PROBLEMS AT THE DEVELOPMENT OF PERSONAL BETA-PARTICLE DOSEMETERS
-BETA PARTICLE DOSEMETERS-

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1. ABSTRACT:

Workplaces at which beta radiation might significantly contribute to the doses to the extremities are increasingly found in radiation therapy, radiation source production and nuclear power plants. For the measurement of the individual beta-particle dose, personal dosemeters for fingers, arms and legs are needed. Intercomparison measurements organised from 1996 to 1999 by the PTB have shown that some dosemeter types based on TLD are suitable for this purpose and can be used as legal dosemeters for both photon and beta radiation.
Also, some electronic personal photon dosemeters are investigated in beta radiation fields. It turned out that a few types are also sensitive to beta radiation and measure the personal dose equivalent rate to the skin with a low energy dependence. Only their wearing position is by far not optimal for extremity dosimetry because they are worn on the chest. Advantages and disadvantages are discussed.
The characterisation of workplaces is carried out by measuring dose profiles using area dosemeters. Investigations performed with several commercial types of these dosemeters furnish information about the selection of the suitable measuring device and its correct practical use. The development of improved dosemeters has to go towards smaller detectors and higher sensitivity.
Personal dosemeters have to be robust and acceptable to the user, which generally is not achieved for beta extremity dosemeters. It is an additional problem that even such dosemeters cannot always be worn in the appropriate place.

2. INTRODUCTION

Workplaces at which beta radiation might significantly contribute to the doses to the extremities are found, for example, in contaminated areas of nuclear power plants and in the field of radiation therapy where ^{106}Ru- / ^{106}Ru and ^{90}Sr / ^{90}Y applicators and ^{188}Re, ^{169}Er, ^{186}Re and ^{90}Y radioactive solutions are used for eye tumour irradiation, intravascular brachytherapy (IVB) and radiosynoviorthesis (RSO). Mielcarek and Barth [Mie 2002; Ba 2002] described measurements at such workplaces using highly sensitive thin-layer TL dosemeters for determining the skin dose on hands and fingers. Daily exposures of 1.4 mSv in the production of eye applicators and of more than 100 mSv in the preparation and use of radioactive solutions for RSO and IVB were found. The conclusions drawn from these investigations are the following:

- Optimisation of radiation protection (shielding, observation of dose limits) at the workplaces investigated is necessary.
- Introduction of legal beta particle dosemeter (partial-body) for monitoring the personnel is required.
- Training and information of the personnel about specific problems at beta workplaces are to be ensured.
- The exchange of experience in this field should be increased.

In 1996 and 1998/99, the PTB organised two-step intercomparison measurements of dosemeters to be worn on the extremities and capable of measuring the personal dose equivalent, $H_p(0.07)$, in beta and/or photon radiation fields. The results were evaluated on the basis of recommendations laid down by the German Commission on Radiological Protection [SSK 1994] and have been presented in detail in two PTB reports [Am 1998, Am 2000] and by Helmstädter and Ambrosi [He 2001]. They allowed the following conclusions to be drawn:

- Results from the first step have shown that beta particle personal dosemeter (partial-body) are available and seven of the ten participating dosemeter types fulfil the requirements for use as legal beta dosemeter. Four of them are experimental dosemeters which are not optimised for routine use.
- For participation in the second step in 1998/99, three promising types of the ten beta dosemeter types referred to above as well as two additional dosemeters were selected. The dosemeters were exposed to beta radiation from the newly developed Beta Secondary Standard BSS2 with ^{147}Pm, ^{85}Kr and ^{90}Sr / ^{90}Y source types and, in addition, to photons and to mixtures of the two.

- For beta radiation with mean energies from 0.2 MeV to 1 MeV, all five dosemeter types fulfil the requirements given by the trumpet curves of the SSK; three dosemeters even do so for the expanded energy range from 0.06 MeV to 1 MeV. For photon radiation from 8 keV to 662 keV, this is true only for four dosemeters.
- All dosemeter types match the trumpet curves of the SSK for angles of radiation incidence from 0° to ± 60°.
- Personal beta dosemeters which can be employed in legal metrology for legal measurements are capable of being approved for photon radiation and thus should be approved.

As to the exchange of experience, the situation regarding the parameters and characteristics of some beta-particle dosemeters (partial-body) and the problems involved in the measurement of the maximum of the personal dose equivalent to the skin will be reported on. Additionally, some information about electronic personal dosemeters and area monitoring dosemeters used for characterising beta workplaces will be given.

3. INVESTIGATION OF BETA PARTICLE DOSEMETERS (PARTIAL-BODY)

The technical data of the dosemeter types considered are summarised in Table 1. Figure 1 illustrates, from top to bottom, the dosemeters TD1, TD3, TD4, TD5. They are given in the order of increasing thickness of the TL detector material in terms of areic mass in mg/cm_, including the matrix material. The types are referred to as TD1 to TD5 to preserve anonymity.

Table 1 : Technical data of the dosemeter types according to information from the participants (SEE means secondary electron equilibrium).

Type	Filter before the detector	TL detector material	TL detector, in terms of areic mass, incl. material of the matrix	Type of ring	Radiation quality used for calibration	Remarks
TD1	Aluminised bilaminar PET foil, max. 4 mg/cm_	7 LiF: Mg, Ti	5 mg/cm_	Strip of plastics	^{137}Cs (with SEE)	Commercial dosemeter
TD2	0.5 mg/cm_ aluminised Mylar foil	LiF: Mg,P,Cu	8 mg/cm^2	Flexible ring of plastics	^{60}Co (with SEE)	Newly developed type
TD3	2 mg/cm_ mylar foil	^{nat}LiF: Mg,P,Cu	7.9 mg/cm^2	Ring of high-grade steel	^{137}Cs (with SEE)	Modified standard photon ring with foil window
TD4	9 mg/cm_ PVC (+1 mg/cm_ PE)	^{nat}LiF: Mg,P,Cu	7.9 mg/cm^2	Ring of high-grade steel	^{137}Cs (with SEE)	Modified standard photon ring
TD5	1 mg/cm_ aluminised foil	^{nat}LiF in Teflon	45 mg/cm^2 / 90 mg/cm^2 / 90 mg/cm^2	Textile ribbon (also available as fixed ring)	^{137}Cs (with SEE)	Energy analysis with triple TLD

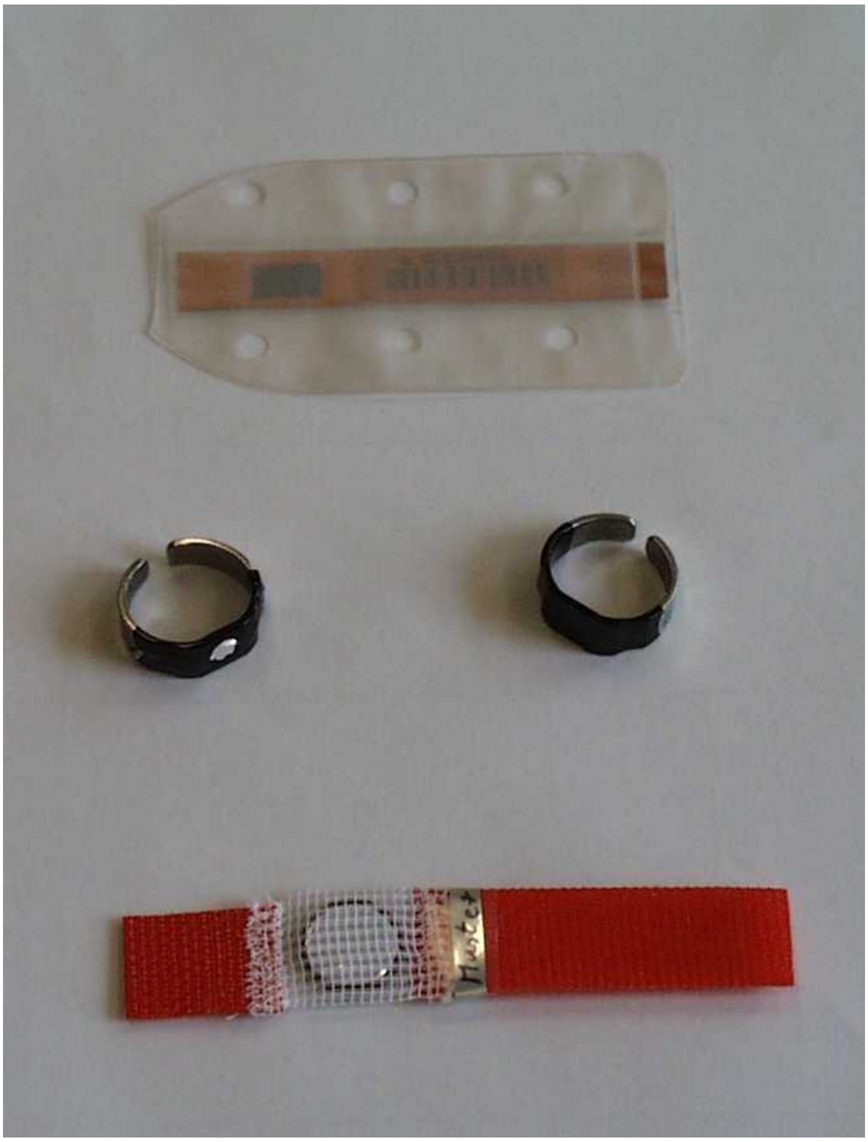

Figure 1: Examples of beta particle dosemeters (partial-body) (from top to bottom: TD1, TD3, TD4, TD5)

The irradiation program for the investigation of the properties can be seen in Figure 2 for photon radiation, in Figure 3 for beta radiation and in Figure 4 for ^{137}Cs and mixed beta / photon radiation. The radiation qualities are designated in accordance with ISO 4037-3 [ISO 1999].

The basis for the assessment of the dosemeter properties is provided by the requirements recommended by the SSK. The minimum rated range of use for energies of the beta particles extends from 0.2 MeV to 1 MeV. As lower limit of the dose range 1 mSv is recommended. The range of the angles of incidence is not explicitly stipulated but should amount to at least ± 60° as for personal photon dosemeters. The maximum allowable relative deviation of the response value from unity is given by so-called "trumpet curves." For mean energies of the beta particles lower than 0.2 MeV, special (less stringent) limits are allowed.

The results of the investigation are summarised in Figures 2 to 4 as response, i.e. as the ratio of the personal dose value $H_{pt,}$ as evaluated by the participant to the conventional true dose value H_{PTB} applied to the dosemeter by the PTB. The designations TD1 to TD5 for the dosemeter types are in keeping with the assignment given in Table 1. The limits according to the "trumpet curves" are also given in each figure as lower limit (LL) and upper limit (UL). The figures show the dependence of the response on energy, dose and angle of incidence for photon radiation (Figure 2), beta radiation (Figure 3) and photon/beta and beta/beta mixed radiation (Figure 4). As described in [He 2001] four of the dosemeters considered fulfil the recommendations of SSK for beta and photon radiation and even three for the expanded mean energy range from 0,05 MeV to 1 MeV.

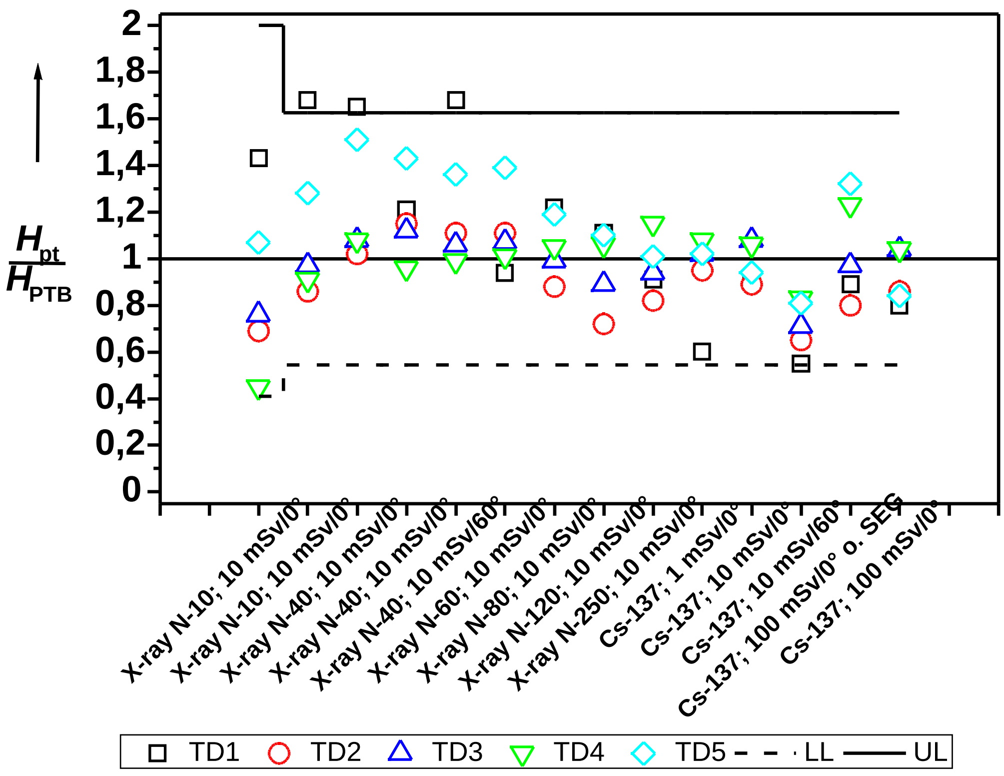

Figure 2: Response H_{pt}/H_{PTB} together with the allowable limits according to the SSK recommendations for beta particle dosemeters (partial-body) for photon irradiations. H_{pt} is the dose value $H_p(0.07)$ determined by the participant and H_{PTB} the conventional true value $H_p(0.07)$ of PTB.

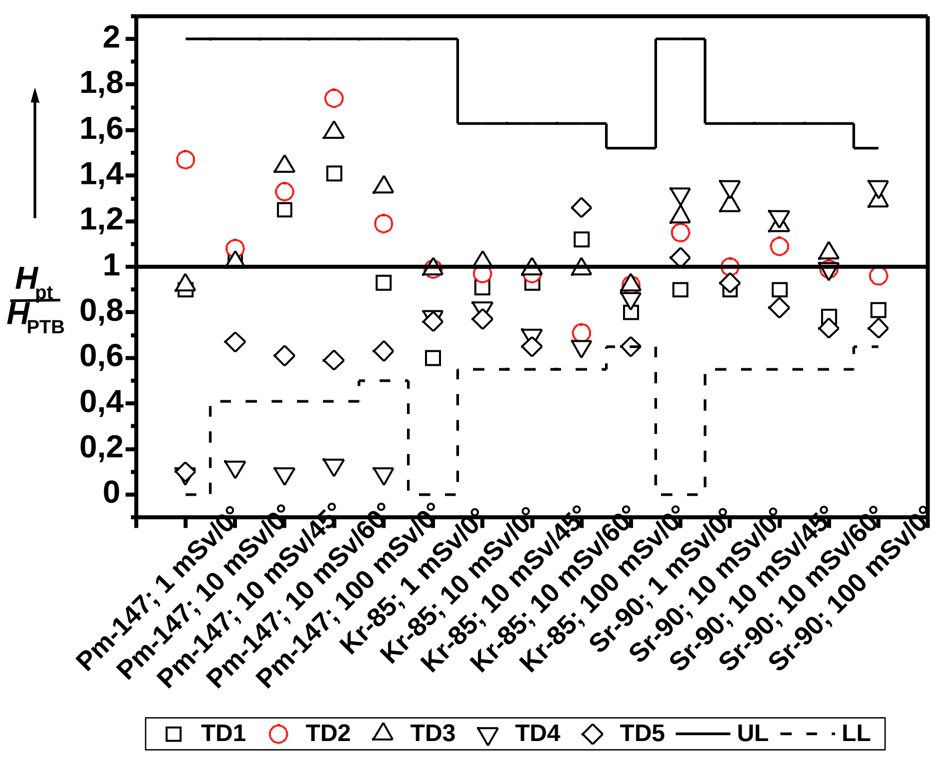

Figure 3: Response H_{pt}/H_{PTB} together with the allowable limits according to the SSK recommendations for beta particle dosemeters (partial-body) for beta irradiations. H_{pt} is the dose value $H_p(0.07)$ determined by the participant and H_{PTB} the conventional true value $H_p(0.07)$ of PTB.

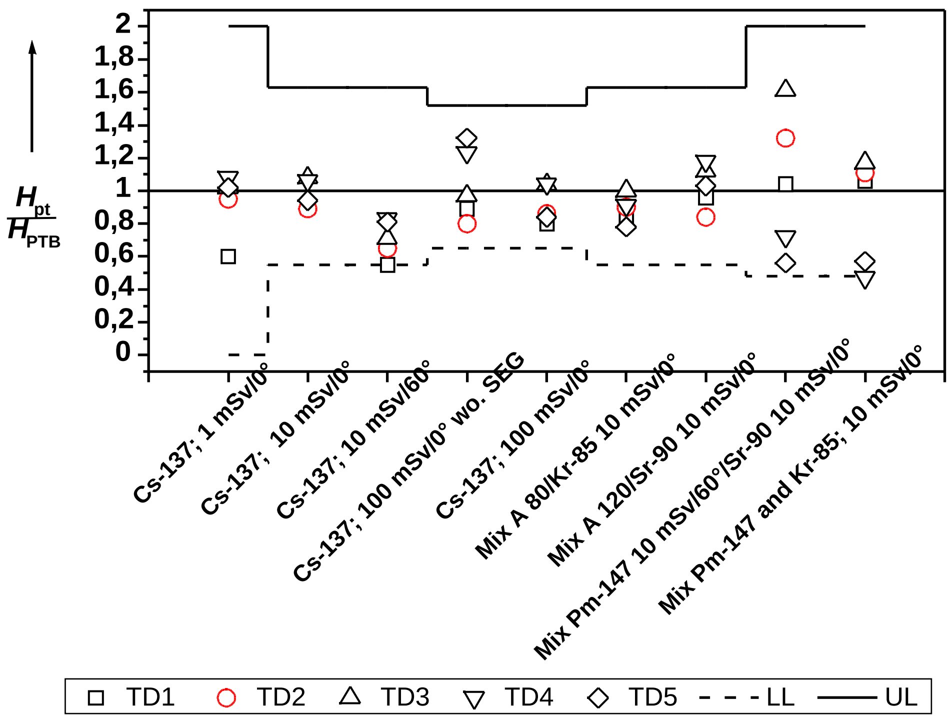

Figure 4: Response H_{pt}/H_{PTB} together with the allowable limits according to the SSK recommendations for beta particle dosemeters (partial-body) for ^{137}Cs and photon/beta mixed irradiations. H_{pt} is the dose value $H_p(0.07)$ determined by the participant and H_{PTB} the conventional true value $H_p(0.07)$ of PTB.

4. PROBLEMS IN PRACTICAL OPERATION OF THE PERSONAL BETA–PARTICLE DOSEMETER WITH TLD

The development of special thermoluminescence dosemeters sensitive to beta radiation has reached a satisfactory level. Thin-layer TLD on a thin foil carrier or thin insensitive (undoped) material is used for individual monitoring.

One essential problem of these dosemeters is their handling during preparation and evaluation. Before use these TLDs must be carefully selected with respect to beta sensitivity, and during use the handling of the thin material and the encapsulation in thin protective layers during the preparation of the ring is mainly manual work, which is cost-intensive. Standard TL cards as are employed for whole-body dosemeters and which are suitable for automated handling cannot be used.

The dosemeter types TD1, TD2 and TD3 show a systematic increase in the response with increasing angle of incidence for low-energy beta radiation as can be seen in Figure 3. The dosemeter TD3 also participated in the EURADOS intercomparison where it did not show such a strong angular dependence. Investigations with a great number of TLDs (30 detectors) based on LiF:(Mg,P,Cu) as detector material in ^{147}Pm beta fields as described by Burgkhardt, Helmstädter and Ambrosi [Bu 2000] showed that all intercomparison results are affected by a very large scatter of the detector response especially for low-energy beta radiation. In Figure 5 these results of comparison measurements and of additional investigations are presented. In view of great standard deviations of the values measured for a single dosemeter better consistent results cannot be expected. The cause for these deviations was the different distribution of the radiation-sensitive material on the detector surface and inhomogenities of the covering mylar foil.

As can be seen in Table 1, all dosemeters which are doped with phosphorus are also suitable for photon radiation. Only TD1 doped with magnesium and titanium without phosphorus is not suitable for low-energy photons.

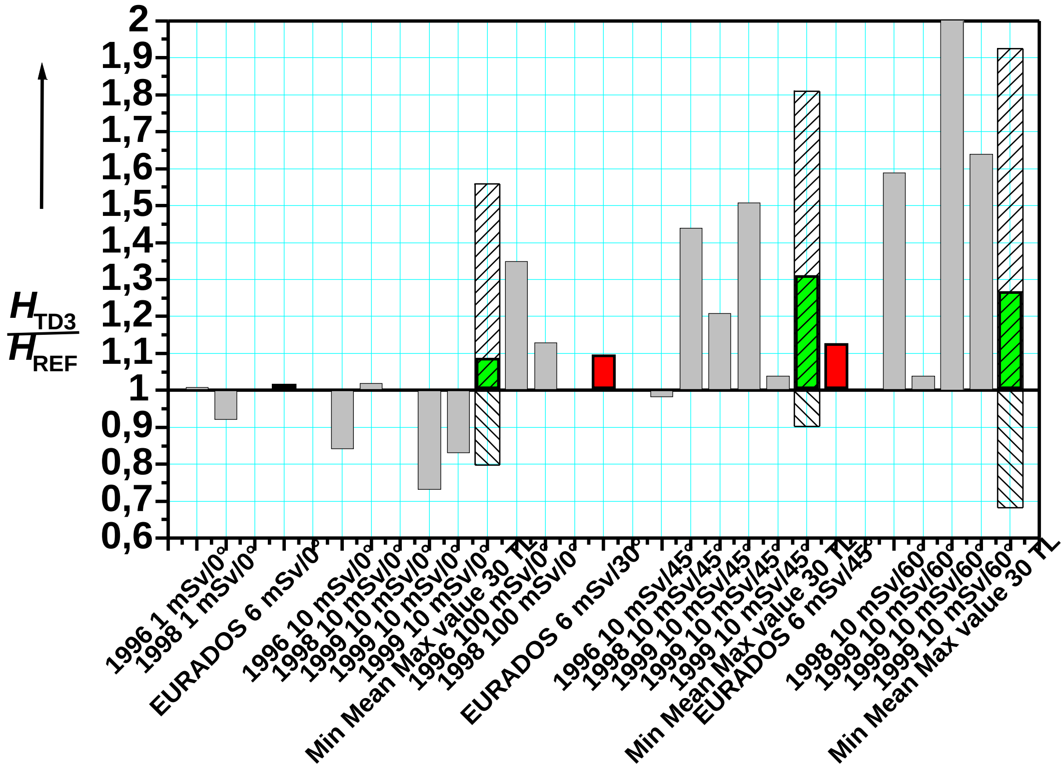

Figure 5: Investigation of the dependence on the angle of incidence in low-energy beta calibration fields (^{147}Pm). The dashed bars show the scatter of the results by giving the minimum, mean and maximum value.

Investigations on standard photon rings in beta radiation fields of ^{85}Kr and ^{90}Sr / ^{90}Y sources proved that these dosemeters cannot be used for beta dose measurements. The response decreases from about 1 for ^{90}Sr / ^{90}Y at 0° incidence to 0.4 at 60° incidence and to 0.2 for ^{85}Kr beta radiation. High-energy beta fields are always accompanied by low-energy components behind the shielding which would be underestimated. For photon rings in beta fields the measuring value 0 therefore does not necessarily imply that there is no beta radiation at all. Especially behind the shielding, a significant contribution to the personal dose equivalent to the skin could be caused by low-energy beta radiation.
The wearing place of the TL dosemeter normally is not the place where the maximum of the exposure occurs. A detailed analysis of the workplaces is therefore needed. For this purpose, electronic personal dosemeters can be used and also area monitoring devices. An ideal beta measuring system would be capable of analysing the spectrometric and dosimetric situation at the workplace. An example of such an instrument is a portable triple detector telescope developed within the scope of a joint European research project in the field of dosimetry of weakly penetrating radiation (see PTB Report [Bö 1998]) and described in detail by Helt-Hansen, Larsen and Christensen [HH 1999]. Unfortunately, this instrument is not commercially available.

5. INVESTIGATIONS OF ELECTRONIC PERSONAL DOSEMETERS

Electronic personal dosemeters were also developed for the measurement of the personal dose equivalent to the skin in beta radiation fields. The detector normally is a semiconductor behind a thin entrance window. The response to beta radiation was investigated in beta fields of the Beta Secondary Standard BSS 2 developed at the PTB [Am 1997]. The results are shown in Figure 6 with reference to the response of TLD detectors and ionisation chambers. It could be concluded that the response is acceptable. The only drawback is that these dosemeters are worn on the chest and cannot estimate the exposure of the finger tip. Due to the fact that for beta radiation any backscatter stems from material about 1 cm around the detector, these electronic dosemeters can also be used to measure the directional dose equivalent $H'(0.07)$. Because of the smallness of their detector, these electronic dosemeters are most suitable for measurements near the source. Further improvements could be achieved by an electronic dosemeter with a separate silicon detector probe.

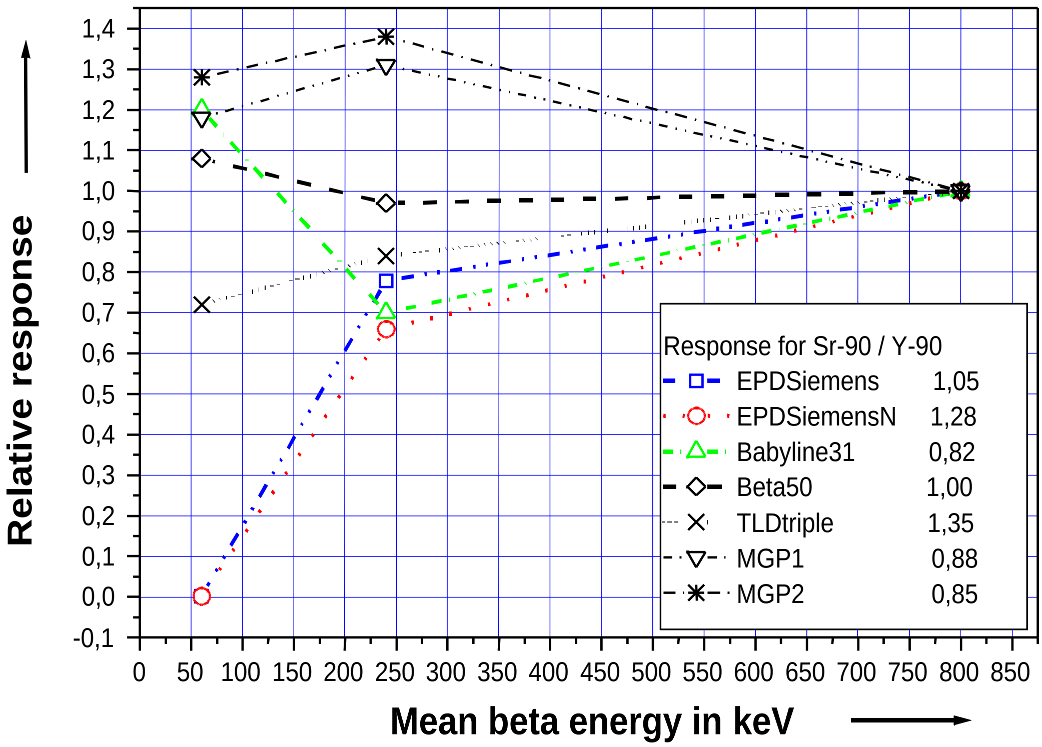

Figure 6: Energy dependence of the relative response to beta radiation normalised to the response for $^{90}Sr/^{90}Y$ of electronic personal dosemeters in comparison to TLD and ionisation chamber dosemeters.

6. INVESTIGATIONS OF AREA MONITORING DOSEMETERS

Additionally, area monitoring dosemeters have to be considered as further possibility for dosimetric measurements at beta workplaces Special devices developed for measurements in beta radiation fields are not realised. In addition to the above-mentioned electronic personal dosemeters, some X-ray gamma dosemeters can be used indeed for measurement of the directional dose equivalent $H'(0.07)$. They have removable caps as cover around their detector (mainly ionisation chambers) and can be used for beta radiation without these caps. Investigations of these dosemeters in beta radiation fields carried out by Helmstädter and Ambrosi at the PTB [He, 2000] came to the conclusion that only ionisation chambers are suitable. The main problem of all of these detectors is the size of the measurement volume. Inside the detector volume, the smaller the calibration distance, the steeper the dose rate. So large corrections must be applied to measurements close to the source. As to the separation of the photon component from the beta component of the field the wall thickness of the cap normally is not sufficient for the beta radiation to be completely absorbed, especially for sources with high beta energies like $^{90}Sr/^{90}Y$.The interpretation of measurements with and without the cap therefore calls for some knowledge of the radiation field.

7. CONCLUSIONS

The description of the situation of the measuring technique for characterising beta workplaces has shown that

- Suitable beta particle dosemeters (partial-body) exist but they need to be improved as regards the optimisation of detector and cover thickness, wearing comfort, robustness, sterilisability and acceptability to the personnel,
- Area monitoring dosemeters for beta radiation fields should be developed with semiconductor detectors (small dimensions and high sensitivity). For example electronic personal dosemeters could be modified for this purpose by separation of the semiconductor (silicon) detector.
- Knowledge of the characteristics of the dosemeters and their application has to be improved (training, exchange of experience and information).
- Spectrometric and dosimetric analysis of workplaces is necessary to find the relation between the place of maximum exposure and the dosemeter wearing place.

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