

Hannover, 23.01.2009

**Technical report**  
**on testing the attenuation properties of the radiation protection board**  
**Knauf Safeboard for X-radiation in accordance with DIN EN 61331-1**  
**dated August 2006.**

Client:	Knauf Gips KG Am Bahnhof 7 97346 Iphofen
Contractor:	TÜV NORD EnSys Hannover GmbH & Co.KG Am TÜV 1 30519 Hannover
Execution of the test:	X-ray room in the technical center Am TÜV 1 30519 Hannover
Testing period:	May 2008

## 1. Scope

9 Knauf Safeboard radiation protection boards have been tested for their attenuation properties in accordance with DIN EN 61331-1:2002. For 4 radiation qualities according to standard and 2 additional radiation qualities, the attenuation properties have been determined in broad and narrow beams. Attenuation properties according to standard are the attenuation ratio and the build up factor. Only protection materials that contain a significant share of lead require the determination of the lead equivalent. However, the determination of a lead equivalent is desired for the tested boards.

The supplied boards of the format 50 x 50 cm<sup>2</sup> consist of 2 charges with slightly different densities depicting the fluctuation in production. Boards 1 to 6 serve the measurement of the wall constructions from 1 to 6 boards. The additionally supplied boards 13 (1) to 13 (3) serve the checking of the homogeneity and variance of the production. From the material of boards 1 to 6, 6 samples of the format 10 x 10 cm<sup>2</sup> are available for the determination of the lead equivalent.

The boards contain barium sulphate (baryte) as determining material for the qualification as x-ray protection board. With the use of barium sulphate, the lead equivalent determined in compliance with the standard will result in the overestimation of the radiation protection properties of the individual boards. Therefore, further measurements in broad beam geometry should be carried out to ensure the determined lead equivalent. A pressed paper board with 0.5 mm lead and 2 gypsum boards of the company Knauf with 0.5 mm and 1 mm lead sheeting are available for these comparative tests. In addition, further attenuation properties for lead taken from table A4 DIN 6812E2006-9 are compared in order to safely exclude overestimation.

**Table 1: Description of product samples**

Number	Description	Comments
6	Boards of dimension 50 x 50 cm <sup>2</sup>	To measure wall constructions up to 6 boards
3	Boards of dimension 50 x 50 cm <sup>2</sup>	To test the homogeneity and product tolerances
6	Boards of dimension 10 x 10 cm <sup>2</sup>	To compare with lead references
1	Board pressed paper of dimension 50 x 50 cm <sup>2</sup> + 0.5 mm lead available in house	To compare with the test items in the broad beam
1	Gypsum plasterboard of dimension 50 x 50 cm <sup>2</sup> + 0.5 mm lead available in house	To compare with the test items in the broad beam
1	Gypsum plasterboard of dimension 50 x 50 cm <sup>2</sup> + 1.0 mm lead	To compare with the test items in the broad beam

## 2. Procedure

A frame displaying the primary beam on the necessary cross section is available for the testing of the boards. The frame consists of a supporting structure and one layer of at least 3 mm lead for the shielding of the primary beam outside the broad beam. The boards that are to be tested can be fixed in mounting rails to the testing position. A further diaphragm of 5 mm sheet lead is available for measurements in the narrow beam. The screen limits the beam to the geometry of the narrow beam. There are insets of 5 mm lead for the primary beam diaphragms limiting the radiation beam insofar as the objectionable scattered radiation is largely avoided. The changing of the samples is partially operated by remote control, otherwise manually. After having switched on and off the X-radiation after a sample or filter change, a dosimeter ensures that it is set to the correct dosage for repeated use.

The measurements of the dose rates are made with a secondary standard dosimeter of the company PTW, type Unidos Nr. T10001 11426 with the detector TM23361-0559 and a survey meter type FH 40 of the company Thermo 018807 for the extension of the measuring range at low dose rates. The dose rates within the primary beam and in the attenuated primary beam could be measured with these measuring devices. The two devices taken together cover a dynamic of  $10^7$ . The limit of the measurable attenuation ratios is determined by the finite size of the secondary blend of 1500 x 1500 mm<sup>2</sup>. Thereby, the measuring point can be reached by photons scattered on air and room walls even if the secondary diaphragm is completely shut. This effect limits the quantity of the measurable attenuation when constructed in accordance with DIN EN 61331-1:2002. The measuring values which have exceeded the limit of the measurable attenuation can be recognized by the higher divergence from the exponential attenuation law and are not considered for further evaluation. These are, as expected, the measurements at low energy and high attenuation at the measurements of several layers of radiation protection boards.

The stability of dose necessary for each measurement is controlled by a dosimeter type PTW-Nomex.

## 3. Qualification of the measurement setup

For the performance of the measurements the standard sets down several basic conditions that are necessary in order to perform measurements conform to standards. These basic conditions have fundamentally been observed.

<b>Table 2</b>		
Condition from DIN EN 61331	Achieved value	Comment
Fluctuation of high voltage <4%	<<4% as it is a converter-generator	The generator supplies direct voltage
The dose rates outside the useful radiation beams $K_{OC}$ (radiation leaking through housing and diaphragm has to be <5% of the dose rate within the primary beam $K_C$ .)	$K_C = 5.84 \text{ mGy/s}$ $K_{OC} = 95.89 \text{ } \mu\text{Gy/s}$	$0,05 * 5,84 \text{ mGy/s} = 0.292 \text{ mGy/s}$ 140 kV 20 mA
The dose rate $K_S$ behind the diaphragm, but within reach of the useful frame has to be lower than $0.01 * K_{IS}$ (dose rate behind the test item)	$K_{IS} = 513 \text{ } \mu\text{Gy/s}$ $K_S = 2.7 \text{ } \mu\text{Gy/s}$	Without test item $0.01 * 513 \text{ } \mu\text{Gy/s} = 5.13 \text{ } \mu\text{Gy/s}$ at 150 kV 20 mA. With test item, both dose rates are lower. The limit is reached when scattered radiation can be determined behind the diaphragm (ca. $10 \text{ } \mu\text{Sv/h}$ or $2\text{-}3 \text{ nGy/s}$ . At attenuation ratios of $10^5$
Diameter of the useful radiation beam 20 mm +/- 1 mm	$50 \times 30 \text{ mm}^2$	Radiation beams fitted to measuring chamber see national comment 5.4.2 of standard
Distance $a > 10 * \sqrt{A}$	$440 \text{ mm} > 10 * \sqrt{150 \text{ mm}^2}$	Requirement met
Distance to wall of X-ray room > 700 mm	> 1300 mm	Requirement met
Distances acc. to pictures 1 and 2	The postulated dimensions could be kept +/- 5 mm	Requirement met
Repeatability of the dose or dose rate	Better 5 % of average value	See table 3

Table 3: Repeatability of dose

Energy Al [kV]	Divergence of monitoring dose from the average value of the dose rate at energy						
	1	2	3	4	5	6	7
60	-0,67%	0,23%	0,25%	0,32%	-0,13%	0,00%	0,00%
70	-3,08%	-2,30%	-2,30%	-2,22%	-2,56%	14,84%	-2,39%
80	-0,92%	0,22%	0,15%	0,15%	0,22%	0,03%	0,15%
90	-0,96%	0,09%	0,09%	0,33%	0,33%	0,04%	0,09%
100	-1,02%	0,06%	0,21%	0,25%	0,29%	0,10%	0,10%
120	-0,98%	0,09%	0,14%	0,22%	0,35%	0,12%	0,07%
150							
Cu [kV]							
50	-0,32%	-0,12%	0,13%	-0,06%	0,42%	-0,12%	0,06%
60	-0,78%	0,19%	0,25%	0,09%	0,23%	0,09%	-0,06%
80	-1,06%	-0,01%	0,25%	0,25%	0,43%	-0,01%	0,16%
100	-1,35%	0,13%	0,13%	0,26%	0,45%	0,19%	0,19%
125	-1,37%	0,13%	0,18%	0,29%	0,40%	0,13%	0,24%
150	-1,06%	0,06%	0,15%	0,24%	0,41%	0,11%	0,11%

## 4. Comparison of 9 boards for different attenuation

Table 4: Dose rates with different test items										
Energy	Dose rate without test item	Dose rate with test item no. [μGy/s]								
	[μGy/s]	1	2	3	4	5	6	13(1)	13(2)	13(3)
50 kV 0,05mm Cu	147,6	0,428	0,455	0,428	0,423	0,4464	0,4436	0,485	0,472	0,4914
60 kV 0,1mm Cu	177,8	0,622	0,663	0,626	0,613	0,6462	0,649	0,719	0,6975	0,727
80 kV 0,15 mm Cu	286,2	3,15	3,307	3,158	3,104	3,255	3,252	3,471	3,467	3,559
100 kV 0,25 mm Cu	389,3	14,4	14,88	14,38	14,23	14,72	14,74	15,62	15,41	15,61
125 kV 0,45 mm Cu	478,9	49,75	50,74	49,57	49,2	50,4	50,4	52,4	51,88	52,36
150 kV 0,7 mm Cu	639,3	120,3	122,1	120	119,3	121,4	121,5	124,9	124	124,8

Table 5: Divergence of the attenuation ratio in per cent										
Energy	Average value	Divergence of the attenuation ratio F from the average value of all 9 boards with energy with item no.								
		1	2	3	4	5	6	13(1)	13(2)	13(3)
50 kV 0,05 mm Cu	327	5,4%	-0,8%	5,4%	6,7%	1,1%	1,7%	-	-	-
60 kV 0,1mm Cu	269	6,1%	-0,4%	5,5%	7,7%	2,2%	1,7%	8,2%	-5,4%	9,2%
80 kV 0,15 mm Cu	87	4,6%	-0,3%	4,4%	6,2%	1,2%	1,3%	5,1%	-4,9%	7,4%
100 kV 0,25 mm Cu	26	3,3%	-0,1%	3,4%	4,5%	1,0%	0,9%	4,8%	-3,5%	4,7%
125 kV 0,45 mm Cu	9	1,9%	0,0%	2,3%	3,1%	0,6%	0,6%	3,2%	-2,2%	3,1%
150 kV 0,7 mm Cu	5	1,4%	-0,1%	1,7%	2,3%	0,5%	0,4%	2,3%	-1,6%	2,2%

The change of the lead equivalent at the change of attenuation can be estimated by comparing the measured attenuation ratio in the broad beam and the attenuation ratio for lead from DIN 6812. The divergence in mmPb is shown in the table.

Table 6: Change of the lead equivalent extrapolated from the divergences of the attenuation ratio									
Al filter- ring at [kV]	1	2	3	4	5	6	13(1)	13(2)	13(3)
60	0,009	-0,001	0,009	0,011	0,003	0,002	-0,012	-0,008	-0,013
70	0,010	-0,001	0,009	0,013	0,003	0,002	-0,012	-0,009	-0,014
80	0,008	-0,001	0,007	0,010	0,002	0,002	-0,011	-0,008	-0,009
90	0,010	-0,001	0,010	0,014	0,003	0,003	-0,014	-0,010	-0,015
100	0,032	-0,033	0,032	0,033	0,029	0,029	-0,042	-0,039	-0,042
120	0,025	-0,007	0,025	0,027	0,022	0,021	-0,042	-0,031	-0,041
150	-0,002	-0,005	-0,021	0,061	-0,004	-0,004	-0,009	-0,008	-0,009

Evaluation: The divergences of the attenuation are below 10 %. The effects for the lead equivalents can be neglected, they are below 0.05 mm Pb.

## 5. Determination of the attenuation ratio F

The attenuation ratio F has been measured with 6 different wall thicknesses in the broad beam. The 6 wall thicknesses have been created by construction with 6 individual boards of charge 1. As the attenuation ratios become very high with low energies and thick wall constructions, measurements of the dose rate behind the attenuating boards are not reliable. For this combination, no measured value is stated. A deviation – recognizable in the graphic representation of the measured dose rates by the number of boards – from the linear attenuation ratio has been taken into consideration as criterion for the validity of the measurement.

A difference between a solid wall made of 4 boards and a wall construction with air layer and 2 by 2 boards could not be determined.

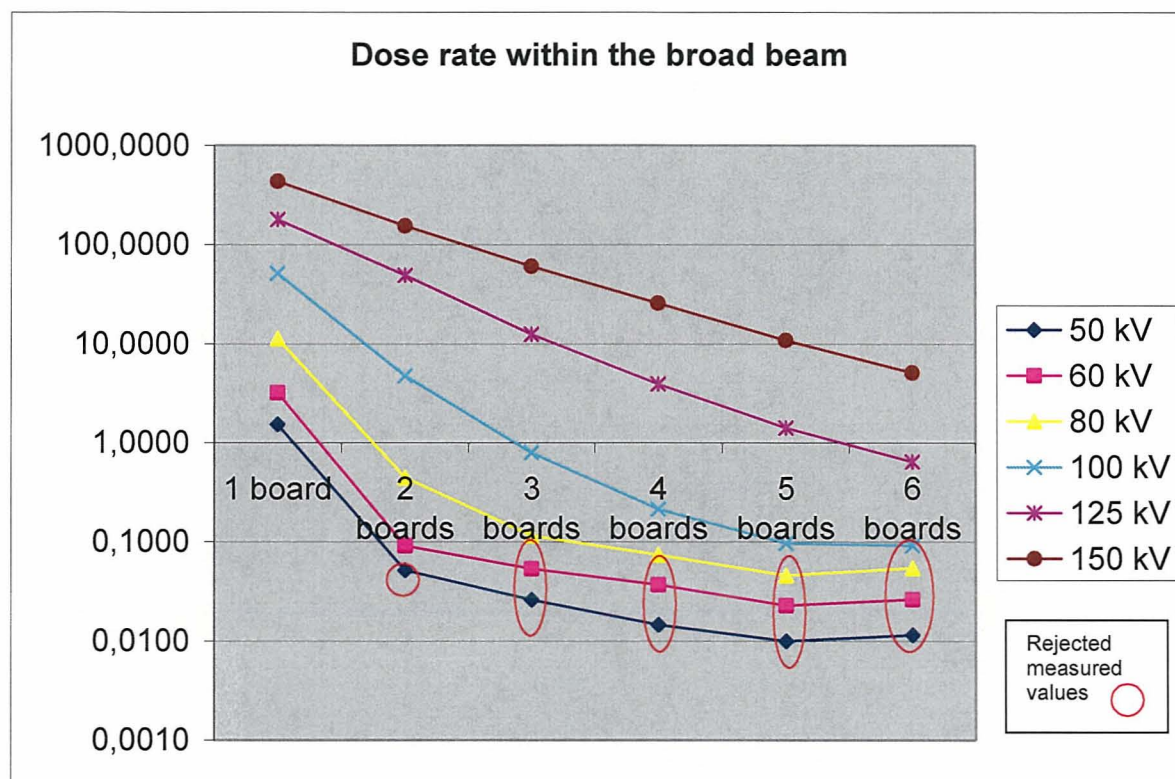


Chart 1 – Dose rate at increasing number of boards for different energies in mGy/h

Table 7:	Attenuation ratio F DIN EN 61331					
Energy	1 board	2 boards	3 boards	4 boards	5 boards	6 boards
50 kV 0,05 mm Cu	320	9546	18910	33704	49545	42712
60 kV 0,1 mm Cu	213	7464	12757	18464	29984	25986
80 kV 0,15 mm Cu	119	3036	11677	18350	29503	24923
100 kV 0,25 mm Cu	40	432	2581	9598	21199	22293
125 kV 0,45 mm Cu	15	56	218	694	1925	4234
150 kV 0,7 mm Cu	9	24	62	146	346	738

## 6. Determination of the build up factor

The build up factor B is defined in compliance with DIN EN 61331-1:2002.  $B = \frac{\dot{K}_I}{c \cdot \dot{K}_e}$

with correction factor c at  $c = \left( \frac{1500 + a}{1550} \right)^2$  and a as distance between test item and loca-

tion when measuring in the narrow beam. It describes the ratio of the dose rate in the broad beam to the dose rate in the narrow beam (measurement of absorption). Also with attenuation measurements in the narrow beam, the divergence from the linear attenuation coefficient determines the end of a reliable measurement.



Table 8: Build up factor B

Energy	1 board	2 boards	3 boards	4 boards	5 boards	6 boards
50 kV 0,05 mm Cu	4,9	<del>19,0</del>	<del>74,0</del>	=	=	=
60 kV 0,1 mm Cu	9,6	28,9	<del>119,6</del>	<del>69,4</del>	<del>42,7</del>	=
80 kV 0,15 mm Cu	5,5	10,0	<del>43,7</del>	<del>58,6</del>	<del>39,1</del>	<del>40,9</del>
100 kV 0,25 mm Cu	3,6	3,7	4,5	7,5	<del>14,4</del>	<del>30,7</del>
125 kV 0,45 mm Cu	3,0	4,1	4,0	4,2	5,0	7,3
150 kV 0,7 mm Cu	2,8	3,3	3,7	3,4	4,3	4,5

## 7. Determination of the lead equivalent

The DIN EN 6113 describes the determination of an attenuation equivalent by comparison of the dose rates behind the test item to those behind a reference material. Indication of the attenuation equivalent of the reference material in mm is made by indicating the chemical symbols of the reference materials, the radiation quality and the total filtering. A comparison with lead as reference material is usually only intended with substances developing a significant proportion of lead. If this comparison is made for boards containing barium, comparatively high lead equivalents develop which might overestimate the actual attenuation coefficient.

The lead equivalent was determined by comparison of the dose rate behind the test item with one or several layers of lead. The finest gradation is 0.05 mm Pb. The limit of the process is reached when no sufficient dose rate is available for differentiation at low energy. For these cases, it was not possible to determine the lead equivalent. The lead equivalents in the following table are average values taken from both layers with the least divergence of the dose rate to the dose rate behind the test items.

Table 9: Lead equivalents acc. to DIN EN 61331-1:2002

	50 kV 0,05 mm Cu	60 kV 0,1 mm Cu	80 kV 0,15 mm Cu	100 kV 0,25 mm Cu	125 kV 0,45 mm Cu	150 kV 0,7 mm Cu
1 board	0,38	0,63	0,93	0,83	0,58	0,43
2 boards	0,78	1,28	1,93	1,68	1,03	0,78
3 boards		1,63	2,73	2,40	1,50	1,20
4 boards				3,23	1,98	1,38
5 boards				3,88	2,45	1,80
6 boards				4,28	2,85	2,08

## 8. Final determination of a lead equivalent

The lead equivalents of DIN EN 61331 determined within the narrow beam overestimate the protection effect, as only the absorption of the photons determines the attenuation. The fluorescent X-radiation and photons that are scattered by the Compton Effect are not included. These, when measured in the broad beam, hit the detector and reduce the attenuation factor. These effects are described in the standard by the build up factor or are included in the measurement in the broad beam respectively.

As these attenuation factors are unusual for the planning of X-radiation rooms, a lead equivalent is to be indicated which describes the radiation protection boards with sufficient reliability. For that purpose, further boards have been tested in the broad beam. These measurements shall enable a correction of the lead equivalents. For the practical radiation protection, especially the decrease of the lead equivalent with high energies is relevant. The likewise decrease of the lead equivalent at low energies is significantly less relevant as the actual attenuation of the board is very high due to the lower energy.

The lead equivalent increases in an almost linear way with the number of used boards. The increase from board to board depends on the energy. The lead equivalent of the board itself depends on the energy and has its highest value in the average kV range of the X-ray tube voltage. Under the assumption that these two effects are independent of one another outstanding values can be calculated. From the comparison of measured values of the lead-reinforced boards in the broad beam, a correction can be determined in order to reduce the overestimation of the measurements in the narrow beam. This correction has influences on the lead equivalent in the range of 80-100 kV. A corrected lead equivalent is determined which ensures that the boards will not be overestimated.

As basic condition, the lead equivalents of DIN 6812 determined in the radiation beam may not be exceeded.

Having made these corrections, the following lead equivalent thicknesses are determined for the radiation protection board and serve as minimum thicknesses.

Table 10: Determined lead equivalents in mm Pb for different energies and number of boards. Valid for a nominal thickness of 12.5 mm per board.							
[kV]	60	70	80	90	100	125	150
1 board	0,45	0,60	0,75	0,70	0,70	0,50	0,40
2 boards	0,90	1,20	1,50	1,40	1,40	1,00	0,80
3 boards	1,35	1,80	2,20	2,10	2,10	1,50	1,10
4 boards	1,80	2,30	2,90	2,80	2,80	2,00	1,40
5 boards					3,40	2,40	1,70
6 boards					4,00	2,80	2,00

TÜV NORD Röntgentechnik

  
Jürgen Feldmann

Hannover, 23.01.2009