

The Formwork Experts.

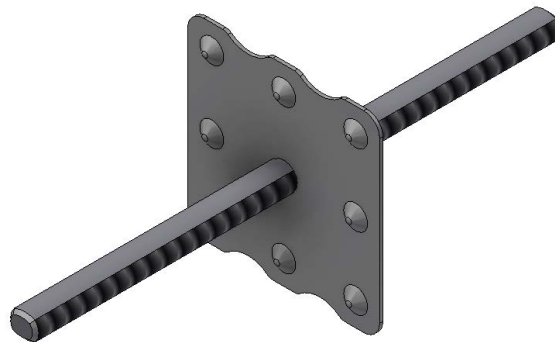
Water stop G 15,0

Art.-No.: 581818000

Test Report

Radiation safety

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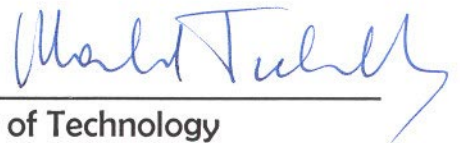


Expert's opinion on Influence of Doka form ties on the shielding properties of concrete walls for photon radiation

Manfred Tschurlovits

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This report consists of 18 pages



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Terms of reference and range of application

The subject of this report is to investigate to what extent the DOKA form ties change the properties of concrete walls in terms of attenuation of photons in relation to pure concrete or reinforced concrete. The major question is therefore how some steel parts or openings left by form ties after removal of formwork in the concrete interfere with the shielding effect of normal concrete, where the shielding is designed following national or international standards / e.g. DIN.

This report applies for photon radiation, i.e. from radionuclides emitting gamma-radiation as well as radiation producing equipment as X-ray installations and low energy accelerators.

Content

- 1) Basic processes of interaction of photons with matter- mass attenuation coefficient, μ/ρ of elemental media
- 2) Shielding of Photons: properties of materials involved: air, concrete and iron
Properties of the material under consideration
- 3) Considerations on geometrical conditions for different design variants of Doka form ties
- 4) Conclusions

1. Basic processes of interaction of photons with matter

1.1 General and narrow beam attenuation

The mass Attenuation Coefficient, μ/ρ of an elemental medium describes the interaction and is based upon the cross section of interactions. The total cross section can be written as the sum over contributions from the principal photon interactions,

$$\sigma_{\text{tot}} = \sigma_{\text{pe}} + \sigma_{\text{coh}} + \sigma_{\text{incoh}} + \sigma_{\text{pair}} + \sigma_{\text{trip}} + \sigma_{\text{ph.n.}} \quad (1)$$

where σ_{pe} is the atomic photoeffect cross section, σ_{coh} and σ_{incoh} are the coherent (Rayleigh) and the incoherent (Compton) scattering cross sections, respectively, σ_{pair}

Expert's report: Influence of **Doka** form ties on the shielding properties of concrete walls

and σ_{trip} are the cross sections for electron-positron production in the fields of the nucleus and of the atomic electrons, respectively, and $\sigma_{\text{ph.n.}}$ is the photonuclear cross section. The physical effects can be found in texts as / At 68, Sh 96/. σ_{tot} is the total cross section for an interaction by the photon, frequently given in units of b/atom (barns/atom), where $b = 10^{-24} \text{ cm}^2$.

The attenuation coefficient μ is related with σ_{tot} by

$$\mu = (N_A \cdot \rho / M) \sigma_{\text{tot}} \quad (2)$$

where N_A ... Avogadro number

ρ ... density

M ... molar mass

σ_{tot} ...total cross section

The attenuation coefficient, photon interaction cross sections and related quantities as **mass attenuation coefficient** $\mu/\rho [\text{cm}^2 \cdot \text{cm}^{-1}]$ (see below) are strongly dependent on the energy of the incident photons. (see figure below)

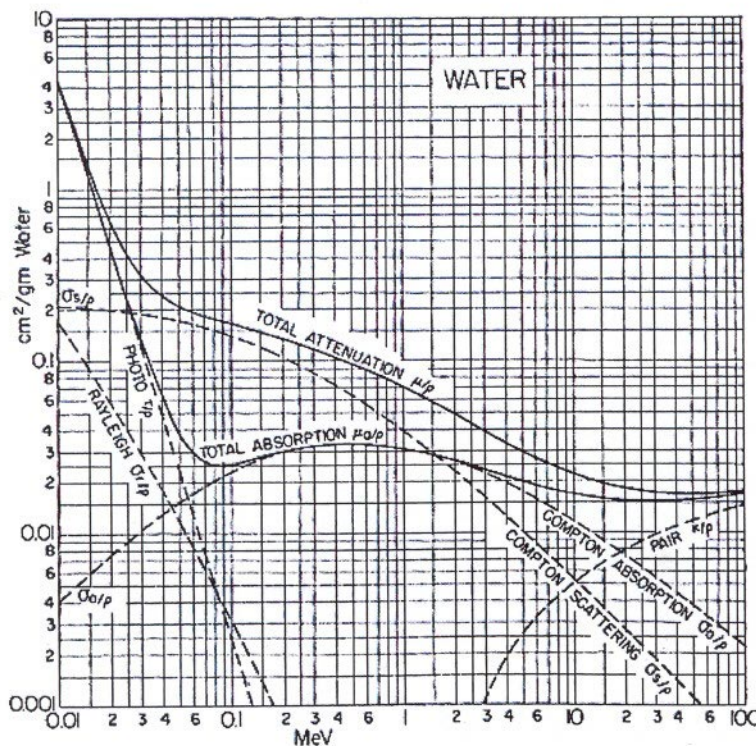


FIG. 7. Mass attenuation coefficients for photons in water. From Evans (1963).

Fig. 1 shows the contribution of the different interaction processes to the total attenuation. Water is taken as an example, which may serve as an example for light media. One can see that the photoelectric effect is dominant in the lower energy range, Compton absorption at medium energies, and pair production at energies well above 1,02 MeV. The unbroken line μ/ρ is relevant for the present consideration.

Fig.1 Mass attenuation for photons in water /At 1968/

The importance of the basic effects in dependence of the photon energy is roughly shown in the table 1

Photon energy	Importance of interaction effect		
	photo	compton	pair
10 keV	95%	5%	<<
25 keV	50%	50%	<<
60 keV	7%	93%	<<
150 keV	<<	≈100%	<<
4 MeV	<<	94%	6%
10 MeV	<<	77%	23%

Table 1: importance of the basic effects in dependence of energy

However, the coefficient shown above can be used or calculation of shielding without further modification only under special circumstances, called "**narrow beam attenuation**".

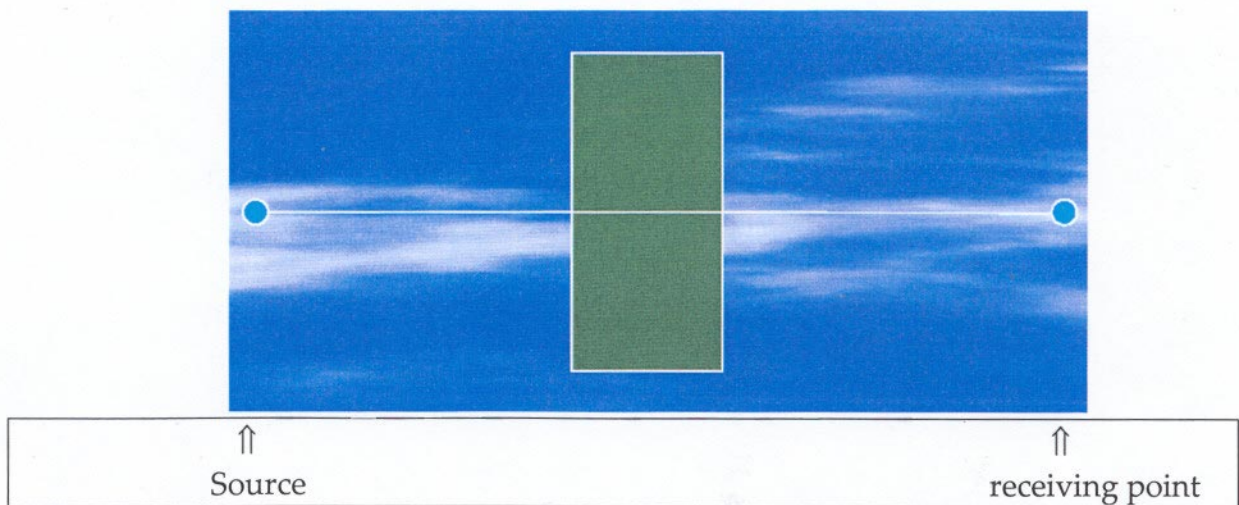


Fig.2 Schematic draw of the narrow beam attenuation.

A narrow beam of monoenergetic photons with a dose rate I_0 , at the point of interest (receiving point) without shielding leads to a dose rate I_x after penetration of a layer of material with mass thickness (rather mass per unit area) d and density ρ : This is described by the exponential attenuation law using the **mass attenuation coefficient** $\mu/\rho [\text{cm}^2.\text{cm}^{-1}]$ as

$$I_x = I_o \cdot e^{-(\mu/\rho)d} \quad (3)$$

Note that the mass thickness d is defined as the mass per unit area, and is obtained by multiplying the thickness x by the density ρ , i.e. $d = \rho \cdot x$

An identical frequently used notation is

$$I_x = I_o \cdot e^{-\mu \cdot x} \quad (4)$$

where x is the thickness of the layer of material [cm], and μ is the **linear photon attenuation coefficient** [cm^{-1}]

Data on the coefficient μ/ρ can be found in various references, the most recent and most complete set is those found in the current NIST database / Hu 06/.

However, the considerations shown above apply only for the hypothetical case of a narrow beam geometry. This condition is practically not existent and underestimate reality, where a "broad beam geometry" applies.

1.2 Broad beam attenuation

As mentioned above, the considerations laid down in 1.1 apply only for a well defined geometrical condition, usually called "narrow beam condition".

This condition implies that only straightforward absorption takes place, and that scattering is excluded. In practical situations, however, scattering can not be excluded, and this geometry is called "broad beam condition".

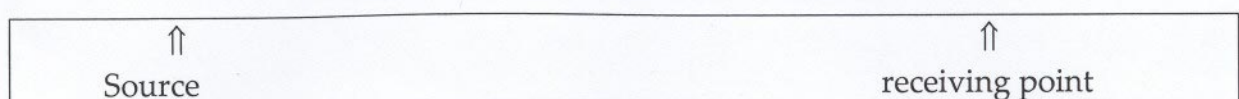
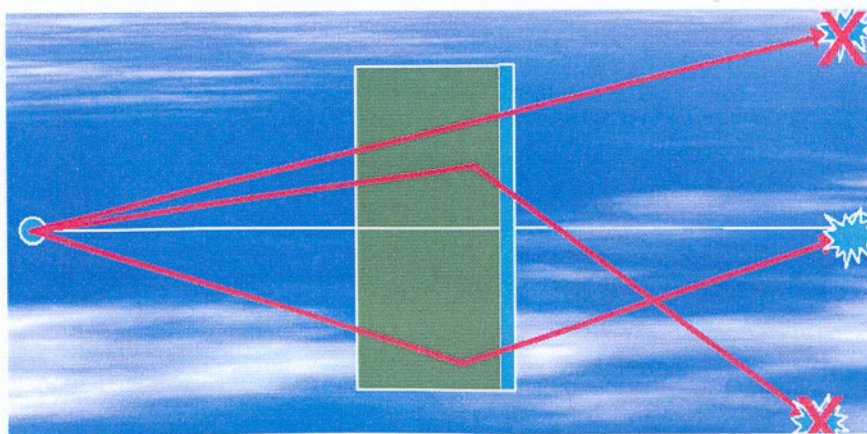


Fig.3 broad beam geometry

This additional scattering lead to a higher dose rate at the receiving point than predicted by equs. (3) or (4). This is classically approached by a "build up factor B", which is defined as:

$$B(\mu x) = 1 + \frac{I_{x,scatter}}{I_{x,direct}} \quad (5)$$

The physical basis of this enhancement of the flux of photons on the receiving point is compton scattering, the factor B being a function of (E, Z, and x), where E is the energy of the photons, Z the mass number of the material, and x is the thickness of the layer of material [cm]. This effect is high for large field sizes and for photons of lower energies and gradually decreasing with energy. In addition, the build up factors depend on the source and shield geometries. For the same material thickness between source and detector, buildup factors are conceptually slightly different for point sources in an infinite medium and for a slab shield. However, this approach mirrors reality in a sufficient extent and is used in most cases. The composition of the shielding as considered here is no critical issue.

Some approaches are available for estimates of B [Ja 75, Sh 96, Sh 04/.

If the reliability of the approach is not sufficient, Monte Carlo (MC) calculations have to be carried out. This applies also for complex cases.

Monte Carlo Calculations

Deterministic calculations as shown above need one run of the calculation, and the result is a single number. Usually based upon conservative parameters, they lead to conservative results. Possible variability of the parameters is not taken into account. Monte Carlo (MC)- Calculations are based on a large number of calculations rather than upon a single deterministic calculation. Every simulation is based upon events that happen randomly, and so the outcome of a calculation not absolutely predictable, except the number of runs is large, see below. This element of chance reminds one of gambling and so the originators of the Monte Carlo technique, Ulam and von Neumann, both respectable scientists, called the technique *Monte Carlo* to emphasize its gaming aspect. Although there is a gaming aspect to Monte Carlo calculations, modern computers permit the calculation of the history of millions of photons and hence to obtain reliable results. For example, a code can be found in: [MC 1/ Monte Carlo (MC)- Calculations permit also parameter variations, the identification of critical parameters as well as the solution of complex cases.



2. Shielding of photons: Properties of materials involved: air, concrete and iron

Substances subject of consideration are usually not pure elements, but are composed of some compounds in different proportions. In the present case, only compounds constituting the bulk of material have to be considered, and elements in trace quantities are negligible in photon interactions. Some examples of compounds are shown below in table 2, the major contributions are shown in bold

Table 2 basic data of some materials

Material	Density (g/cm ³)	Composition elements	Element number Z: fraction by weight
Air, Dry (near sea level)	1.205E-03	C Carbon, N Nitrogen O Oxygen Ar Argon	6: 0.000124 7: 0.755268 8: 0.231781 18: 0.012827
Concrete, Ordinary	2.300E+00	C Carbon, O Oxygen Si Silicon	1: 0.022100 6: 0.002484 8: 0.574930 11: 0.015208 13: 0.019953 14: 0.304627 19: 0.010045 20: 0.042951 26: 0.006435:
Concrete, Barite (TYPE BA)	3.350E+00	O Oxygen S Sulphur Ca Calcium Fe Iron Ba Barium	1: 0.003585 8: 0.311622 13: 0.004183 14: 0.010457 16: 0.107858 20: 0.050194 26: 0.047505 56: 0.46340
Water, Liquid	1.000E+00		1: 0.111898 8: 0.888102
Iron	7.874E+00		26

Mixtures and compounds. Values of the mass attenuation coefficient, μ/ρ , for mixtures and compounds (assumed homogeneous) are obtained according to simple additivity:

$$\mu/\rho = \sum_i w_i (\mu/\rho)_i \quad (6)$$

where w_i is the fraction by weight of the i^{th} atomic constituent, and the $(\mu/\rho)_i$ values are shown below. The assumed fractions by weight are given in Table 2. To obtain $(\mu/\rho)_i$ values at all the absorption edges of all constituent elements, interpolation has been performed separately.

Comparison of numerical values

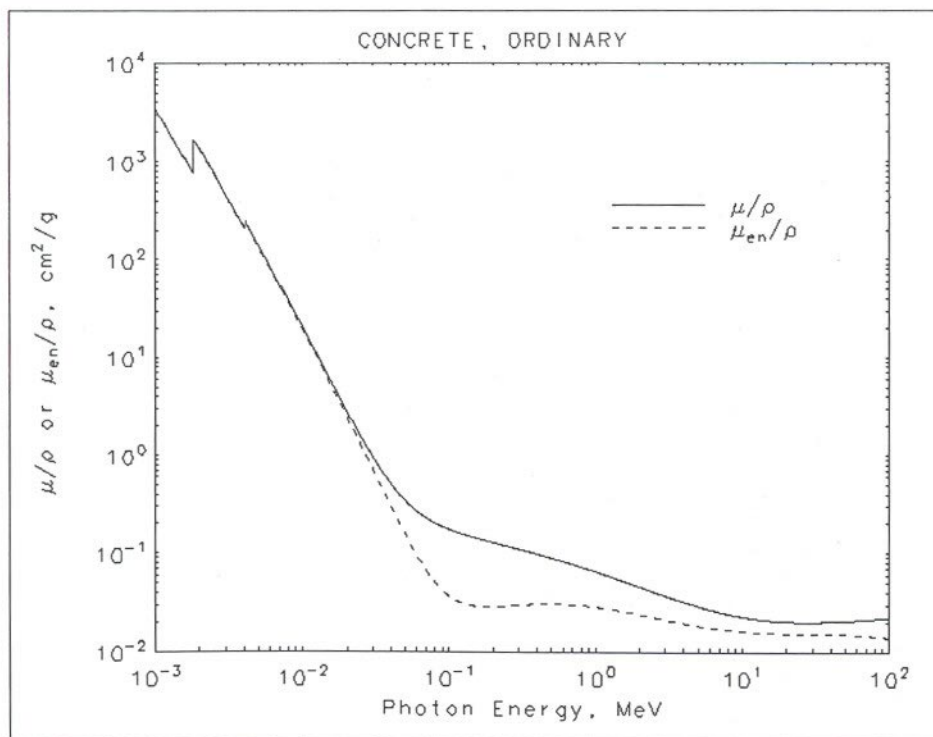
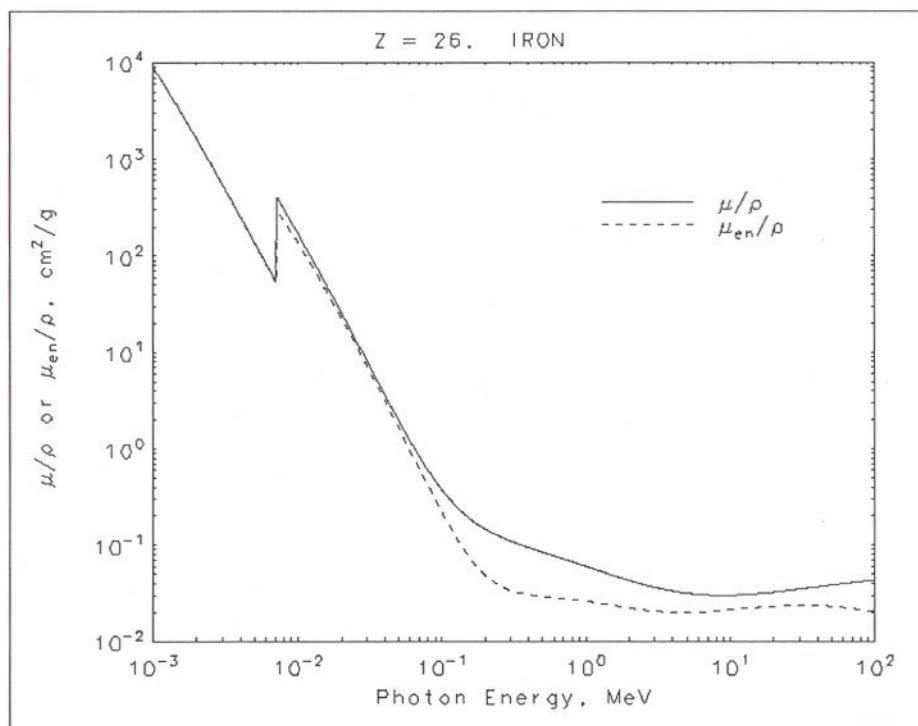
In order to demonstrate the shielding properties, the mass attenuation coefficient μ/ρ is listed below for some energies of covering the energy range of interest

Energy	material	μ/ρ [cm ² /g]
0,1 MeV	ordinary concrete,	1.738E-01
	iron	3.717E-01
0,5	ordinary concrete,	8.915E-02
	iron	8.414E-02
1,0 MeV	ordinary concrete	6.495E-02
	iron	5.995E-02
10 MeV	ordinary concrete	2.278E-02
	iron	2.994E-02

In the case of reinforced concrete, or when tie rods remain embedded in the concrete, a certain volume of concrete is replaced by iron. As the shielding effects as described by equ (3) and (4) is coined by the product $(\mu/\rho) \cdot \rho$, the effectiveness of shielding of embedded tie rods is better than by undisturbed concrete because of the higher density.

Trace elements do not change the shielding properties of photons due to their low concentration in the mixture. However, they are important, however, in neutron shielding, which is not considered here.

These data show linear attenuation coefficients. As shown above, build up takes place in addition. The mass attenuation coefficient of some substance is shown below

Figs 4 and 5: Mass attenuation coefficients μ/ρ for iron and concrete

Numerical data of μ/ρ , shadowed area of specific interest

Iron
Z = 26

Energy (MeV)	μ/ρ (cm ² /g)	μ_{en}/ρ (cm ² /g)
1.00000E-03	9.085E+03	9.052E+03
1.50000E-03	3.399E+03	3.388E+03
2.00000E-03	1.626E+03	1.620E+03
3.00000E-03	5.576E+02	5.535E+02
4.00000E-03	2.567E+02	2.536E+02
5.00000E-03	1.398E+02	1.372E+02
6.00000E-03	8.484E+01	8.265E+01
7.11200E-03	5.319E+01	5.133E+01
K 7.11200E-03	4.076E+02	2.978E+02
8.00000E-03	3.056E+02	2.316E+02
1.00000E-02	1.706E+02	1.369E+02
1.50000E-02	5.708E+01	4.896E+01
2.00000E-02	2.568E+01	2.260E+01
3.00000E-02	8.176E+00	7.251E+00
4.00000E-02	3.629E+00	3.155E+00
5.00000E-02	1.958E+00	1.638E+00
6.00000E-02	1.205E+00	9.555E-01
8.00000E-02	5.952E-01	4.104E-01
1.00000E-01	3.717E-01	2.177E-01
1.50000E-01	1.964E-01	7.961E-02
2.00000E-01	1.460E-01	4.825E-02
3.00000E-01	1.099E-01	3.361E-02
4.00000E-01	9.400E-02	3.039E-02
5.00000E-01	8.414E-02	2.914E-02
6.00000E-01	7.704E-02	2.836E-02
8.00000E-01	6.699E-02	2.714E-02
1.00000E+00	5.995E-02	2.603E-02
1.25000E+00	5.350E-02	2.472E-02
1.50000E+00	4.883E-02	2.360E-02
2.00000E+00	4.265E-02	2.199E-02
3.00000E+00	3.621E-02	2.042E-02

Expert's report: Influence of **Doka** form ties on the shielding properties of concrete walls

4.00000E+00	3.312E-02	1.990E-02
5.00000E+00	3.146E-02	1.983E-02
6.00000E+00	3.057E-02	1.997E-02
8.00000E+00	2.991E-02	2.050E-02
1.00000E+01	2.994E-02	2.108E-02
1.50000E+01	3.092E-02	2.221E-02
2.00000E+01	3.224E-02	2.292E-02

Concrete, OrdinaryNumerical data of μ/ρ , shadowed area of specific interest

	Energy (MeV)	μ/ρ (cm ² /g)	μ_{cn}/ρ (cm ² /g)
	1.00000E-03	3.466E+03	3.456E+03
	1.03542E-03	3.164E+03	3.156E+03
	1.07210E-03	2.889E+03	2.880E+03
11 K	1.07210E-03	2.978E+03	2.968E+03
	1.18283E-03	2.302E+03	2.295E+03
	1.30500E-03	1.775E+03	1.769E+03
12 K	1.30500E-03	1.781E+03	1.775E+03
	1.50000E-03	1.227E+03	1.223E+03
	1.55960E-03	1.104E+03	1.100E+03
13 K	1.55960E-03	1.176E+03	1.169E+03
	1.69350E-03	9.419E+02	9.365E+02
	1.83890E-03	7.525E+02	7.482E+02
14 K	1.83890E-03	1.631E+03	1.587E+03
	2.00000E-03	1.368E+03	1.333E+03
	3.00000E-03	4.646E+02	4.552E+02
	3.60740E-03	2.804E+02	2.751E+02
19 K	3.60740E-03	2.911E+02	2.844E+02
	4.00000E-03	2.188E+02	2.139E+02
	4.03810E-03	2.131E+02	2.084E+02
20 K	4.03810E-03	2.520E+02	2.415E+02
	5.00000E-03	1.401E+02	1.348E+02
	6.00000E-03	8.401E+01	8.094E+01
	7.11200E-03	5.187E+01	4.995E+01
26 K	7.11200E-03	5.415E+01	5.153E+01
	8.00000E-03	3.878E+01	3.689E+01
	1.00000E-02	2.045E+01	1.937E+01

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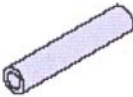
1.50000E-02	6.351E+00	5.855E+00
2.00000E-02	2.806E+00	2.462E+00
3.00000E-02	9.601E-01	7.157E-01
4.00000E-02	5.058E-01	2.995E-01
5.00000E-02	3.412E-01	1.563E-01
6.00000E-02	2.660E-01	9.554E-02
8.00000E-02	2.014E-01	5.050E-02
1.00000E-01	1.738E-01	3.649E-02
1.50000E-01	1.436E-01	2.897E-02
2.00000E-01	1.282E-01	2.868E-02
3.00000E-01	1.097E-01	2.969E-02
4.00000E-01	9.783E-02	3.024E-02
5.00000E-01	8.915E-02	3.033E-02
6.00000E-01	8.236E-02	3.015E-02
8.00000E-01	7.227E-02	2.940E-02
1.00000E+00	6.495E-02	2.843E-02
1.25000E+00	5.807E-02	2.716E-02
1.50000E+00	5.288E-02	2.595E-02
2.00000E+00	4.557E-02	2.395E-02
3.00000E+00	3.701E-02	2.120E-02
4.00000E+00	3.217E-02	1.951E-02
5.00000E+00	2.908E-02	1.840E-02
6.00000E+00	2.697E-02	1.763E-02
8.00000E+00	2.432E-02	1.669E-02
1.00000E+01	2.278E-02	1.617E-02
1.50000E+01	2.096E-02	1.559E-02
2.00000E+01	2.030E-02	1.539E-0

One has to note that the data above (from <http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z26.htm>) cover a range from 10^{-2} MeV to 20 MeV being larger than the range applicable here. The product $(\mu/\rho)\rho$ of iron is always larger than that of concrete, even in the range below 10^{-1} MeV, where concrete walls are rarely used for shielding of photons because only small thicknesses are required

3. Considerations on geometrical conditions for different design variants of Doka form ties

Doka form ties are to be used in different design variants / Do 06/ Only variants classified as "radiation proof" are considered here and discussed below. The following designs have to be considered

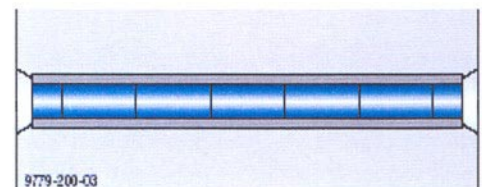
Radiation-proof

 Fibre-concrete tube 22mm	Water stop G 15.0	Water stop 15.0 or Water stop S 15.0 (sulphate-resistant)	Expendable Tie-rod 15.0 with 2 anchor cones
 Page 12	 Page 16	 Page 18	 Page 22

The figure above taken from /Do 06/ shows the major characteristics of the design variants classified as "radiation proof".

3.1 Fibre concrete tube

The design: "fibre-concrete tube 22 mm" is to be used for wall thicknesses of 8 cm and above/ Do 06 p.12/let the tube open after removal of formwork. In order to prove sufficient shielding, the opening has entirely filled with concrete plugs. The shielding will be identical with the bulk material provided that the density of the plugs is the same than that of concrete. Quality control has to prove the complete filling.



However, the as the tube material has a lower density than concrete, the shielding effect might under some (rather hypothetical) circumstances be a little lower than that of bulk concrete. The cones can be disregarded. Both limitations apply for smaller wall thicknesses, as at larger shielding thickness scattering become important.

A quantitative statement on the reduction of the shielding effect can not be made in general. This is because the effect depends on the location of the source in relation to the form tie, the dimension of the source, and the wall thickness

This does not imply that this design can not be used for shielding purposes, but a MC calculation taking into account geometrical constraints (as dimensions of the source, distance source- shielding, thickness of the shielding, number of ties per square meters, etc), i.e. all parameters influencing the solid angle of propagation) have to be applied to prove the validity of the assumptions.

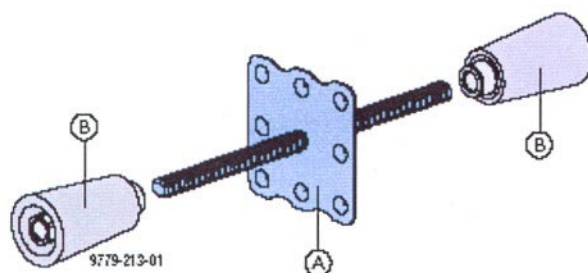
3.2 Water stop G:

The tie rods remains embedded in the concrete.

Water stop G 15.0



Can be mounted in walls with a thickness of 25 cm and above.



A Water stop G 15.0

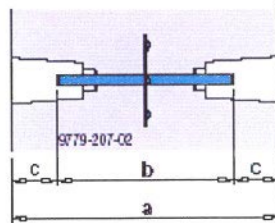
B Anchor cone 15.0

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As the tie rod has a higher density than concrete, the shielding is even better. The tie rod has the same importance as the concrete reinforcement.

In order to provide homogenous shielding properties, the space left by the anchor cone after removal of formwork has to be filled with concrete with the same density then concrete

Formwork stripped from around form-tie point



If the volume left after removal of the anchor cone is filled with asbestos cement or mortar with a density of 20 kN/m^3 /Ze 06/, there will be formally a little smaller attenuation then for concrete. This will however not be effective as this form tie is applied in walls with a thickness of concrete at larger than 25 cm /Do 06 p.16/.

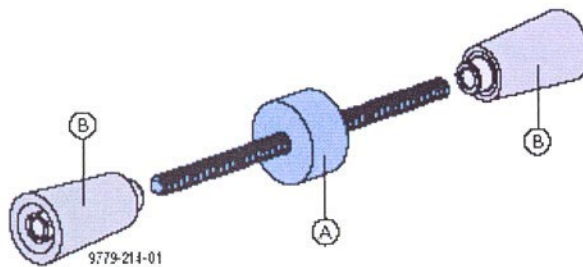
3.3 Water stop 15.0

The same requirements as at 3.2 above apply.

3.4 Water stop S:

Water stop 15.0

Can be mounted in walls with a thickness of 33 cm and above.

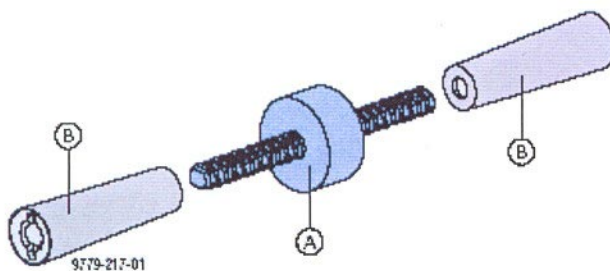


A Water stop 15.0

B Anchor cone 15.0

Water stop 20.0

Can be mounted in walls with a thickness of 42 cm and above.



A Water stop 20.0

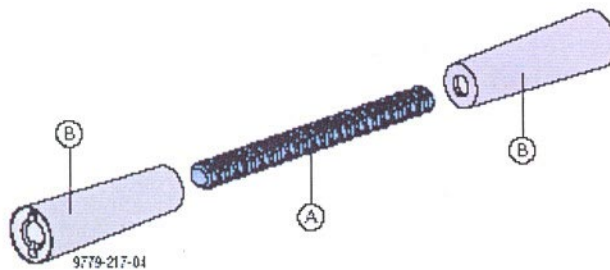
B Anchoring cone 20.0 + Sealing sleeve 20.0

The tie rods remains embedded in the concrete. The sealing sleeve is of not importance with regard to shielding properties, as the thickness can be disregarded relative to the wall thickness.

3.5 Expendable tie rod with anchor cone

Expendable tie-rod with Anchor cones 20.0

Can be mounted in walls with a thickness of 35 cm and above.

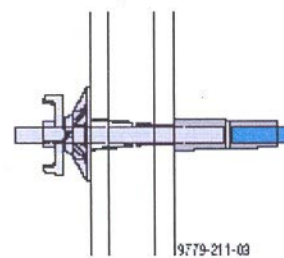


A Tie-rod 20.0

B Anchoring cone 20.0 + Sealing sleeve 20.0

Preparing the for

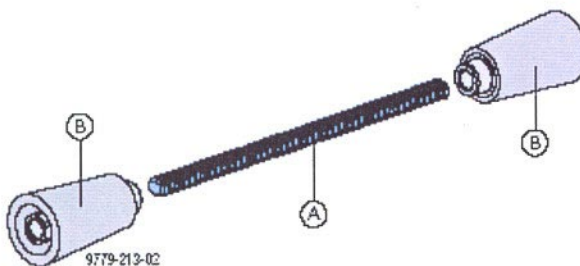
The anchoring cones are used over and over again embedded in the concrete.

Form-tie point enclosure

A Tie-rod 20.0

B Anchoring cone 20.0 + Sealing sleeve 20.0

Can be mounted in walls with a thickness of 25 cm and above.



A Tie-rod 15.0

B Anchor cone 15.0

As the tie rod remains in the wall, the same issues as discussed in 3.2 to 3.4 apply, provided that the space left by the anchor cone after removal of formwork is filled with material with the same density then the concrete used for the wall.

4. Conclusions

The application of Doka form ties

- **Water stop G:**
- **Water stop S:**
- **Expendable tie rod with anchor cone**

does not interfere or reduce the shielding properties of broad beams of photons , provided that the space left by the anchor cone after removal of formwork is filled with material with the same density then the concrete used for the wall.

The application of the form tie

- **fibre concrete tube**

requires of the filling if the hole with concrete plugs and quality control of this procedure. The shielding properties might possibly be insignificantly reduced under certain rather hypothetical conditions as small wall thickness and source with small dimensions.

Manfred Tschurlovits

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/MC 1/ e.g. <http://www.nea.fr/abs/html/cc-0638.html>

/DI/ DIN 54 113: Zerörungsfreie Prüfung 1 – 3

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