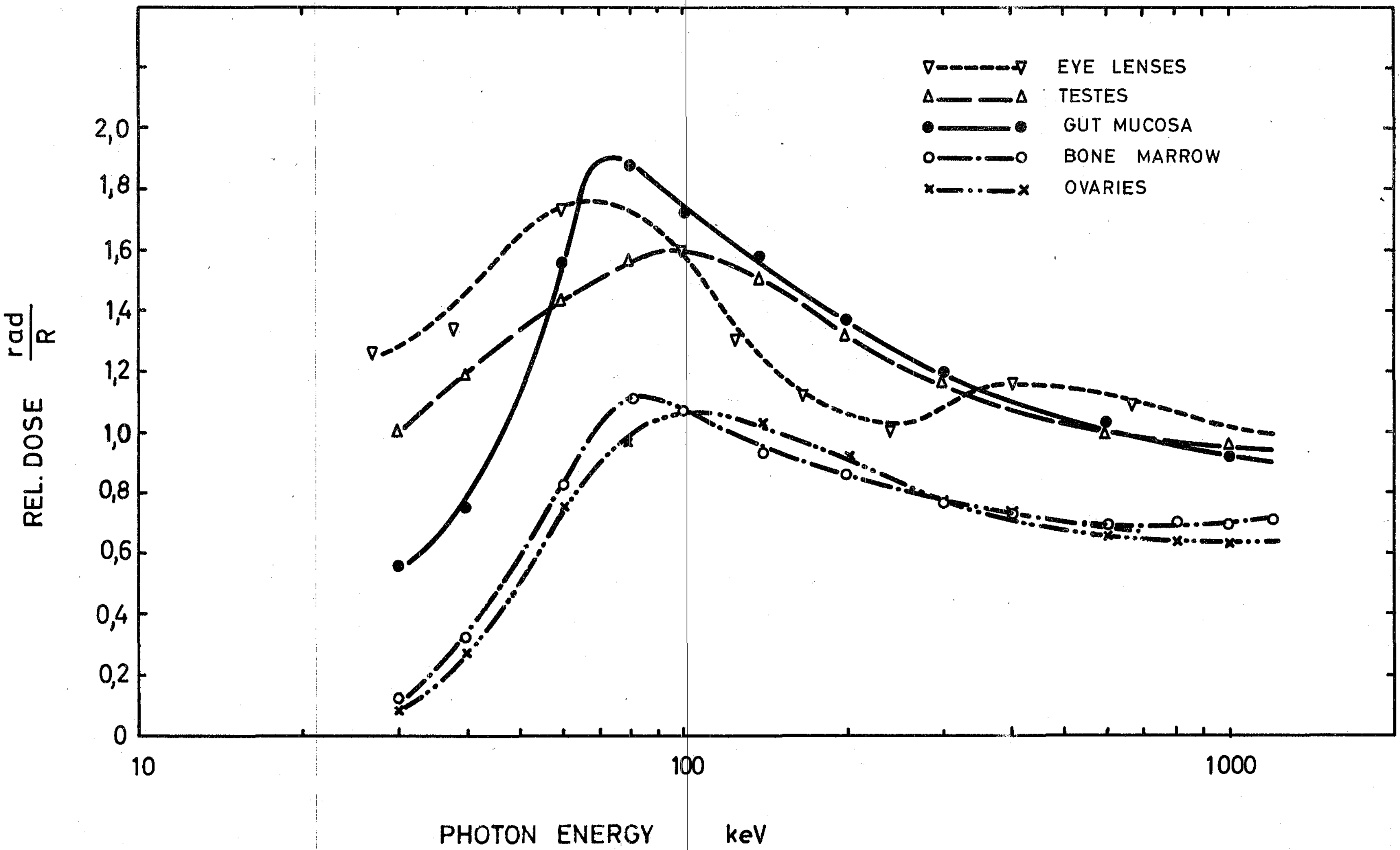


Fig. 1: Absorbed dose in critical organs for frontal exposure

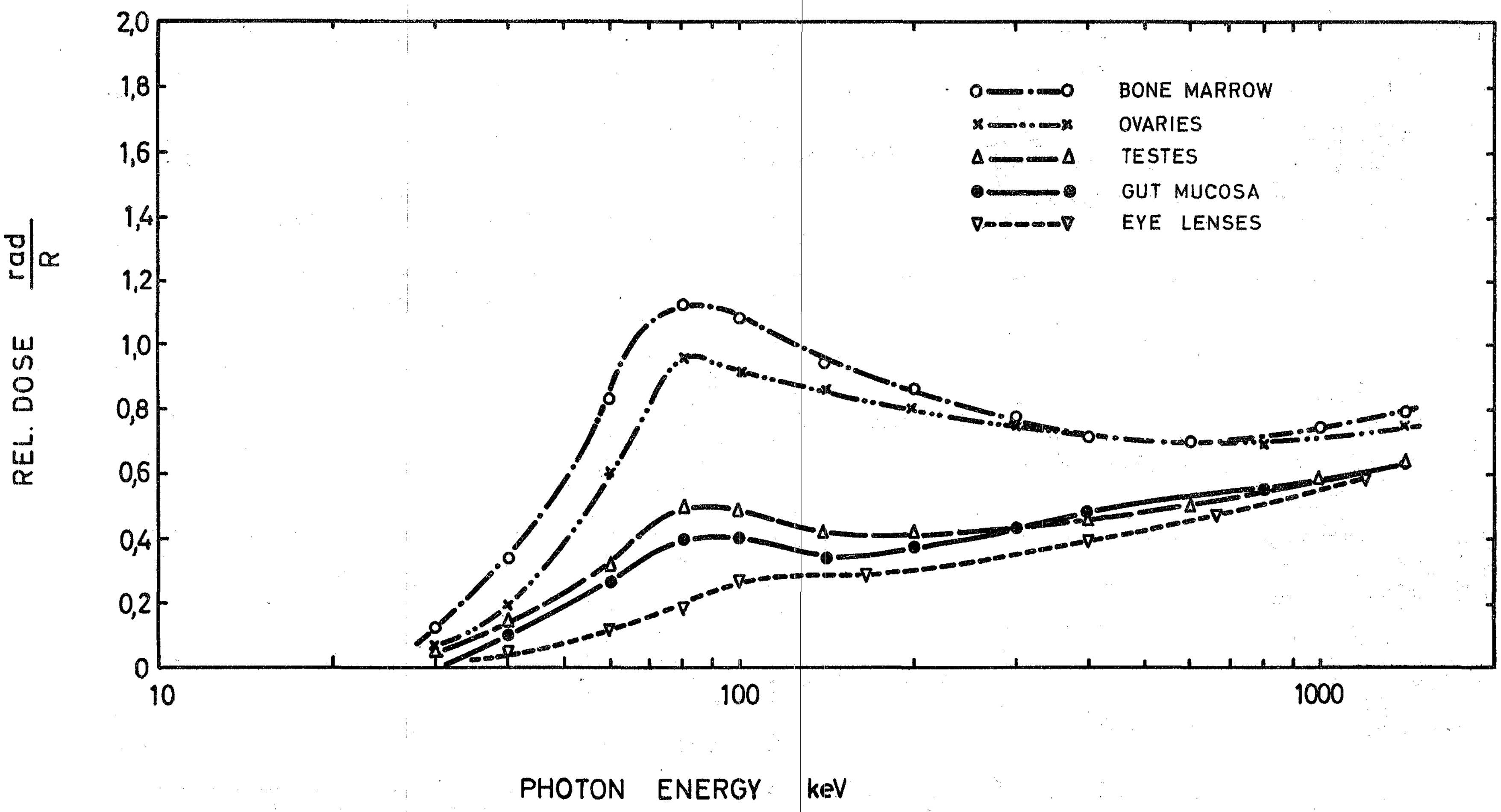


Fig. 2: Absorbed dose in critical organs for exposure from behind

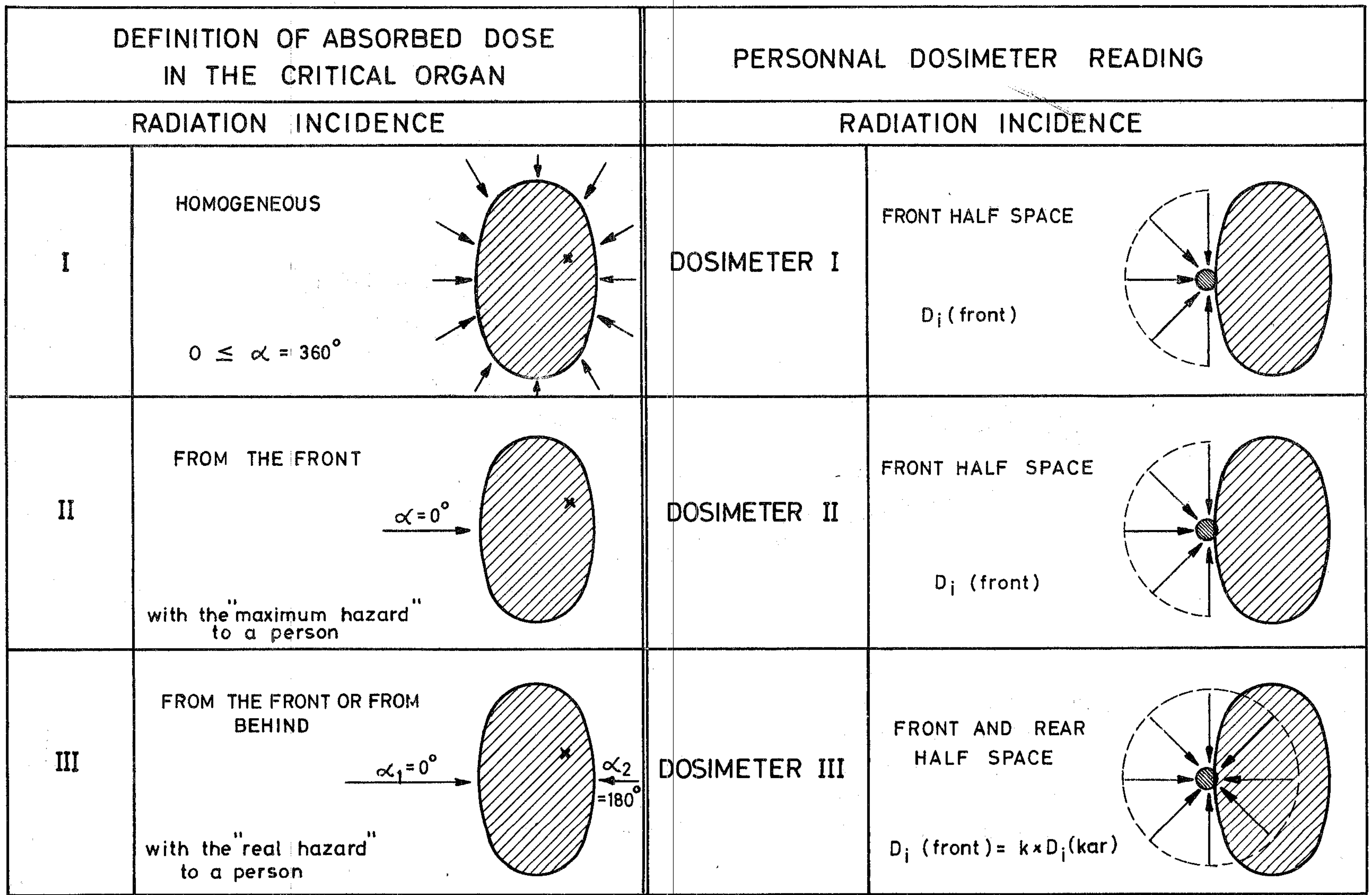


FIG. 3: PHANTOM CALIBRATION FOR ORGAN DOSE INDICATION

Since a dosimeter worn on the front of the body will indicate the exposure from behind with much less sensitivity, the problem of reducing the influence of the body on the dose reading is restricted mainly to these requirements:

- Energy independence of the dose reading for an exposure from the front half space referred to the absorbed dose in the respective organ in the case of frontal exposure
- Energy independence of the dose reading for an exposure from the rear half space referred to the absorbed dose in the respective organ in the case of exposure from behind
- Independently, an attempt is made to get a statement on the direction of radiation incidence, at least on the existence of an exposure from the front or from behind.

If the requirements are fulfilled, the absorbed dose in the respective organ, again independent of the radiation energy, is easily calculated for an exposure from behind considering a correction factor for exposure from behind (ratio of dose reading for frontal exposure to dose reading for exposure from behind referred to the same exposure).

The information about the direction of radiation incidence is not needed if the dosimeter has the dose sensitivity and direction dependence wanted for the measurement of the respective organ dose.

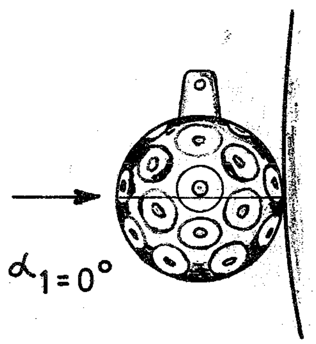
Below, two different methods were adopted to realize an indication of the organ dose by a personnel dosimeter in the way outlined, i.e. by improving the energy compensating filter in the dosimeter capsule and by an improvement of the method of fluorescence measurement.

3) Phosphate Glass Dosimeters for Measurements of the Organ Dose

In the Karlsruhe Nuclear Research Center different energy compensating filters for the Yokota glass (11) of the size 8 x 8 x 4.7 mm^3 were developed in the past 5 years to reduce the energy dependence of the dose reading and the influence of body orientation (see Fig. 4):

PHOSPHATEGLASS DOSIMETERS FOR ORGAN DOSE INDICATION

DOSIMETER I



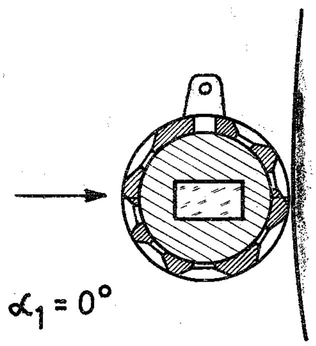
FOR ENERGY INDEPENDENT DOSE MEASUREMENT

spherical capsule
2 mm tin, perforated

ENERGY DEPENDENCE

exposure	± 10 % (>45 keV)
organ dose	± 20 % (> 60 keV)

DOSIMETER II



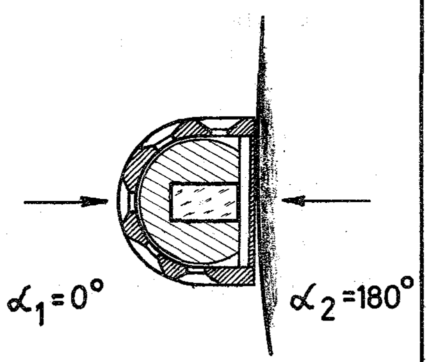
FOR ORGAN DOSE INDICATION

spherical capsule
1.2 mm tin, perforated

ENERGY DEPENDENCE

organ dose	± 16 % (>50 keV)

DOSIMETER III



FOR ORGAN DOSE INDICATION AND REDUCTION OF BODY INFLUENCE

half-spherical capsule
2 mm tin, perforated

ENERGY DEPENDENCE

± 20 % for α_1 (>50 keV)
± 26 % for α_2 (>70 keV)
(Testes and gut muc. without corr.factor for α_2)

FIG. 4:

- Phosphate glass dosimeter I with the direction independent indication of the exposure on the phantom for a radiation incidence from the frontal half space
- Phosphate glass dosimeter II with the direction independent indication of the absorbed dose in all critical organs of interest for a radiation incidence from the frontal half space
- Phosphate glass dosimeter III with the direction independent indication of the absorbed dose in the respective organ, e.g. testes and gut mucosa, for all directions of radiation incidence from the front or rear half space.

All phosphate glass dosimeters realize the indication of the absorbed dose in the organs such as testes, ovaries, gut mucosa, bone marrow, eye lenses, due to the different definitions oforgan dose (see Tab. 2).

3.1 Phosphate Glass Dosimeter I (12)

This routine dosimeter is energy independent and non-directional in its dose reading owing to its spherical capsule. The phosphate glass is contained in a plastic sphere and is covered by two perforated tin hemispheres of 2 mm thickness (holes in 15 % of the surface). For free-air exposure the energy dependence is ± 8 % above a quantum energy of 45 keV. For a phantom irradiation in case of a frontal exposure (exposure from the frontal half space), nearly the quantity exposure is obtained on the surface of the phantom.

Similar to many other personnel dosimeters, dosimeter I indicates the absorbed dose in the critical organs above 60 keV to the extent that definition 1 (rotating phantom calibration) is used as a basis of the organ dose (see Tab. 2). The spherical dosimeter described here is used in Karlsruhe as a routine dosimeter in personnel dosimetry and for environmental monitoring (see (13)).

3.2 Phosphate Glass Dosimeter II (10,14)

This design of a spherical dosimeter is distinguished from phosphate glass dosimeter I in the use of a 1.2 mm thick perforated tin capsule. It was developed specially for the measurement of the absorbed dose in the critical organs. For calibration to an organ dose definition II (direction of radiation incidence with a maximum hazard to a person) was used as the basis.

Energy Dependence of the Dosimeter Reading					
Critical Organ	Dosimeter I	Dosimeter II	Dosimeter III		
			Front	Back	Correction Factor Front/Back
	60 keV - 1.2 MeV	50 keV - 1.2 MeV	50 keV - 1.2MeV	70 keV - 1.2MeV	
Testes D_t	± 9 %	± 14 %	± 13 %	± 20 %	1.33
Gut Mucosa D_g	± 16 %	± 16 %	± 14 %	± 25 %	1.24
Bone Marrow D_b	± 18 %	± 11 %	± 14 %	± 26 %	4.38
Ovaries D_o	± 20 %	± 15 %	± 20 %	± 16 %	4.2
Eye Lenses D_e	± 15 %	± 14 %	± 14 %	-	-

Table 2: Energy Dependence of the Dosimeter Reading for Indication of absorbed Dose in the Critical Organs

Phantom calibrations (see Tab. 2) indicated the reading of this dosimeter to be within ±16 % proportional to the absorbed dose in the most important critical organs for frontal exposure above 50 keV. In this case it is possible on the basis of calibration factor dependent on the organ to obtain the absorbed dose in the desired organ quite easily from the dosimeter reading directly:

$$D_b = 0.57 \times D_g = 0.6 \times D_t = 1.17 \times D_o$$

D_i = absorbed dose in the critical organs:
D_b bone marrow, D_g gut mucosa, D_t testes, D_o ovaries

Dosimeter II has the advantage to indicate an absorbed dose in the respective organ independent of the energy and independent of converting afterwards from the dosimeter reading to the dose in any desired organ without additional dosimeter calibration. A disadvantage, as in all personnel dosimeters, is the low sensitivity of the dosimeter in the case of radiation incidence from behind; hence, no information is available on the absorbed dose in the critical organ for this ease of exposure.

3.3 Phosphate Glass Dosimeter III

The energy compensating filter of the phosphate glass dosimeter III consists of a 2 mm thick perforated tin hemisphere on the dosimeter side facing away from the body and of a plastic filter with a 0.5 mm thick copper foil on the dosimeter side facing the body. The version of this encapsulation of the hemisphere turned out to be particularly suitable for increasing the dose reading, above all, for low-energy X-rays in the case of radiation incidence from behind. Since the dose sensitivity of the phosphate glass at 50 keV is higher by a factor of 6 than the sensitivity at 1.2 MeV opening of the energy compensating filter on the side facing the body should result in the desired increase of the sensitivity for exposure from behind.

The dose reading of phosphate glass dosimeter III referred to an exposure of 1 R is shown in Fig. 5 for exposure from the front and the rear. In the case of frontal exposure the energy dependence already achieved by dosimeter II is attained, i.e. ± 14 % above 50 keV for all critical organs of interest (exception: ovaries ± 20 %, see Fig. 6).

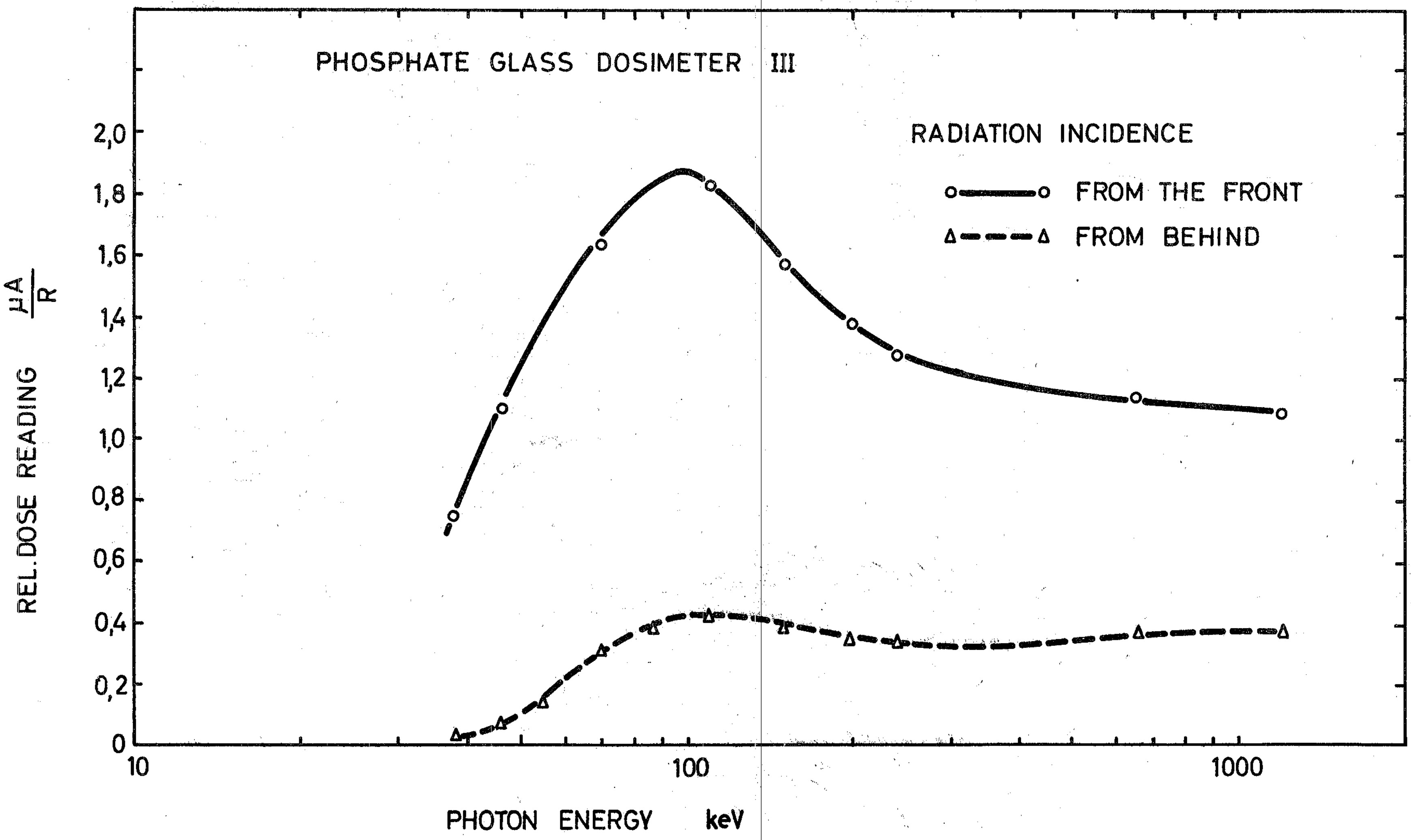


Fig. 5: Dose reading of phosphate glass dosimeter III

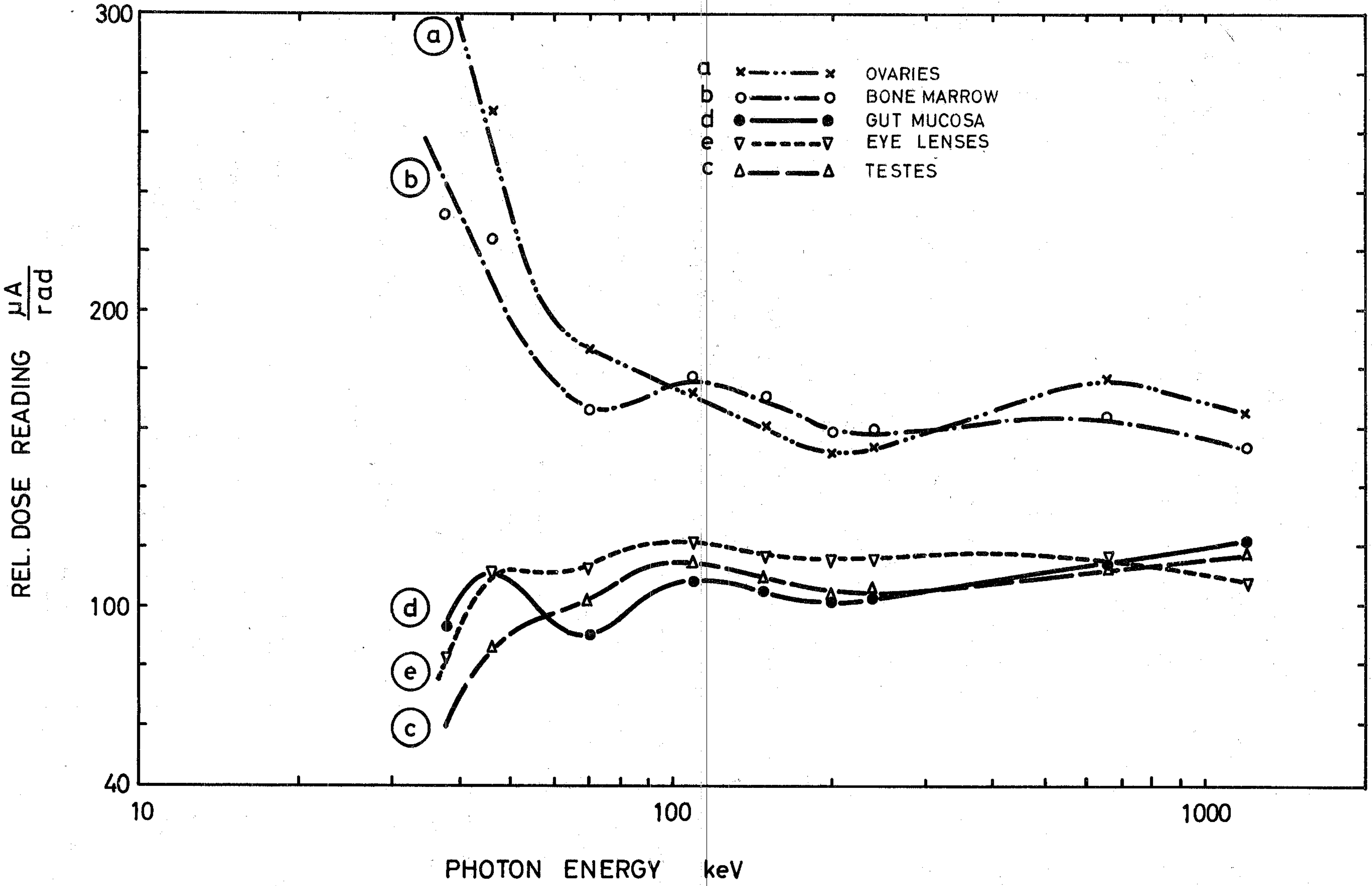


Fig. 6: Organ dose indication of phosphate glass dosimeter III for frontal exposure

For the case of an exposure from behind, of course, a more unfavourable energy independence is achieved (see Fig. 7). This is an energy dependence of ± 38 %, which is obtained for the ~~absorbed~~ dose in the critical organs such as gut mucosa and testes above 50 keV, and an energy dependence of ± 26 % above 70 keV for the absorbed dose in all critical organs (see Tab. 2). Only the indication of the absorbed dose in the eye lenses is energy-dependent from an exposure from behind.

The corresponding mean correction factor for exposure from behind (ratio of the dose reading for frontal radiation incidence to the dose reading for radiation incidence from behind)on the phantom referred to the same exposure) results from Fig. 6 and 7 to a value of 1.33 and 1.24 for the absorbed dose in the organ such as testes and gut mucosa.
Fig. 8 and 9 show the direction dependence of dosimeter III found for the indication of the absorbed dose in the testes and gut mucosa by phantom exposures with quantum energies of 50, 150 and 660 keV. In case of an exposure from the frontal half space, the dose reading was referred to the organ dose for frontal exposure, in case of an exposure from the rear half space to the organ dose for exposure from behind.
For the indication of the absorbed dose in the testes the direction dependence of the dose reading was found to be within ± 20 %. Therefore dosimeter III is energy and direction dependent within ± 30 % in the energy range of 70 keV to 1.2 MeV referred to any direction of radiation incidence from the front or rear half space. No correction factor for an exposure from behind has to be considered.
The organ dose indication of dosimeter III thus is roughly energy independent for exposure from the rear and the front, at least for the organs such as testes and gut mucosa.
However, a distinction between frontal exposure and exposure from behind is necessary for the correct dose indication in the ovaries and bone marrow. The conventional method of fluorescence measurement technique offers no possibility to indicate the direction of radiation incidence.

4) New Method of Differential Fluorescence Measurement

4.1 Method

Generally silver-activated phosphate glasses are excited to fluorescence and evaluated in the entire glass body. Our experiments on the improvement of fluorescence measurement stated that the phosphate glass can be continuously

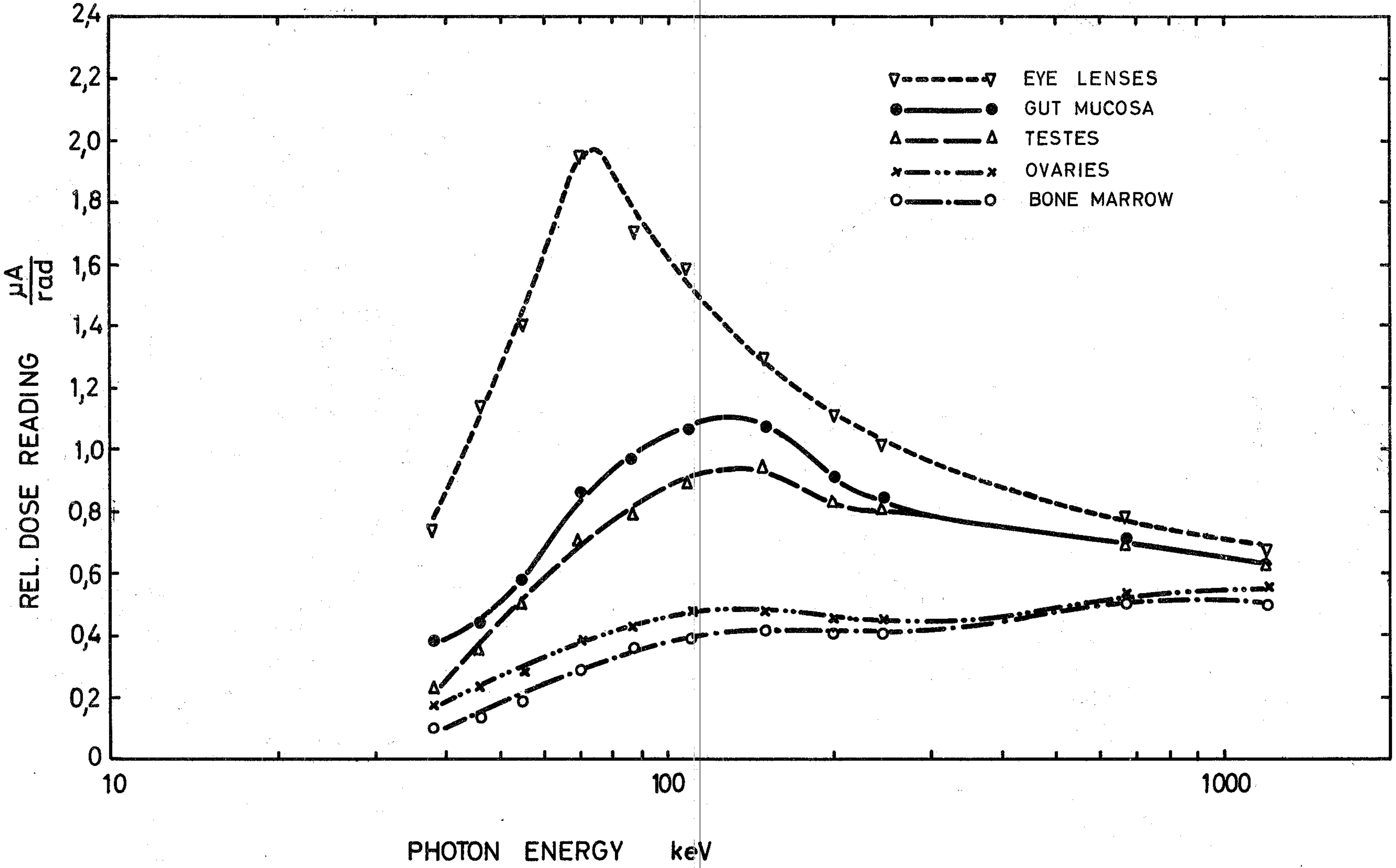


Fig. 7: Organ dose indication of phosphate glass dosimeter III for exposure from behind

INDICATION OF ABSORBED DOSE IN TESTES

RADIATION INCIDENCE

FROM FRONT FROM BEHIND

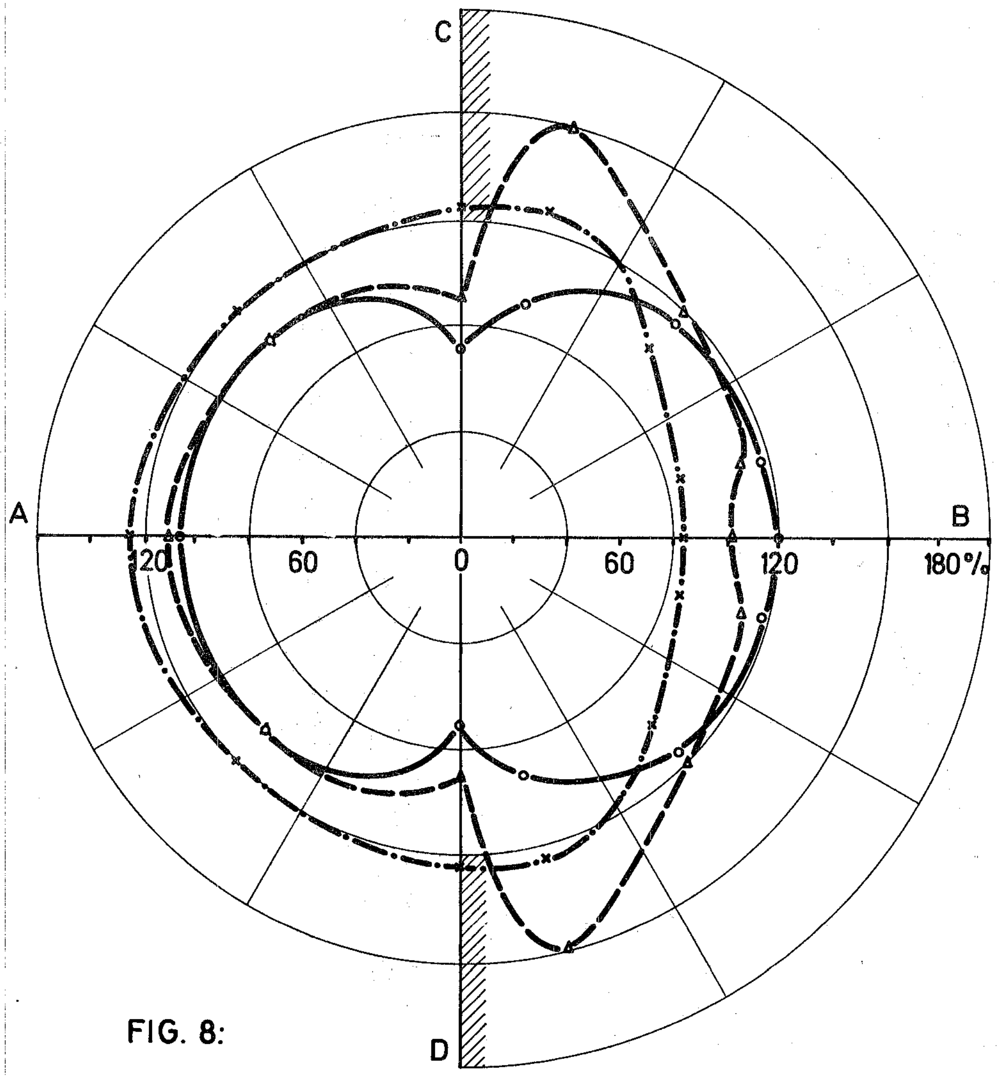


FIG. 8:

Cs 137 x—·—x
150 keV Δ— —Δ
50 keV o——o

INDICATION OF ABSORBED DOSE IN GUT MUCOSA

RADIATION INCIDENCE

FROM FRONT FROM BEHIND

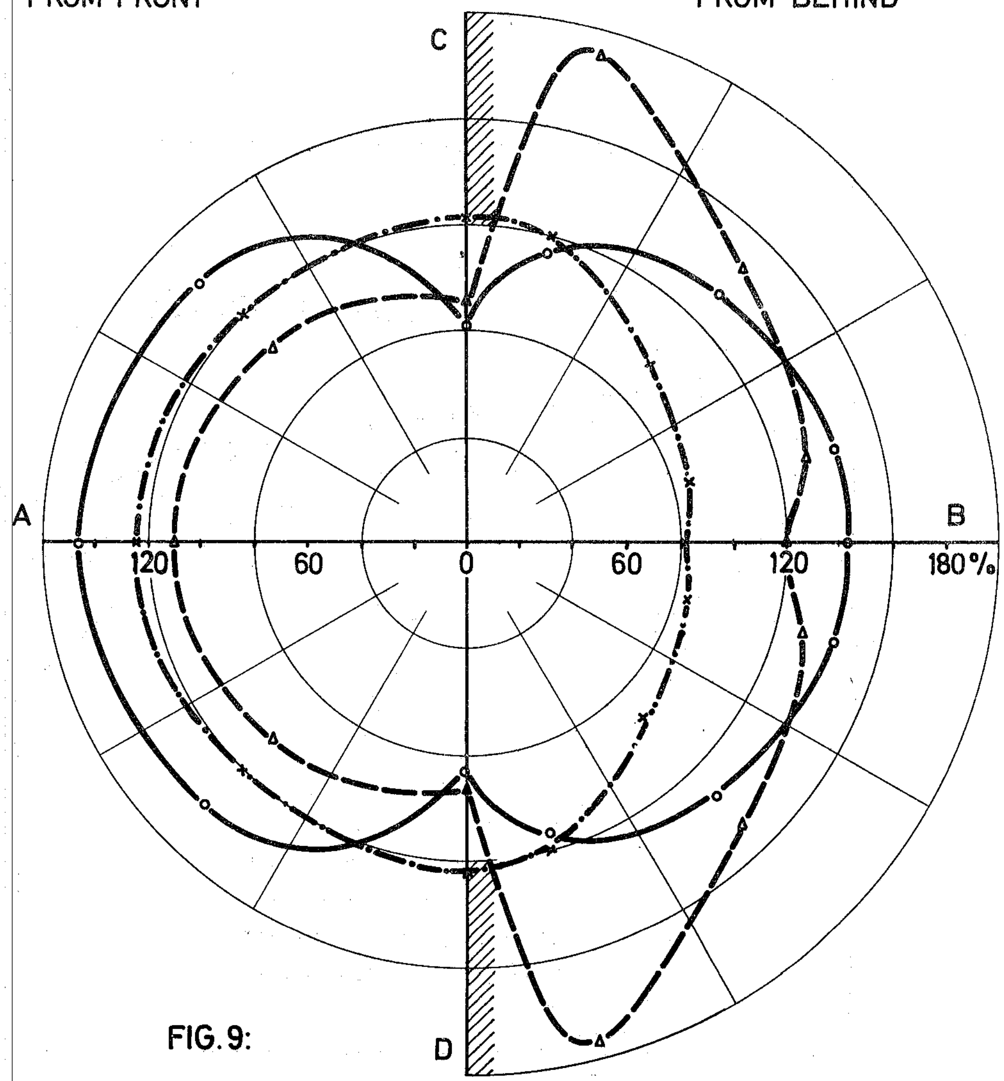


FIG. 9:

Cs 137 x—·—x
150 keV Δ— —Δ
50 keV o——o

scanned in any depth of the glass using a differential evaluation technique. Fig. 10 shows the schematic arrangement of the measurement. The glass is moved on a slide continuously in the x-direction through a gap and excited to fluorescence by UV light in the y-direction. The fluorescence intensity is detected in the z-direction. By means of a recorder the differential fluorescence intensity can be directly recorded as a function of the glass depth within 5 seconds (15,16).

Proving the new technique the following results were obtained:
From the decrease of the differential fluorescence intensity it is possible to derive the radiation quality for X-rays below 300 keV (see Fig. 11). If the radiation quality and the corresponding dose sensitivity of the glass are known, the free-air exposure is obtained from the differential dose reading in a given depth. By evaluation in three levels which are perpendicular to each other, the direction of radiation entrance and exit can be determined. This paper cannot deal completely with the advantages of this new measurement technique and the possibilities for personnel monitoring.

The differential method of evaluation offers the possibility for our problem to supply direct information on the existence of a radiation incidence from the rear or the front.

4.2 Application of Differential Fluorescence Measurement with Phosphate Glass Dosimeter III

It is obvious to determine the organ dose independent of the energy by the conventional measuring method for phosphate glass dosimeter III and to apply the differential fluorescence measurement in addition to determine the direction of radiation incidence in case of major radiation burden. Hence, phantom exposures were carried out on phosphate glass dosimeters III to ascertain whether it may be distinguished between rear exposure and frontal exposure by a differential evaluation of the glass. Fig. 12 shows the shape of the depth dose curves for both directions of exposure as a function of the glass depth. The exposure was carried out with homogeneous X-rays in the energy range between 40 keV and 660 keV. For frontal exposure no decrease of the depth dose distribution is observed due to the dosimeter capsule, above all with high-energy gamma radiation > 100 keV. However, with exposure from behind a significant decrease of the depth dose curve in the direction of the radiation incidence is observed in all cases. Hence, a distinction between directions of radiation incidence is possible with the method outlined.

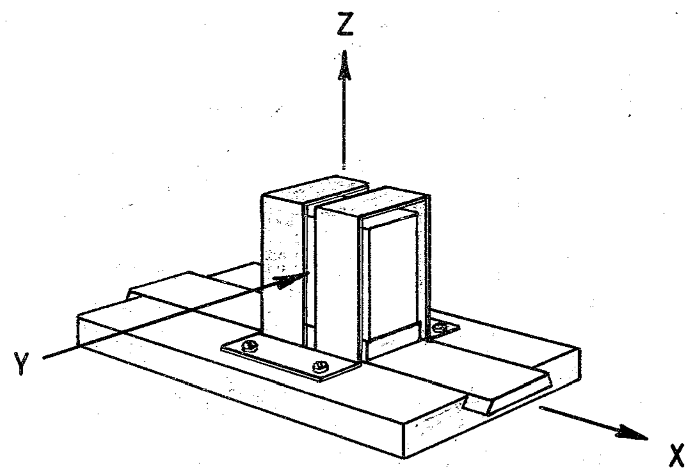


Fig. 10: Arrangement for differential fluorescence measurement

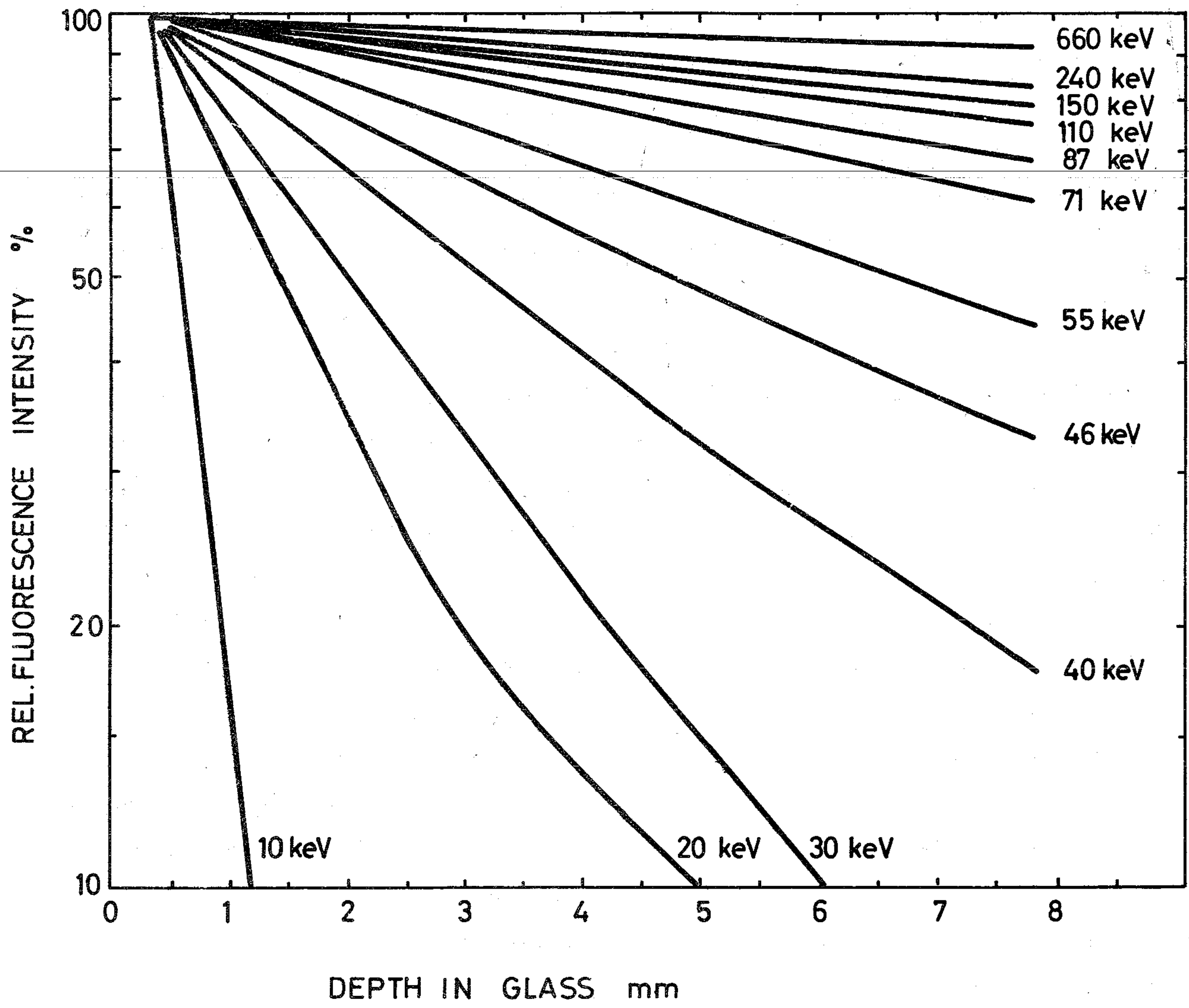
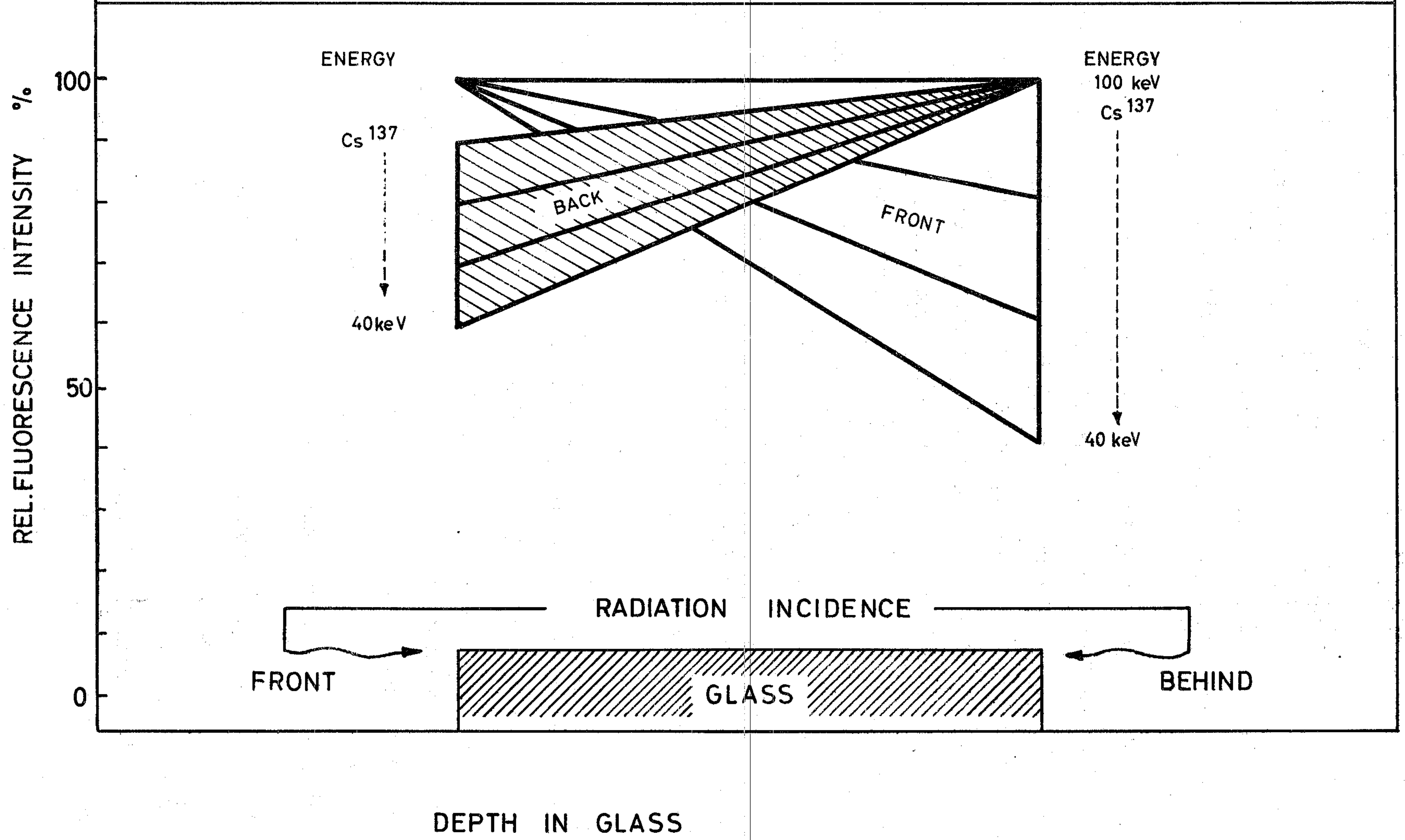


Fig. 11: Depth dose distribution curves of the Yokota glass

FIG. 12: DEPTH DOSE DISTRIBUTION IN GLASS DOSIMETER III FOR DIFFERENT IRRADIATION INCIDENCE AND QUANTUM ENERGY



However, to determine the direction of radiation incidence ,three measurements would be sufficient as well, e.g. in the center of the body, on the sides of the glass facing the body and away from the body, respectively.
The phosphate glass dosimeter III described here for the evaluation of which the energy independent dose measurement was combined with the differential depth dose measurement, may be regarded as a dosimeter with energy independent and non-directional indication of the organ dose.

The influence of body orientation was reduced to a sufficient extent, at least for directions of radiation incidence from the frontal half space. An exposure from behind will be encountered from the decrease of the depth dose distribution, when the glass is scanned in the direction AB. Scanning of the glass in the direction CD (perpendicular to AB, parallel to the surface of the body) still permits a distinction between exposure from the front or from behind even at oblique incidence of radiation due to partial covering of the detector. In the case of exposure from behind an other value of the dose sensitivity must be taken into account for the estimation of the corresponding organ dose (see Tab. 3). Thus, phosphate glass dosimeter III achieves an energy independent indication of the absorbed dose in all organs of interest for any direction of radiation incidence from the front or rear half space.

5) Further Possibilities of Reducing the Influence of the Body

So, conventional dosimeter encapsulations of the type described above do not solve the problem generally as to determining an organ dose by a personnel dosimeter independent of the orientation of the person relative to the radiation incidence. The problem was reduced to the question how to distinguish a frontal exposure from an exposure from behind, especially in case of an exposure accident. Such evidence can be given in various ways:

- In many cases of accidental exposure the radiation field is known, so the direction of radiation incidence or the orientation of the body can be estimated.
- A simple distinction between the two directions of radiation incidence can be made by wearing one dosimeter each on the front and the rear of the body.
- In a combination of two phosphate glasses in a common capsule with an absorption foil in-between, the difference in dose readings referring to the glass facing the body and the glass looking away from the body may give

Table 3: Determination of the Organ Dose for Dosimeter III

Determination of the Organ Dose D_x(rad) from the dosimeter reading F(μA)	
Radiation incidence from the front	Radiation incidence from behind
Testes $D_t = 0.0097 \times F$	Testes $D_t = 0.0128 \times F$
Gut mucosa $D_g = 0.98 \times D_t$	Gut mucosa $D_g = 0.92 \times D_t$
Bone marrow $D_b = 0.59 \times D_t$	Bone marrow $D_b = 1.93 \times D_t$
Ovaries $D_o = 0.54 \times D_t$	Ovaries $D_o = 1.72 \times D_t$
Eye Lenses $D_e = 0.97 \times D_t$	
$D_b = 0.60 \times D_g = 0.59 \times D_t = 1.08 \times D_o$	$D_b = 2.09 \times D_g = 1.93 \times D_t = 1.12 \times D_o$

information on the incidence from the rear.

- As an improvement of the method of fluorescence measurement a continuous scanning of the glass is possible to determine the direction of radiation incidence. The decrease of the measured depth dose distribution in the glass enables distinguishing between an exposure from the front and an exposure from behind.

Neglecting trivial solutions,only an increase in size of the dosimeter capsule or an improvement of the evaluation method will be successful. An increase in size of the dosimeter capsule (two glasses with an additional filter in between) is undesirable in general,since, on the one hand, only a single dosimeter safeguards a sufficiently good accuracy of dose measurement and energy independence while, on the other hand, the present capsule of dosimeter II (hemisphere) is already complicated enough in design. Hence, it would be obvious to achieve additional improvements in the evaluation technique, i.e. the excitation of fluorescence and the fluorescence measurement of the phosphate glass.

In this paper it was shown that an improvement of the energy compensating filter and of the technique of fluorescence measurement is very successful to reduce the influence of body orientation on the dose indication of a personnel dosimeter (see Fig. 13). The dosimeter capsule III described has the purpose of measuring the absorbed dose in the critical organs independent of the radiation energy. A distinction between exposures from the rear or from the front was found by the differential fluorescence evaluation of the phosphate glass.

The new measuring method to determine the depth dose distribution in the glass in principle also offers the possibility of using a phosphate glass dosimeter without the usual energy compensating filter. In that case the dose is determined by an energy dependent method of evaluation.
To assess the direction of radiation incidence the glass dosimeter is scanned first in three levels perpendicular to each other. In a cylindrical glass this can be done by rotating the glass around its axis of rotation. From the decrease in the differential fluorescence intensity in the direction of radiation incidence the radiation quality and thus the exposure or an organ dose can be determined with the dose sensitivity taken into account. Experimental results so far obtained in local dosimetry show a measuring accuracy of 10 % also for inhomogeneous radiation and exposure to two-component mixtures of radiation (16) when the direction of radiation incidence is known. This work will be continued in the field of personnel dosimetry.

FIG. 13: REDUCTION OF BODY INFLUENCE ON THE DOSIMETER READING

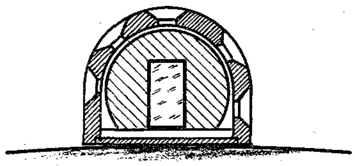
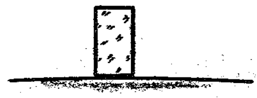
	Improvement of the energy compensation filter	Improvement of the fluorescence measurement
DOSIMETER	 Phosphate glass in perforated, half-spherical capsule	 Phosphate glass
FLUORESCENCE MEASUREMENT	Fluorescence measurement in the entire glass body	Measurement of depth dose distribution in glass by multi-scanning method
ORGAN DOSE INDICATION	Energy independent organ dose indication above 50 keV front: ± 14 % back: ± 38 %	Organ dose determination with information of radiation quality and radiation incidence from depth dose distribution (energy dependent method)
REDUCTION OF BODY INFLUENCE	ONLY FOR TESTES AND GUT MUCOSA: No distinction between frontal exposure and exposure from behind Correction factor for exposure from behind (bone marrow, ovaries)	Indication of radiation incidence (frontal exposure or from behind)
	Combination of both methods: Phosphate glass dosim.III	
	Energy independent dose reading	Information of radiation incidence

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Fig. 1	Absorbed dose in various organs of an Alderson phantom as a function of quantum energy referred to an exposure of 1 R and radiation incidence on the frontside of the phantom (1)
Fig. 2	Absorbed dose in various organs of an Alderson phantom as a function of quantum energy referred to an exposure of 1 R and radiation incidence from behind the phantom (1)
Fig. 3	Phantom calibration for organ dose indication
Fig. 4	Phosphate glass dosimeters for organ dose indication
Fig. 5	Dosimeter reading of phosphate glass dosimeter III exposed at the frontside of an Alderson phantom as a function of quantum energy for a radiation incidence from the front and from behind the phantom referred to an exposure of 1 R
Fig. 6	Dosimeter reading of phosphate glass dosimeter III exposed at the frontside of an Alderson phantom as a function of quantum energy referred to the absorbed dose of 1 rad in different organs and radiation incidence from the front
Fig. 7	Dosimeter reading of phosphate glass dosimeter III exposed at the frontside of an Alderson phantom as a function of quantum energy for a radiation incidence from the front and from behind the phantom referred to an exposure of 1 R and radiation incidence from behind the phantom
Fig. 8	The direction dependence of the relative dose reading pf phosphate glass dosimeter III at the frontside of an Alderson phantom for quantum energies 50, 150 and 660 keV referred to the absorbed dose of 1 rad in the critical organ such as testes and radiation incidence from the frot and from behind.
Fig. 9	The direction dependence of the relative dose reading of phosphate glass dosimeter III at the frontside of an Alderson phantom for quantum energies 50, 150 and 660 keV referred to the absorbed dose of 1 rad in the critical organ such as gut mucosa and radiation incidence from the front and from behind
Fig. 10	Arrangement for the differential evaluation technique of phosphate glasses: Glass is moved in the x-direction Fluorescence stimulation in the y-direction Fluorescence measurement in z-direction
Fig. 11	The differential fluorescence intensity of the Yokota phosphate glass as a function of glass depth for different quantum energy referred to an exposure of 1 R
Fig. 12	See figure
Fig. 13	See figure