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Stocktaking Concerning the Situation of Individual Dose and Incorporation Monitoring at Nuclear Facilities

Recommendation of the German Commission on Radiological Protection

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Empfehlung der Strahlenschutzkommission

**In the event of any doubts about the meaning,
the German original as published shall prevail.**

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1 Introduction

According to Sec. 62 of the Radiological Protection Ordinance /SSV 76/, the body doses have to be determined and the individual doses measured in the case of persons who stay in controlled access areas. The dose limits of the Radiological Protection Ordinance refer to body doses. However, body doses cannot be measured directly. As a rule, they are conservatively derived from the individual dose measured and from the results of the incorporation measurements.

The value measured by means of a suitably calibrated individual dosemeter is considered as individual dose. Thus, the individual dose is a measured quantity of practical radiological protection in the case of external exposure. Similarly, incorporation monitoring furnishes measured quantities when handling unsealed radioactive materials. As a rule, said control is effected by a direct measurement of body activity or of the activity of the excretions. In special cases, it may be effected indirectly by measuring the activity of the air.

The determination of the body dose can be waived if there is no suspicion that limits may have been exceeded /SSV 76/. Only if this suspicion occurs as a result of the measurements of the individual dose or of the incorporation monitoring or as a result of other circumstances, will it be necessary to determine the body doses considering the circumstances under which the irradiation occurred. Otherwise, the body dose will be considered equal to the individual dose or to the dose determined by incorporation measurement and comparison with the annual limits of activity intake.

The measurements for individual dose monitoring and incorporation monitoring as carried out by the authorities and the licensees thus aim at monitoring adherence to the limits, and in particular those contained in Annex X to the Radiological Protection Ordinance. The individual dosimetry and incorporation monitoring presently carried out by the authorities and the licensees fulfill this function.

The monitoring of the safety of occupationally exposed persons and the optimization of radiological protection are not only ensured by an individual dose monitoring system of a relatively high standard which is sufficiently conservative and reliable in the range of the dose limits, but also by a set of additional harmonized measures such as contamination and local dose rate measurements as well as determinations of the activity of the air. These measurements are predominantly of a preventive character while individual dose measurements and measurements of the body activity should rather be considered as a confirmation that the approved radiation exposure and workplace conditions do not have deteriorated unnoticed.

For doses far below the dose limits, for example in the range of natural radiation exposure, the measured data of individual dose monitoring and incorporation monitoring are only of slight practical relevance. They serve to monitor and evaluate in terms of quality the efficacy of the licensee's radiological protection measures, and they also serve to preserve evidence. However, as the preservation of evidence is gaining in importance, the question arises whether body doses below the limits are also approximated with a sufficient degree of certainty by the present system of individual dosimetry and incorporation monitoring as practised by authorities and licensees. The question will be dealt with in this stocktaking effort with respect to the various potential exposures and kinds of radiation.

The question cannot be addressed separately for authorities and licensees, but both must be viewed within one and the same context.

Apart from its primary task of checking and documenting the individual dose by an independent body, the individual dosimetry carried out by the authorities also furnishes statements with respect to the collective radiation exposure for the qualitative assessment of preventive radiological protection.

The elaboration of workplace-specific models of exposure and the physical description of the radiation field – which are the preconditions for a realistic determination of body doses – cannot be performed in a routine effort by dosimetry as carried out by the authorities. Therefore, both the individual determination of the body dose which might be necessary and the workplace-specific optimization of radiological protection must remain a task to be performed by the licensee's radiological protection system. The Commission on Radiological Protection (SSK) repeats its recommendation /SSK 88/ aiming at a merger of individual dosimetry and incorporation monitoring carried out by the authorities and the licensees, so that the data will also be available for the central dose register. Moreover, the SSK recommended /SSK 88/ that the documentation and editing of the data derived from individual dosimetry and from incorporation measurements should be brought into line.

The individual dosemeters issued by the measuring laboratories are subject to a multiple quality control. Besides the internal control carried out by the measuring laboratory itself, the PTB carries out reference measurements for photon dosemeters once a year. International comparisons, e.g. within the EC, showed that the results of German measuring laboratories were within the leading group. A regular exchange of experience among the measuring laboratories and close contacts to research laboratories lead to constant improvements in individual dose monitoring.

There are no ideal dosemeters which would be equally well suited for all kinds of radiation and measuring tasks. In each case, the dosemeter which is best suited for the relevant purpose has to be chosen. The more complex the radiation field, the more sophisticated and expensive the individual dosemeters. It may even be necessary that a person wears several individual dosemeter at a time /SSV 76, RöV 87/.

As far as incorporation and individual dose monitoring are concerned, this stocktaking addresses the present state of the art in separate chapters dealing with photon, beta and neutron radiation. Reference is made to possible improvements. Major emphasis is placed on the special problem of measuring small doses.

2 Photon Dosimetry

The overwhelming share of exposure, with respect to both the number of persons monitored and the level of the doses, is caused by photons. Thus, photon dosemeters account for most of the evaluations in individual dose monitoring done by the German measuring laboratories. Of these dosemeters, more than 95% were film dosemeters, less than 1% phosphate glass dosemeters and about 3% thermoluminescence dosemeters; the latter are exclusively used as partial body dosemeters. A description of the various designs used by the measuring laboratories is found in /Bö 86/. In Europe, film dosemeters account for more than 80% of all

whole body dosemeters used. In those countries where the legislator also permits the use of thermoluminescence dosemeters, this share amounts to 60% /Har 86/.

The preferred use of the film dosemeter is due to the fact that it does not only provide the measured dose as such and the possibility of its filing for documentation purposes, but also additional information concerning the conditions of irradiation such as direction of radiation incidence or radiation quality. In many cases, these data contribute to the determination of the body dose and are thus of particular importance in the case of increased exposures as they permit selected measures aiming at an improvement of working conditions.

The film dosemeter has a lower limit of detection of 0.2 to 0.4 mSv for very hard gamma radiation (>0.4 MeV according to DIN 6816). For soft radiation (< 0.06 MeV), the limit of detection is even 0.02 mSv. This means that out of a collective of dosemeters subjected to this dose 95% are recognized as irradiated. However, it should not always be possible to reach this value in routine conditions. In the case of a visual sampling, it may happen that even doses up to 0.4 mSv are not detected for hard and very hard (> 0.15 MeV) gamma radiation. Here, e.g. a photometric scanning with a view to background deviations may be of some help.

Thermoluminescence dosemeters (TLDs) and photoluminescence dosemeters offer themselves as alternatives to the film dosemeter. The exoelectron dosemeter cannot yet be used in routine operations. Unlike film dosemeters, TLDs can be used more than once. In principle, this permits a single detector calibration which leads to a somewhat smaller spread than in the case of films which allow only a batch calibration on the basis of representative samples.

However, the greater spread of the film dosemeter in the lower dose range up to 0.4 mSv should not be overrated. The measurement precisions (confidence intervals) required in the official Guideline /AM 79/ and in DIN 6816 /DIN 84/ are adhered to. This means that the measuring error may be ± 100% in the case of doses of 0.2 mSv. However, taken a statistical distribution of the measuring deviations around the true value, the measurement precisions with respect to the lifetime dose are sufficient for all practical purposes and for securing evidence.

Adherence to the measurement precisions required in DIN 6816 is confirmed by regular comparative measurements carried out by the PTB for all dosemeters in conditions as they prevail for such comparative measurements. The comparative measurements show that in the dose range from 0.2 to 1000 mSv and for photon energies of 20 keV to 3 MeV all the respective film, photoluminescence and thermoluminescence dosemeters fulfill the conditions specified for the precision of measurement and that the differences in measured results are insignificant. For example, comparative measurements carried out by the PTB in 1986 with respect to the range of low doses showed that even for very hard photon radiation, for which the response of the film is at its lowest, the results were within the limits as specified in the Guideline /AM 79/. The conditions for the comparative measurements had always been chosen in such a way that the limits of the dosemeters where addressed by mixed and oblique radiation so that the measurements mainly covered all the radiation conditions occurring at the facilities monitored. This means that the conditions were sufficiently realistic in this respect.

On the other hand, it will hardly be possible to avoid a particularly careful evaluation of test measurements which may therefore provide more favorable results than routine measurements. This is true in principle, but should be differently weighted for the various kinds of dosemeters. Thus, it should be examined whether the Guideline /AM 79/ should be changed

to the effect that comparative measurements are carried out with dosemeters which are channeled into routine measurements without being noticed. It is in particular the reliability of the visual detection of unirradiated films by the personnel of the measuring laboratories that could be verified in this way.

For about one year now, all films which may have been exposed to very hard photon radiation have been scanned photometrically without any exception. In the case of softer photon radiation, the visual detection of small doses is continued, as this is possible without any difficulty and with a very low limit of detection because of the increased response of the film.

Within the scope of the Calibration Code, all kinds of individual dosemeter designs for photon radiation which are used by official or licensee dosimetry departments require an official approval. This approval may be granted on the basis of a design test or extended one-time comparative measurements. Participation in additional regular comparative measurements is also required.

The DGB Study /DGB 86/ contains a report on measurements which seem to demonstrate that the errors in film dosimetry below 0.8 mSv are much greater than the values established in the above Guideline /AM 79/ and the DIN standards and those determined by the PTB comparative measurements. These measurements were carried out with various individual dosemeters and, in some cases, with local dose rate meters. As far as the conclusions derived from these results are concerned, other interpretations than those made by the authors are possible with respect to a number of points:

- As far as the individual dose measurements are concerned, it was not taken into consideration that the film dosemeters eliminate natural background radiation from the measured value, as the natural radiation must not be included in the determination of occupational radiation exposure. Therefore, all the other dosemeter values have to be reduced by this value, and this considerably counteracts the impression that the film would underestimate small doses.

- It is reported that the film has a tendency of supplying lower doses than the pen-type dosemeter. This statement is not supported by other investigations.

  Thus, in accordance with /RU 86/, the agreement of the two dosemeter systems is good. Nevertheless, such a tendency could be imagined, in particular in the case of a visual evaluation of the pen-type dosemeter. However, this tendency would probably be at the expense of the pen-type dosemeter, since this type of dosemeter tends towards an overestimation of smaller doses because of subjectively justified inaccuracies of reading in the lower dose range and because of fading. The discrepancies observed by some authors /Sch 87/ even with respect to higher doses in the case of certain radiation fields should be investigated further.

As a summary, it can be stated that film dosemeters as compared with solid state dosemeters involve a somewhat greater uncertainty of measurement in the lower dose range (< 0.4 mSv) in the case of very hard gamma radiation. However, in relation to the lifetime dose, the disadvantages with respect to the accuracy of measurement are small, and they are compensated by the good documentability and the additional information referred to which the film provides and which is of great importance in practice, in particular with respect to the higher doses and the exceeding of dose limits which are really relevant for the health of the personnel. Therefore, the Commission does not see any necessity for a fundamental change of

the existing system of individual photon dosimetry. The review of the official Guideline /AM 79/, which is anyhow necessary because of the new Calibration Code, should ensure the quality control of the measuring laboratories with dosemeters which are channeled into operations without being noticed.

3 Beta Dosimetry

In most cases, the dose generated by beta radiation is a partial body dose of the skin of uncovered extremities. It is predominantly monitored by partial body dosemeters with thermoluminescence probes. As a control dosemeter for the irradiation of the other parts of the human body the film dosemeter continues to be important and should be suitable for the detection of intermediate and hard beta radiation in line with this task.

In the case of hard beta radiation, e.g. from Sr 90/Y 90 or T1 204, the dose is detected with a sufficient degree of certainty with film dosemeters. At some measuring laboratories, the determination of the individual doses is carried out in accordance with DIN 6816 and does not require any special evaluation. Sensitivity and energy-dependence of the film are sufficient for all practical purposes even in the low dose range.

For a detection of beta radiation with intermediate energies above about 100 keV, the film dosemeter is, in principle, well suited. This was clearly indicated by comparative measurements in the EC in 1986. In practice, however, the radiation fields concerned are mixed photon/beta radiation fields, and it is generally difficult to make a separate determination of the dose shares from photon radiation and beta radiation. In these cases, as in the case of the body dose determination, an adjustment must be made on the basis of further information to be supplied by the licensee with respect to the kind of the activity and the radiation field.

As a rule, the calibration is only effected with one reference condition, e.g. with an Sr 90 source. In principle, the calibration of the individual dosemeters should be carried out as far as possible on the basis of the radiation fields as they occur during operation. A calibration with point-type beta emitters, as it is usual with the commercially available secondary standards, will be sufficient if the dependence of the response on the energy, the angle of incidence and the distance of the source is taken into consideration. However, it is neither feasible nor desirable to base the calibration on individual real radiation fields, as the real radiation fields fluctuate to such an extent that such a procedure would involve far greater measuring errors. Therefore, a calibration should be preferred that covers the conditions of reality in a conservative way.

The measuring detection of the predominantly soft beta radiation, which above all leads to a partial body dose of the skin of the hands, is unsatisfactory with the aid of standard finger dosemeter as doses below the limits are actually not detected correctly. The finger dosemeters issued by German measuring laboratories are intended for photon radiation. These probes considerably underestimate exposures from beta radiation. There is only one measuring laboratory that evaluates a finger dosemeter with thin thermoluminescence detectors which is applicable in the entire energy range of beta radiation. Other designs of finger dosemeters, e.g. with exoelectron detectors, are being tested. Another problem is the extremely inhomogeneous irradiation conditions with respect to the hands which aggravate a dose measurement at the point subjected to the most severe radiation exposure.

In sum, it can be said that there is at present only one measuring laboratory that offers partial body dosemeters for beta radiation in accordance with the state of the art. When reviewing the official Guideline /AM 79/ it should also be considered whether it should be ensured that each beta dosemeter used for monitoring purposes be accompanied by a set of complete technical specifications including the range of measurement, the dependence on energy and angle of incidence, etc. These specifications could e.g. be determined within the scope of one-time extended comparative measurements by PTB which are not effected, as in the case of photon dosemeters, within the scope of the Calibration Code. A quality control of the measuring laboratories, if possible with the aid of dosemeters channeled in unnoticed, should be introduced to arrive at an approach similar to that used for photon dosimetry.

4 Neutron Dosimetry

The measuring methods for individual neutron dosimetry are difficult and require further development /SSK 88/: This is the reason why neutron dosimetry has not yet reached the same quality standard as photon dosimetry.

The nuclear track film which has been in frequent use until recently is only suited for the detection of fast neutrons with energies of more than 1 MeV. In addition, in the universal cartridges issued by the measuring laboratories, thermal neutrons can be detected through (n,γ)-reactions with the aid of the gamma film and a Cd-filter. For epithermal neutrons, the cartridge cannot be used for detection purposes. While the shortcomings in the low-energy range can still be accepted because of the fact that their share of the dose is, as a rule, relatively small, the weaknesses of the nuclear track film, because of its energy dependence, turn out to be a decisive disadvantage of this dosimetric method when it comes to detecting fast neutrons.

This is the reason why back in 1983 an albedo neutron dosemeter with TL-detector was tested which was then introduced in early 1987 to replace the nuclear track film. There is a good chance that this system may become a universal dosemeter for all neutrons. However, it requires a range and workplace-specific calibration. The results of the practical tests remain to be seen before it will be possible to make a final evaluation of this dosimetric system. However, it is in line with the state of the art as alternatives such as nuclear track etching detectors are still in the development stage.

The local dose rate measurements with the aid of the so-called rem counters which are carried out by licensees ensure that in spite of this transitional situation the contribution of the neutron dose to the determination of the body dose of occupationally exposed persons is sufficiently taken into consideration. All in all, this method is very conservative although the response for thermal neutrons may be reduced /DGB 86/. At nuclear facilities, this aspect is overcompensated by the fact that in the case of intermediate energies the doses are overestimated by a factor of 3 and more /SSK 88/.

The Commission recommends to wait for the outcome of the experience with albedo dosimetry, the further development of nuclear track etching detectors and the discussion focusing on the increase of the quality factor for neutrons and to make a new evaluation in due time.

5 Incorporation Monitoring

As far as internal exposure is concerned, the body dose has to be determined by using dose factors from the activity intake, for example by measuring the contamination of the air, or from the activity of the incorporated radionuclides, for example by whole body measurements or an analysis of the human excrements. For this purpose, the method to be used should be that for which the required data are known, or can be determined, in a more complete or more accurate way /SSK 88/. In these conditions, it is incontestable that the measurement accuracy is sufficient to demonstrate that the limits are not even exceeded if the doses due to external exposure are included.

The sensitivity of these detection methods has to be designed in such a way that an incorporation at the beginning of the period of monitoring is still recognized if it is above 5% of the annual limit of intake (ALI) /BMI 78/. This is above all a matter of the length of the period of monitoring and thus of the frequency of the measurements. With the detection methods as used in practice, adherence to this requirement may cause difficulties in the case of certain nuclides and practicable monitoring periods. However, for the majority of radionuclides the demonstration does not cause any problem, since these can be exactly demonstrated through a sufficient high-energy gamma radiation in the whole body counter. The whole body and partial body measuring laboratories which are at present recognized or under construction in the Federal Republic of Germany reach lower detection limits of 0.05 to 0.1 kBq. If the respective monitoring processes adhere to the time intervals which are provided for in the “Guideline for Physical Radiological Protection Monitoring (Secs. 62 and 63 of the Radiological Protection Ordinance)”/BMI 78/ and in the “Calculation Basis for the Determination of the Body Dose in the Case of Internal Radiation Exposure (Guideline under Sec. 63 of the Radiological Protection Ordinance)”/BMI 81/, the required conditions for a detection of 5% of the annual limits of intake during the respective period of monitoring are fulfilled. Should the necessary time intervals become unreasonably short in the case of radionuclides having very short half-lives, the individual incorporation measurements of each person can be replaced by cyclic measurements of random samples of consecutive persons overlapping each other chronologically, as “substitutes” for the incorporation conditions of the group, provided a group of several persons is concerned.

In the case of mere alpha and beta emitters, excretion analyses shall be carried out. For certain plutonium compounds, this method has an insufficient sensitivity as a result of the extremely low ALI. These compounds could only be detected with the required sensitivity by 14-day stools analyses. Such a method seems hardly practicable.

Thus, an indirect incorporation monitoring by measuring the activity concentration in the room air and considering the times of stay should be preferred for monitoring the plutonium incorporation. This method ensures that incorporations in the order of magnitude of 5% of the ALI will not remain undetected provided the air sampling is done at the representative point. However, the corresponding activity concentrations in the order of magnitude of between 10^{-3} and 10^{-2} Bq/m^3 do not constitute any problem in terms of measuring technique. From this point of view, i.e. by taking air samples and collecting them over a corresponding period of time for later evaluation at the laboratory, it is possible to specify this value at a clearly lower level so that it is possible to cover to a far-reaching extent any undetected spatial fluctuations in concentration.

If the activity concentrations to be specified in this way are reached or exceeded, individual checks of the persons concerned will be started. These persons are then requested to collect urine and stool samples during the following three days for analysis purposes. On the basis of these measurements, a sufficiently exact estimate of the individual dose is possible, as the time of intake is known. In addition, whole body and partial body measurements can be carried out.

Thus, it can be said that the existing system of incorporation monitoring, if applied in a technically sound way, can detect not only limits but also incorporations in the range of 5% of the ALIs.

6 Conclusions with a View to the DGB Study

The comment /SSK 88/ of the SSK on occupational radiation exposure in the Federal Republic of Germany remains fully valid even if the results of the DGB Study /DGB 86/ are appreciated.

Only a small part of the shortcomings described in /DGB 86/ can be confirmed, and their description in the assessment of the results of the project is partly incorrect or constitutes too much of a global approach.

Actually existing shortcomings of the dosemeters for partial body dosimetry and neutron dosimetry had been known before and have been compensated for by the development and introduction of dosemeters as well as a series of supplementary monitoring measures in conjunction with official and licensee monitoring.

The further development of dosimetry such as required in the DGB Study /DGB 86/ is, to a far-reaching extent, in agreement with the research emphasis as recommended by the SSK.

The Commission is in agreement with the decisive statement of the DGB Study, i.e. that radiological protection, and in particular the qualified individual dose monitoring of the personnel at nuclear facilities, has always been and still is ensured.

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