Hanover, 01.06.2012

# Technical Report
# Testing the radiation protection properties of hollow wall boxes against X-ray radiation in accordance with DIN EN 61331-1 dated August 2006 and DIN 6812:2010.

Client: Kaiser GmbH & Co. KG
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D-58579 Schalksmühle

Contractor: TÜV NORD EnSys
Hannover GmbH & Co. KG
Am TÜV 1
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Test Procedure: X-ray room at the Technical Centre
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Period of testing: March to April 2012

## Task

As a rule, structural radiation protection measures are required for X-ray rooms used for X-ray diagnostics. In Germany, the basis for planning and carrying out the testing is DIN 6812. Lead-lined lightweight boards made of plasterboard and special radiation protection plates with higher density gypsum mixtures are available for these protection measures. For the electrical installation of the devices, cavity wall boxes are used in cavity walls, making the installation process simple. The cavity wall boxes that are commonly used are made of thin plastic and have no radiation protection properties. For this reason, the mounting hole must be manually closed off at the back with lead sheeting. Kaiser has developed a cavity wall box that is intended to make the installation of the electrical equipment easier. This lead-free box complements the lead-free radiation protection walls.

The determination of a lead equivalent for plate-shaped radiation protection materials is described in DIN 61331-1. The first step was therefore to investigate different materials with regard to their suitability as an attenuating material. The second step was to investigate different cavity wall boxes for their radiation protection properties. The finished hollow wall box is cylindrically shaped, with a base that is almost flat. The transition from the wall to the base is chamfered at 45°. The openings for the supply lines are cut out here during installation. In addition, each box contains two incompletely shielded openings near the fastening tab (lug bearing).

The specification of a lead equivalent for the material used is therefore not sufficient, because additional changes are made when using the product. There may also be gaps in the transitions between wall and the cavity wall box. These gaps are dependent on the thickness of the cavity walls, the number of boxes installed and the radiation direction that is under consideration. This is why structural feed-throughs must also be evaluated. In this way, the suitability of the boxes for lead-free walls with a lead equivalent of up to 3 mm can be determined.

## Test basis

DIN EN 61331-1 is to be used as the basis for the determination of the lead equivalents of plate-shaped protective materials. The test pieces required for this test could be manufactured in the form of box covers. When evaluating their suitability as a component for an X-ray room according to DIN 6812: 2010, the evaluation of the cavity wall box samples was carried out taking into account the limit values for the personal dose according to the X-ray Ordinance. The guidelines in DIN 6812: 2010 were used to calculate the partial body dose.

## Procedure

Three different thicknesses of the available materials, in plate form, were tested for their attenuating properties. The test was carried out using X-ray tube voltages ranging from 40 to 150 kV. The determination of the lead equivalent value was measured by comparison with a known reference thickness of lead at the same time.

The cavity wall boxes themselves were tested in groups of three recessed in a wall. Two cable feed-throughs were cut out in each of the two outer cavity wall boxes. The cavity wall boxes were considered to create an inhomogeneity within the homogeneous wall and tested according to DIN 61331-1, Sections 5.4.3 and 5.6.3. The ten measuring points required by DIN 61331-1 were positioned in a 3 x 9 matrix in an almost random basis across the boxes and the wall. This meant that the measuring points were distributed over the boxes, the wall material and the structural openings. The attenuation of orthogonal irradiation was determined for each measurement point by moving the sample itself.

Since not every combination of wall construction and cavity wall box can be tested, a mathematical model was created with which the suitability of different walls can be estimated. No general statement can be made for any particular installation situation. However, the assumed relationships reflect a conservative estimate.

**Qualification of the test setup**

Two different dosimeters were used for dose and dose rate measurements. This allows the entire range of dose rates to be covered. The fluctuations in the air characteristics during measurement amounted to less than 5% of the average value. The correctness of the X-ray tube voltage was checked at regular intervals as part of quality assurance for the X-ray machine. In order to reduce the influence of the multiple scattered photons during measurement, the dose measurement behind the test object was carried out in a shielding box with an entrance aperture diameter d=24 mm. The geometry ensures that the active volume of the measuring chambers in use is always completely irradiated with X-rays, even with the small radiation field involved.

Measuring equipment used: Diagnostic dosimeter Diados No. 0065
PTW NOMEX QA No. 230204
Lead foils and sheets as reference material

**Results of the lead equivalent measurement**

The shielding material used in the boxes requires a material thickness that is a number of times greater than lead for the same attenuating effect. When measuring the box in a wall with 1.5 mm lead, a 2.1 mm lead equivalent was achieved for the base of the box. This over-dimensioning has the effect that, even at maximum X-ray tube voltage, the attenuating effect of the box is determined by the remaining openings.

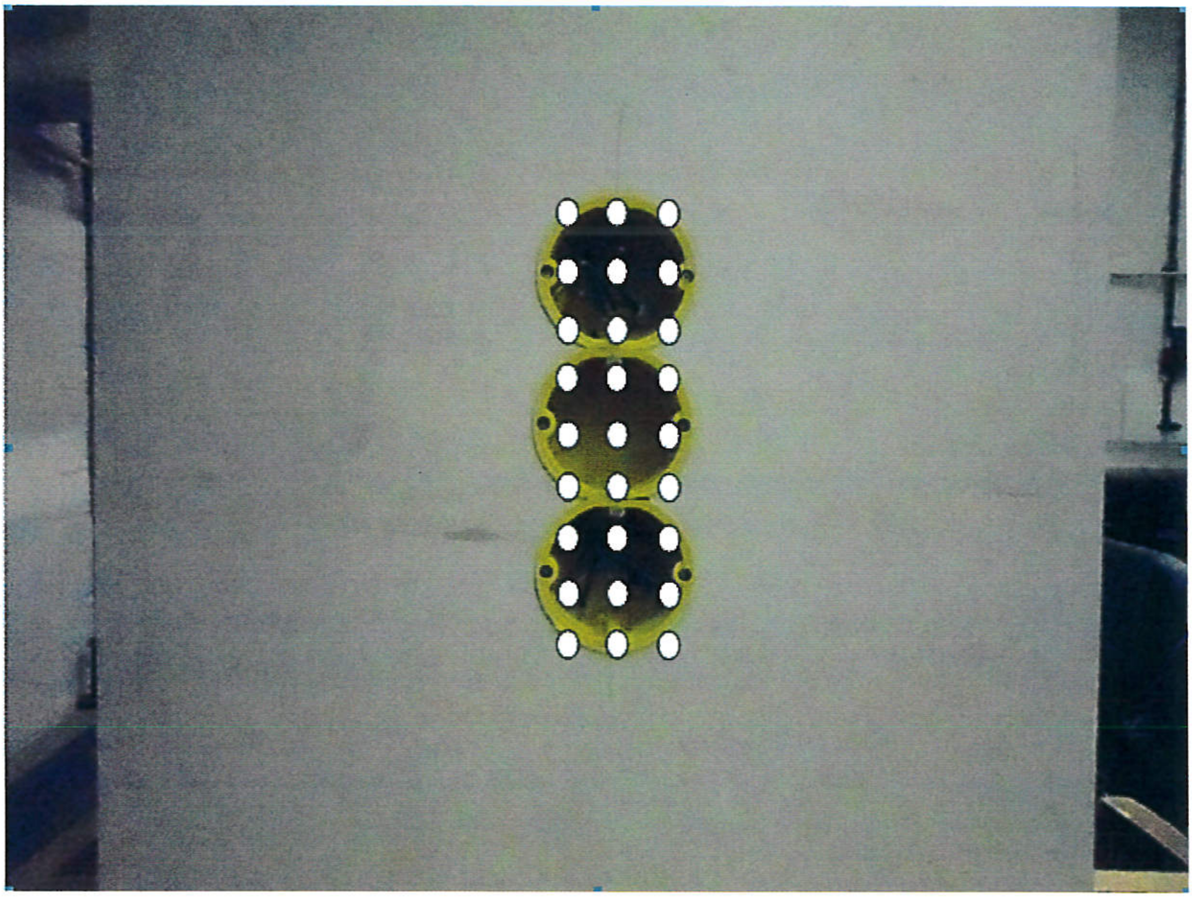


Figure 1 Principle distribution of the measuring points, 3 rows of 9 points

Figure 2 X-ray of 3 installed boxes

## Calculation model

When designing an X-ray room according to DIN 6812, a simplified calculation model is used. The radiation source is defined by the X-ray tube voltage, filtering and the product of current and time for one week of operation. In the simplified model approach of DIN 6812, the generated radiation hits either a wall (rarely) or, in all cases, a diffuser which uniformly scatters the X-ray radiation in all directions. For different types of devices the yield factors, that are dependent on the size of the radiation field in the centre, are determined for the stray radiation. This defines the dose for a location at a distance of one metre. When considering different distances between the X-ray tube, diffuser and location, an inverse square law is approximately valid for distances greater than 1 m. Additional effects such as interference radiation from the radiation protection housing of the X-ray source are taken into account using empirically determined factors. This calculation model is suitable for calculating large-area shielding. At the same time, operating data were determined for the classes of X-ray machines specified in the standard. These were not usually exceeded.

This procedure is not suitable for calculating the radiation exposure arising from a built-in cavity wall box. It would also lead to high, unrealistic results where small openings were present.

The requirements of the X-ray Ordinance must be taken into account in order to adapt this calculation model. Both the whole body exposure and the partial body exposure limits must be respected. Partial body exposures arise as a result of the openings in the radiation protection wall, which can be estimated using this calculation method. For the partial body dose, the X-ray Ordinance specifies a limit value for non-occupationally exposed persons of 50 mSv or 15 mSv per year. The 15 mSv limit represents the most stringent requirement and is therefore used as the basis here.

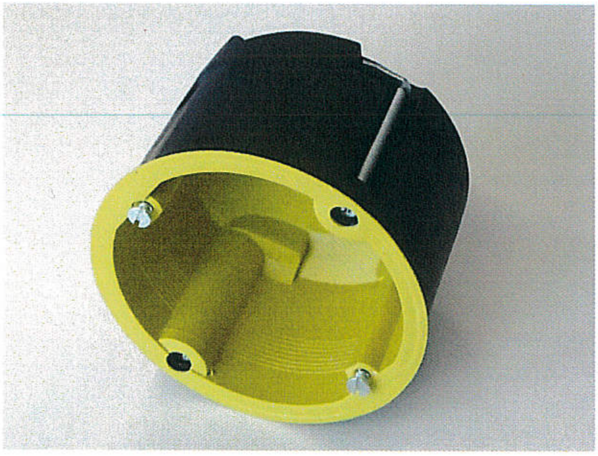


**Figure 3 View of the radiation protection box**

In principle, the partial body exposure resulting from an opening depends on the beam geometry. Different opening areas are used in the calculation model, resulting from the number of wall panels and cavity wall boxes used and the angle of the incident radiation. It takes account of both the orthogonal and the most unfavourable obliquely incident radiation. For the scattered radiation, the assumption of a punctiform scattered radiation source is incorrect. In this case, it must be assumed that there is an extensive source of radiation, of which only a small part is visible at the measuring location. These effects are already taken into account in the DIN 6812 model as a scattered radiation yield at a distance of 1 m from the diffuser. The dose is therefore calculated on the basis of this value. The fact that the registered dose used depends on the size of the detector must also be taken into account. A smaller detector would register a higher dose than a large detector with the same aperture.

In order that the result for the evaluation made here is independent of the detector used, the calculation of the averaging of the dose is to be based on an area of 10x10 cm² at a distance of 0.1 m from the finished wall. This area is internationally accepted in order to standardise the assessment of radiation protection measures (see also DIN IEC 60601-1-3). In contrast to the classic approach in DIN 6812 for the calculation of large-area shielding, the following changes and boundary conditions are to be included here:

1. The permissible local dose limit is the minimum limit for the partial body dose for non-occupationally exposed persons of 15 mSv (instead of 1 mSv per year for whole body exposure).

2. The dose is averaged over an area of 100 cm².

3. The attenuation of the finished wall is determined and thus the distance from the openings set at 16 cm. This corresponds to a 10 cm distance from the surface of the finished wall.

4. The walls are always double-planked.

5. The diffuser is, on average, 1.5 m away from the wall, in the case of dental devices 0.5 to 0.75 m (see DIN 6812)

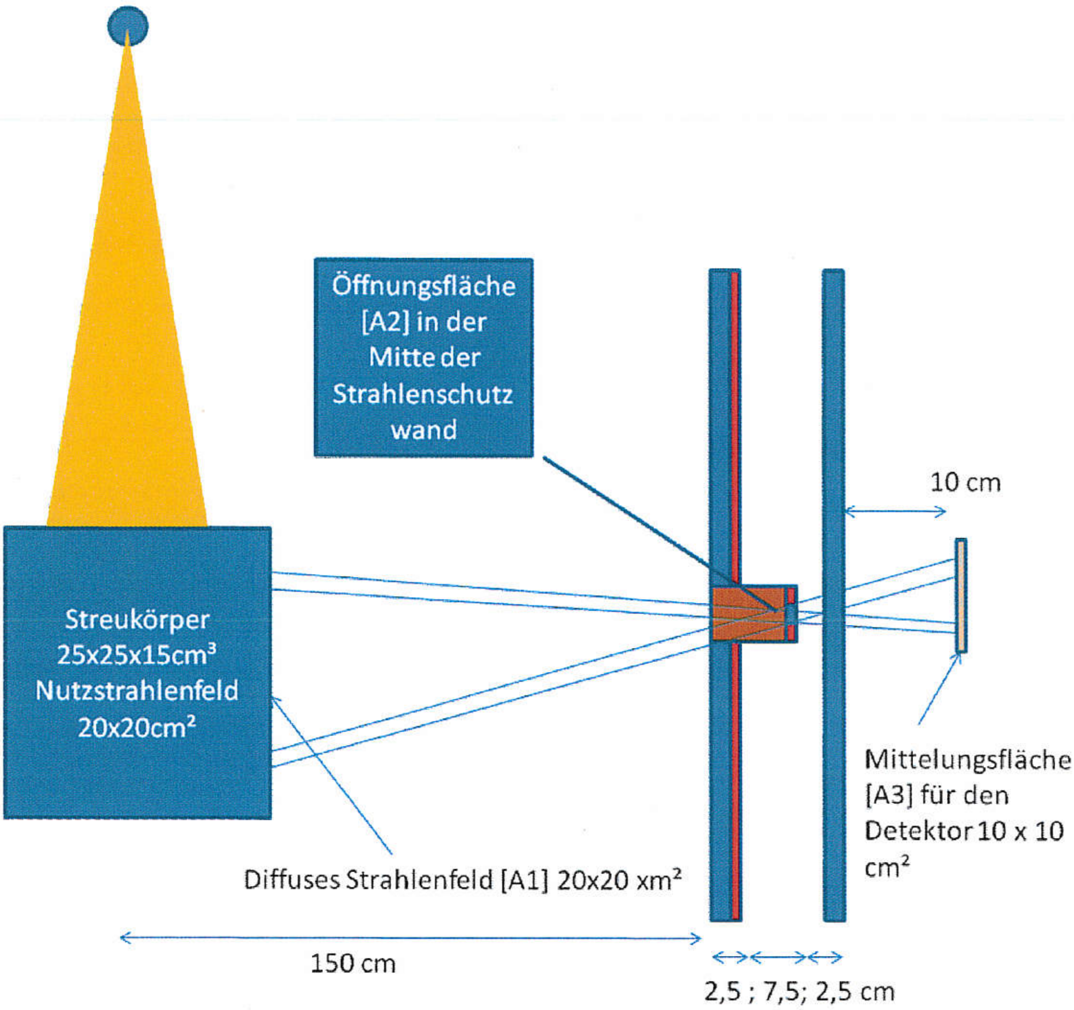



**Figure 4 Radiation geometry**

The dose registered in the averaging area A3 under consideration depends on the distance of the diffuser to the opening in the wall and the distance of the opening to the averaging area. The unopened wall is sufficiently radiopaque. The radiation protection effect of the box itself is better than 1.5 mm of lead at the unopened locations. The registered dose is then, as a conservative approximation, dependent on the ratio of hole diameter to hole distance. The various openings of the box are added together to form an opening area.

In the case of a diagonal beam direction, the calculation of the opening area can be assumed to be equivalent to the intersection of two equally large superimposed circles. These circles are the distance between the wall plate and the base of the box.

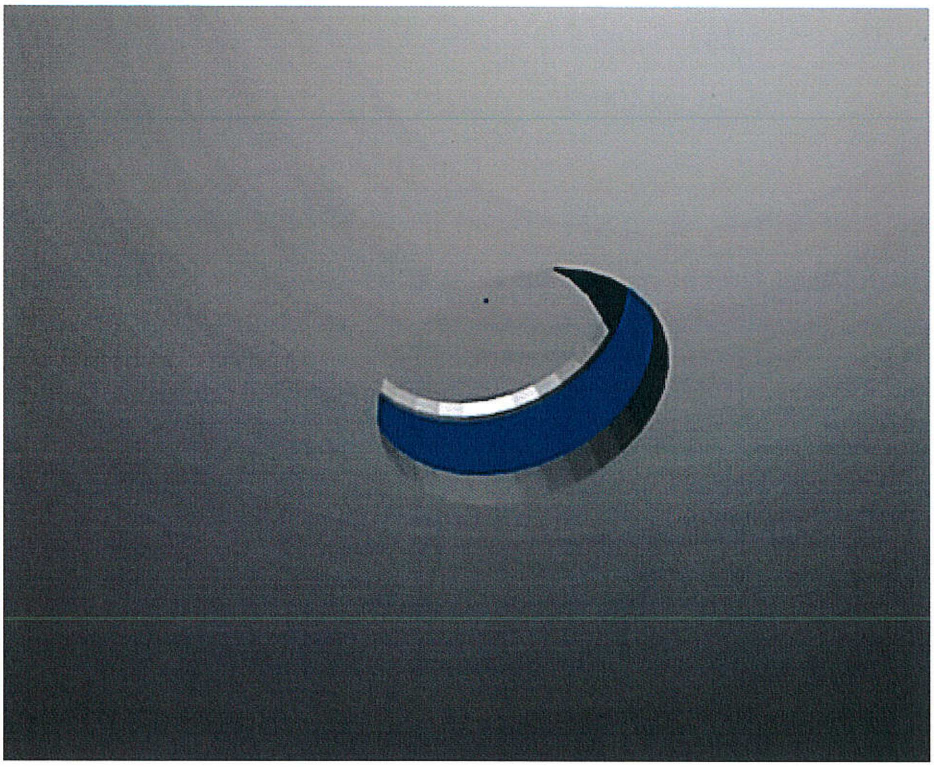


**Figure 5 View of the resulting gap with a diagonal beam direction. The blue colour shows the proportion of low attenuation**

The opening area was determined using CAD data to be 11.6 cm². In addition the averaging is to include the openings for two cable fead-throughs and two lug bearings.
In the diagonal beam direction, the surface is dependent on the angle and the number and order of the radiation protection plates in which the boxes are mounted. In order to limit the number of possible combinations, constructions have been calculated according to Table 2.
However, the opening area is only precisely defined where there is a lead-lined plate because of the thin shielding layer. Safeboard panels create a continuous transition to a panel thickness that is sufficiently effective. For this reason, larger areas are used here.

The area for two Safeboard panels was set at (11.6 cm² * 2 + 2.7 cm²) ~ 39 cm² for two Safeboard panels and (11.6cm² + 2,7cm²) ~ 14.3 cm² for one Safeboard panel.
For diagonal radiation incidence, the distance to the diffuser increases by a factor of 1.4.

For an orthogonal beam direction, four cable feed-throughs and four lug bearings have been set down in the beam path.

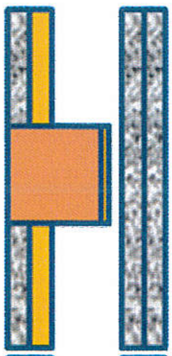
The 0.25 cm² per cable feed-through and 1.1 cm² for a tab bearing give a 5.4 cm² area for orthogonal treatment.

For installation in a lead-lined wall, the opening area of 11.6 cm² calculated from the CAD data was used. For the orthogonal beam direction, the partial covering of the lug bearings with 2 mm of shielding material, the screw and the plastic material for encapsulation were taken into account. The specified opening area of 1.12 cm² is based on a measured X-ray photograph (Figure 2).

| Specified lead equivalent in mm Pb | Number of Safeboard boards on the box side | Number of Safeboard boards on the rear side | Specified opening areas in cm² | Illustration of the wall construction (see Table 2) |
|---|---|---|---|---|
| 0.3 | 1 | 0 | 14.3 | 1, 5 |
| 0.4 | 1 | 0 | 14.3 | 1, 5 |
| 0.6 | 1 | 0 | 14.3 | 1, 5 |
| 1 | 2 | 0 | 39 | 2, 5 |
| 1.1 | 2 | 0 | 39 | 2, 5 |
| 1.5* | - | - | 11.6 | 5 |
| 1.75 | 2 | 1 | 39 | 3 |
| 2.75 | 2 | 2 | 39 | 4 |

Table 1:
specified opening surfaces for combinations of Safeboard boards up to three normal plasterboards:
* The combination with a lead lined plasterboard is due to the low shielding effect of the rear plasterboard walls at distances above 2.5 m for tabletop and under table X-ray devices.

1



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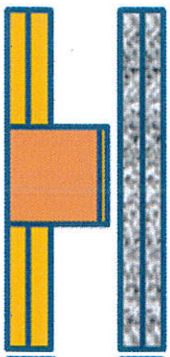

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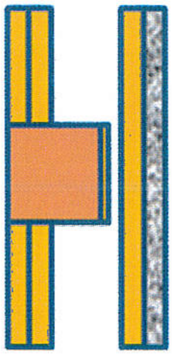

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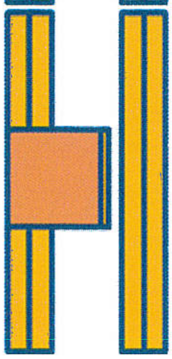

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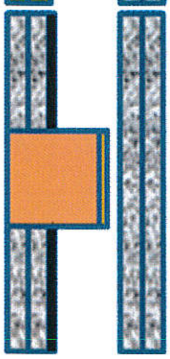

Legend
Plasterboard
Safeboard
Plasterboard with lead lamination

Table 2 Wall structure schematic

| X-ray device class | X-ray tube voltage and operating load | | Dose-yield | Incident dose in 1 m | Distance focus to diffuser | Incident dose at the diffuser | Stray-radiation yield factor | Housing transmission radiation correction factor |
|---|---|---|---|---|---|---|---|---|
| | [kV] | [mA*min/ week] | [mSv / mA*min] | [mSv / week] | [m] | [mSv/week] | | |
| Dental tube device | 70 | 10 | 6 | 60 | 0.2 | 1500 | 0.0002 | 1 |
| Panoramic device | 85 | 100 | 6 | 600 | 0.5 | 2400 | 0.0001 | 1 |
| dental remote recording | 80 | 10 | 5.5 | 55 | 1 | 55 | 0.001 | 1 |
| Volume tomography | 100 | 50 | 8 | 400 | 0.5 | 1600 | 0.0008 | 1 |
| Recording device | 90 | 400 | 7 | 2800 | 1 | 2800 | 0.002 | 1 |
| Surgery BV | 80 | 400 | 5 | 2000 | 0.8 | 3125 | 0.002 | 1 |
| CT | 120 | 20000 | 13 | 260000 | 0.5 | 1040000 | 0.0001 | 3 |
| Fluoroscopy UT | 90 | 1200 | 7 | 8400 | 0.65 | 19882 | 0.002 | 1 |
| Fluoroscopy OT | 90 | 3000 | 7 | 21000 | 1 | 21000 | 0.002 | 1 |
| Therapy simulator | 90 | 1000 | 7 | 7000 | 1 | 7000 | 0.002 | 1 |
| DSA | 90 | 4000 | 7 | 28000 | 0.65 | 66272 | 0.002 | 1 |

For top table fluoroscopy and therapy simulators, the design may require effective beam shielding.

Table 3
Requirements of DIN 6812:2010 for the planning of X-ray rooms for diagnosis

## Calculation of the radiation protection effect

The radiation protection effect is calculated on the basis of the stray radiation yield at a distance of 1 m from the diffuser. This value is defined by DIN 6812 for different types of devices (Table 3). The dose to be screened is the product of the incidence dose at the diffuser and the stray radiation yield factor. The dose is converted to minimum distances to the wall (1.5 m or 0.5 and 0.75 m for dental equipment).

The attenuation of the dose then takes place through the layers of the wall. In the area of the cavity wall box, the attenuation, other than from the material itself, is essentially represented by the ratio of the partial body dose averaging area (100 cm$^2$) to the opening area of the box. The attenuation factors for the material behind the cavity wall opening were determined by the lead equivalents of plasterboard and Safeboard boards. The criterion for the decision on the suitability of a wall structure is the week-related limit for a partial body dose of 300 µSv / week or 15 mSv / year.

## Evaluation

For the wall constructions and boundary conditions described in Tables 1 and 2 it can be demonstrated by the calculation described that the dose limits for partial body exposure are met.

The lead-free radiation protection box type 9074-01 manufactured by Kaiser GmbH & Co. KG, Schalksmühle facilitates the construction of radiation protection walls for X-ray rooms with X-ray devices classified in DIN 6812 with tube voltages in the range 40 to 150 kV.

The wall construction shown by way of an example (Figures in Table 2) in conjunction with Table 1 describes a suitable wall structure and the number and position of the lightweight panels to be used for compliance with the required lead equivalents for planning according to DIN 6812. The number and position of the lead-free lightweight panels used in conjunction with the electrical installation box ensure that the limit values are complied with in accordance with the X-ray Ordinance without requiring additional shielding measures (e.g. lead enclosures) in the installation area.

The electrical installation boxes can be used both as a single box and in multiple combinations using a connection piece type 9060-74. Installation is possible on the one side as well as on the opposite side. In an opposing installation, a lead equivalent of 3 mm Pb is achieved in the partial area of the electrical installation box. If the boxes are placed opposite one another, an offset cable entry should be made in order to avoid continuous openings. In the installation zone, the installation must be carried out in accordance with DIN 18015-3.

In addition, the lead-free radiation protection box type 9074-01 is also suitable for conventional transilluminators in wall constructions with only one lead layer. The limit value is calculated mathematically on the basis of the opening areas that have been determined.

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