INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR.803 - 2

TRAINING COURSE ON DOSIMETRY AND DOSE REDUCTION TECHNIQUES IN DIAGNOSTIC RADIOLOGY

(16 - 25 MARCH 1994)

"THE REALISATION OF THE UNIT GRAY"

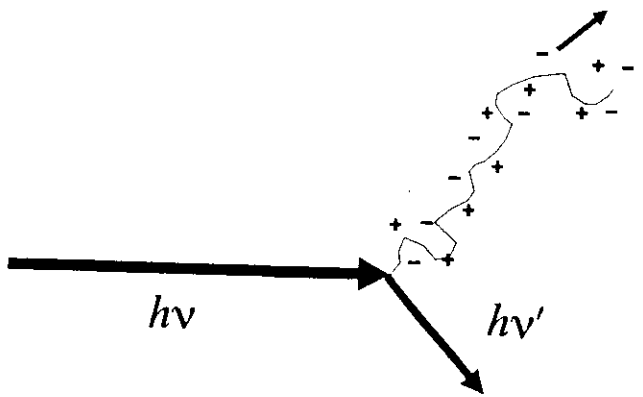
H.M. KRAMER
Physikalisch-Technische Bundesanstait
Bundesallee 100
Postfach 3345
D-3300 Braunschweig
GERMANY

These are preliminary lecture notes, intended only for distribution to participants.

The realisation of the unit gray

H. M. Kramer

The energy transfer process



Absorbed dose

The absorbed dose, D, is the quotient of $\mathrm{d}\bar{\varepsilon}$ by $\mathrm{d}m$, where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionising radiation to matter of mass $\mathrm{d}m$.

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

Unit: J kg^{-1}
The special name for the unit of absorbed dose is gray (Gy)

Kerma

The kerma, K, is the quotient of $\mathrm{d}E_{\mathrm{tr}}$ by $\mathrm{d}m$, where $\mathrm{d}E_{\mathrm{tr}}$ is the sum of the kinetic energies of all charged ionising particles liberated by uncharged ionising particles in a material of mass $\mathrm{d}m$:

$$K = \frac{\mathrm{d}E_{\mathrm{tr}}}{\mathrm{d}m}$$

Unit: J kg^{-1}
The special name for the unit of kerma is gray (Gy)

If the mass element $\mathrm{d}m$ is air we speak of air kerma K_{a}

How to measure the air kerma ?

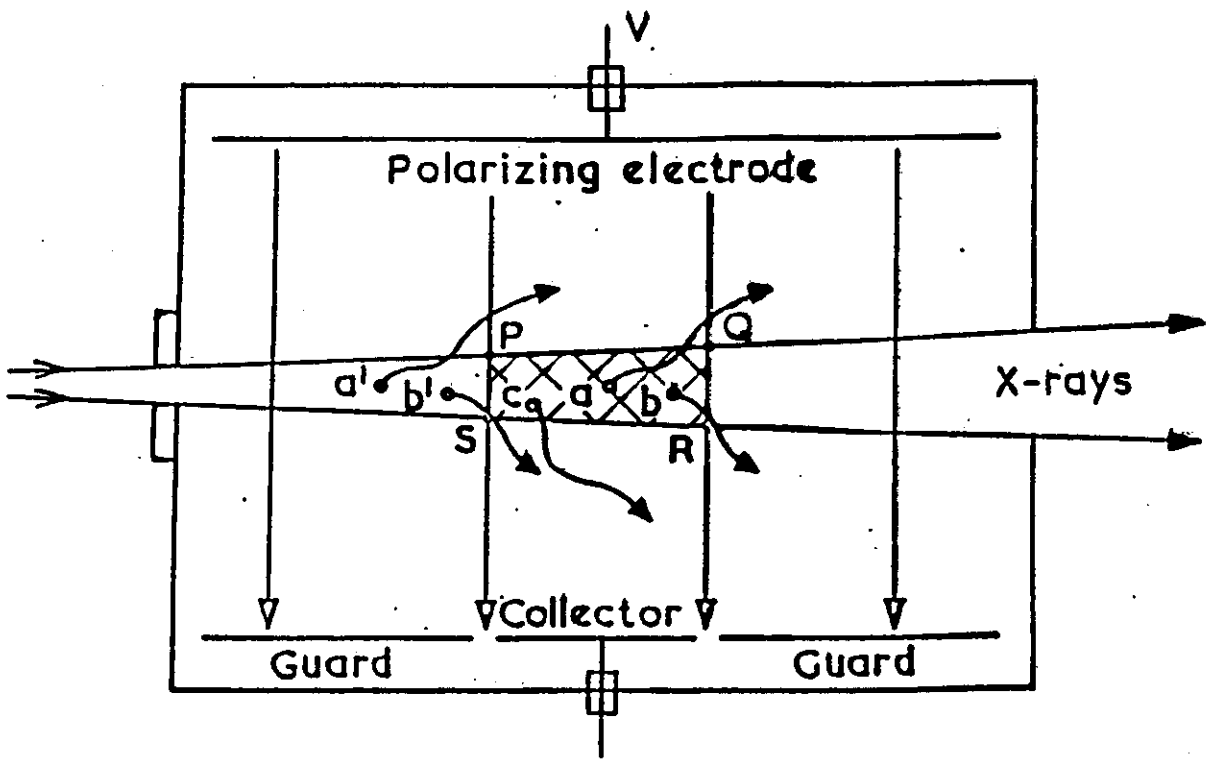
$$K_a = \frac{\mathrm{d}E_{tr}}{\mathrm{d}m_a} \cong \frac{\Delta E_{tr}}{\Delta m_a} = \frac{\Delta E_{tr}}{\rho \Delta V_a}$$

The mean energy expended in a gas per ion pair formed, w, is the quotient E by N, where N is the mean number of ion pairs formed when the initial kinetic energy E of a charged particle is completely dissipated in the gas

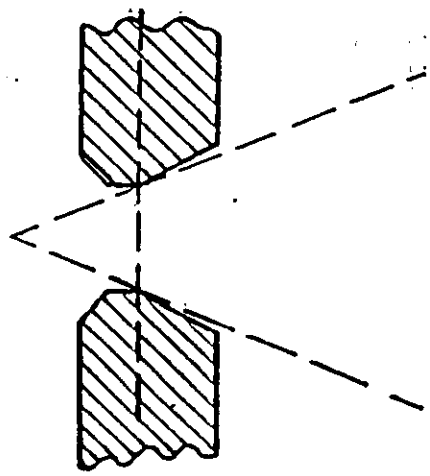
$$E = Q\frac{w}{e}$$

$$K_a = \frac{Qw_a}{m_a(1-g_a)e} = \frac{Qw_a}{\rho_a V_a(1-g_a)e}$$

The free air ionization chamber

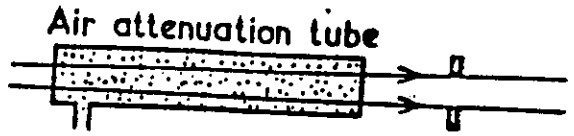


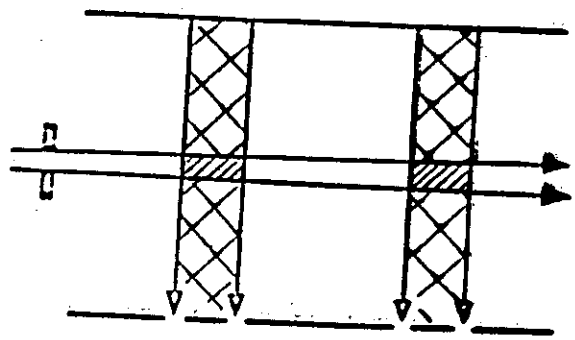
Point of
Measurement

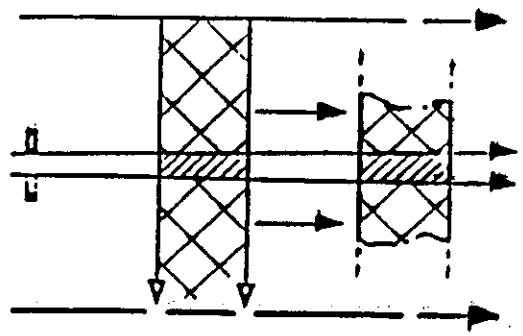


Diaphragm
Profiled Aperture

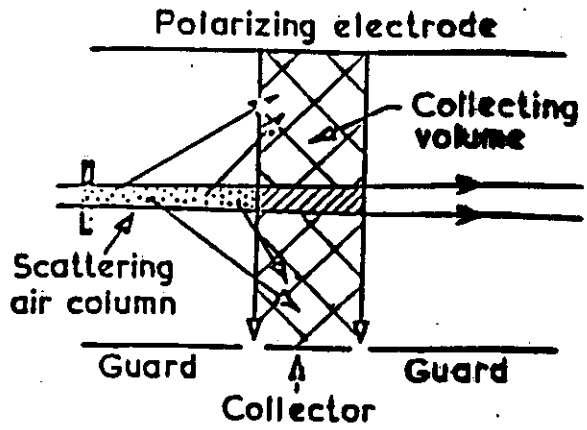
Attenuation in the air

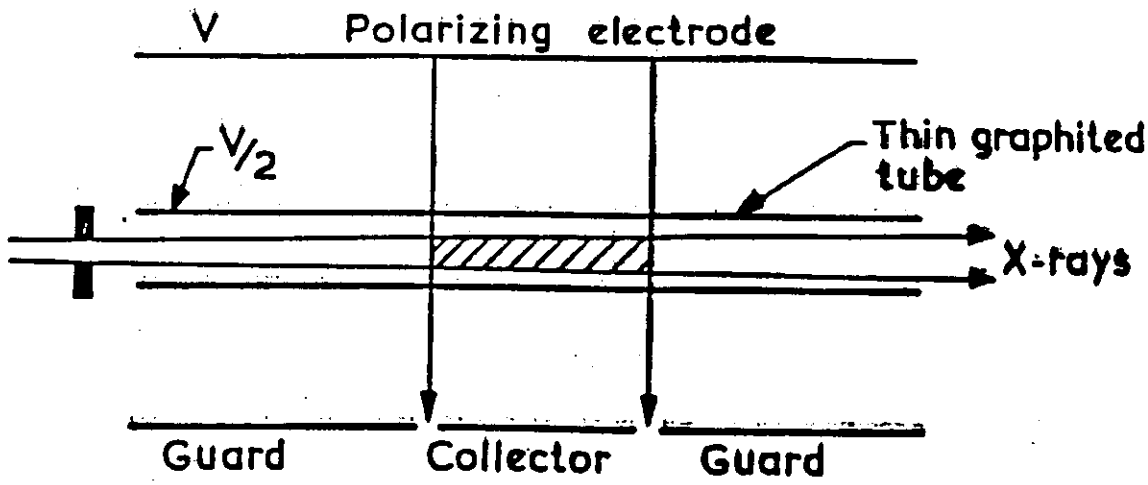






Scattered photons





Other correction factors

density of air

humidity of air

transmission of the diaphragm

transmission of the chamber walls

saturation losses by initial and volume recombination

distortion of the electric field

field size

chamber polarity

Numerical Values Entering into the Determination of the Air Kerma and their Uncertainties

$$K_a = \frac{Q w_a}{\rho_a V_a (1 - g_a) e} \prod k_i$$

Quantity	range of values	uncertainty
Q	10^{-12} to 10^{-8} C	0.06 %
w / e	33.97 V	0.15 %
$\rho(20°\,C, 101.325\,kPa)$	1.2045 kg/m^3	0.01 %
V_a	1 to 200 cm^3	0.05 %
$(1 - g_a)$ at 100 keV	0.9997	----
	combined	0.17 %

Correction factors

influence quantity	value of corr. factor	uncertainty
attenuation	1.00 to ≈1.03	0.15 %
scattering	0.98 to 1.00	0.25 %
air density	0.96 to 1.04	0.03 %
field distortion	0.99 to 1.01	0.25 %
aperture transmission	0.997 to 1.00	0.10 %
polarity	1.00	0.06 %
recombination	1.00 to ≈1.01	0.10 %
field diameter	1.00 to ≈1.005	0.10 %
electron range	1.00 to ≈1.002	0.05 %
	combined	0.43 %

Total uncertainty of a measurement of the air kerma at a confidence level of 67 %

0.5 %

Uncertainty associated with transfer to secondary standard: 0.3 %

Total uncertainty of a calibration factor:

67 % confidence level: 0.6 %

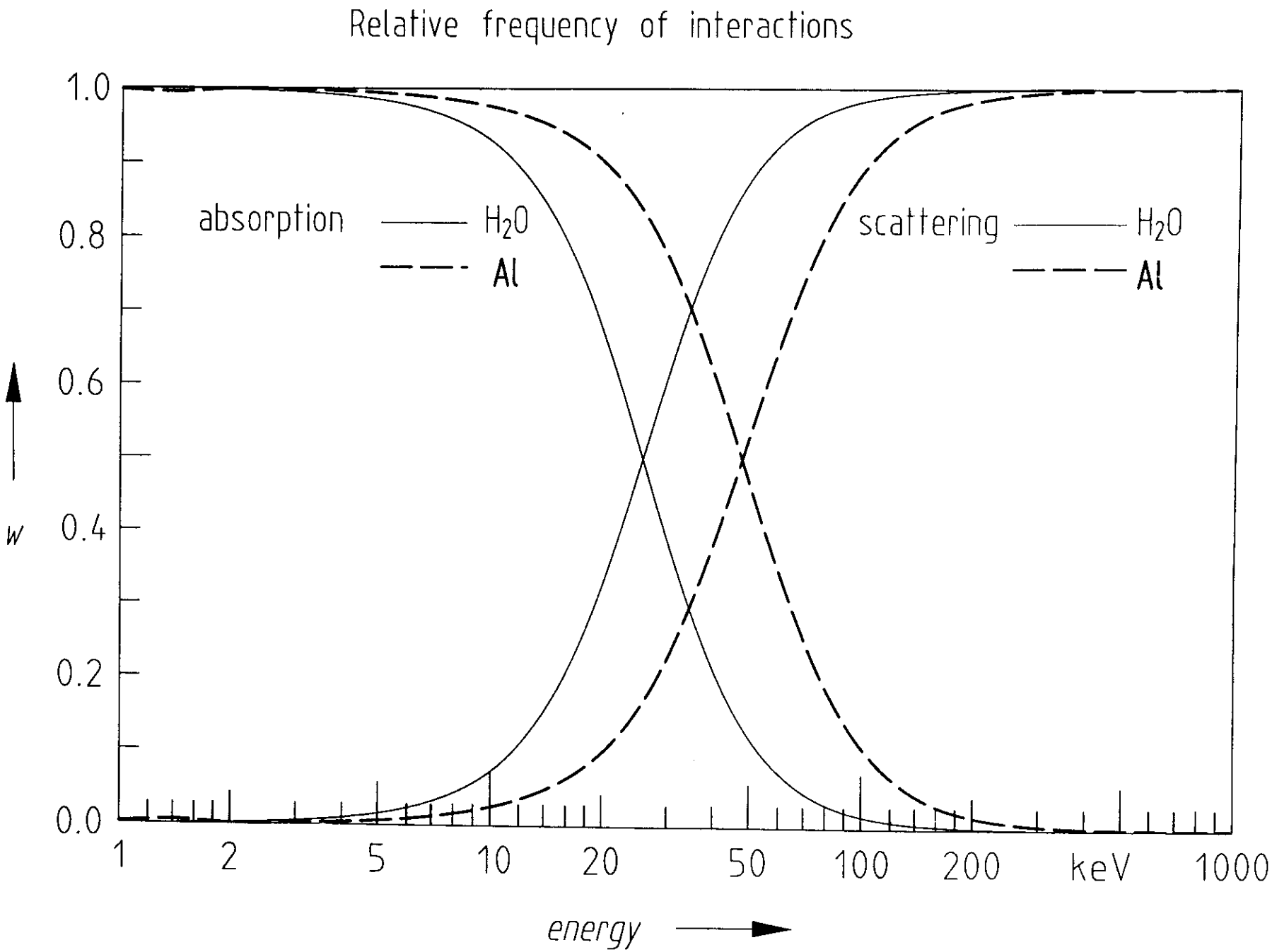
95 % confidence level: 1.2 %

Radiation Fields behind Phantoms

H. M. Kramer

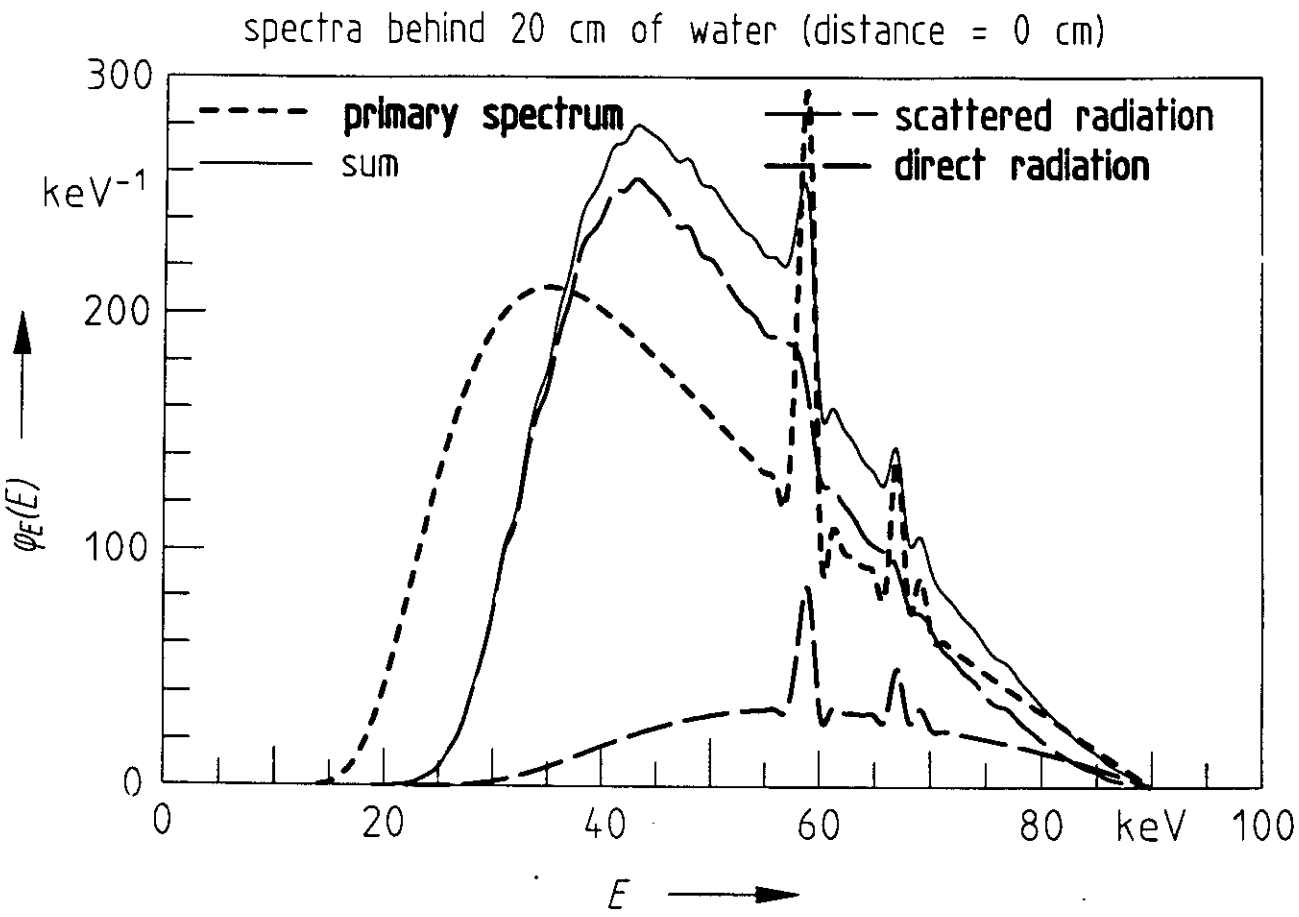
i) **Beam hardening vs. attenuation**

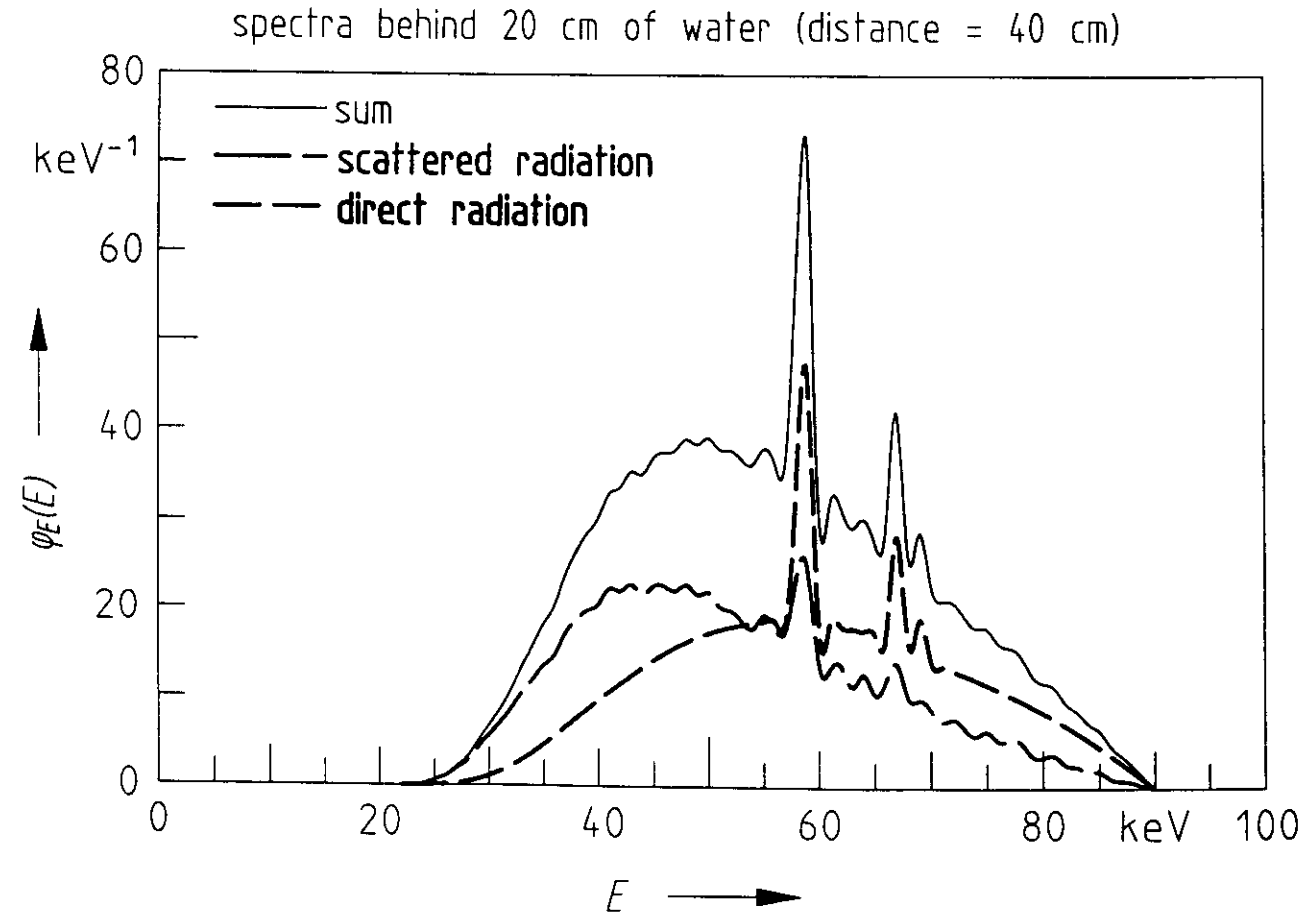
ii) **Scattered radiation**

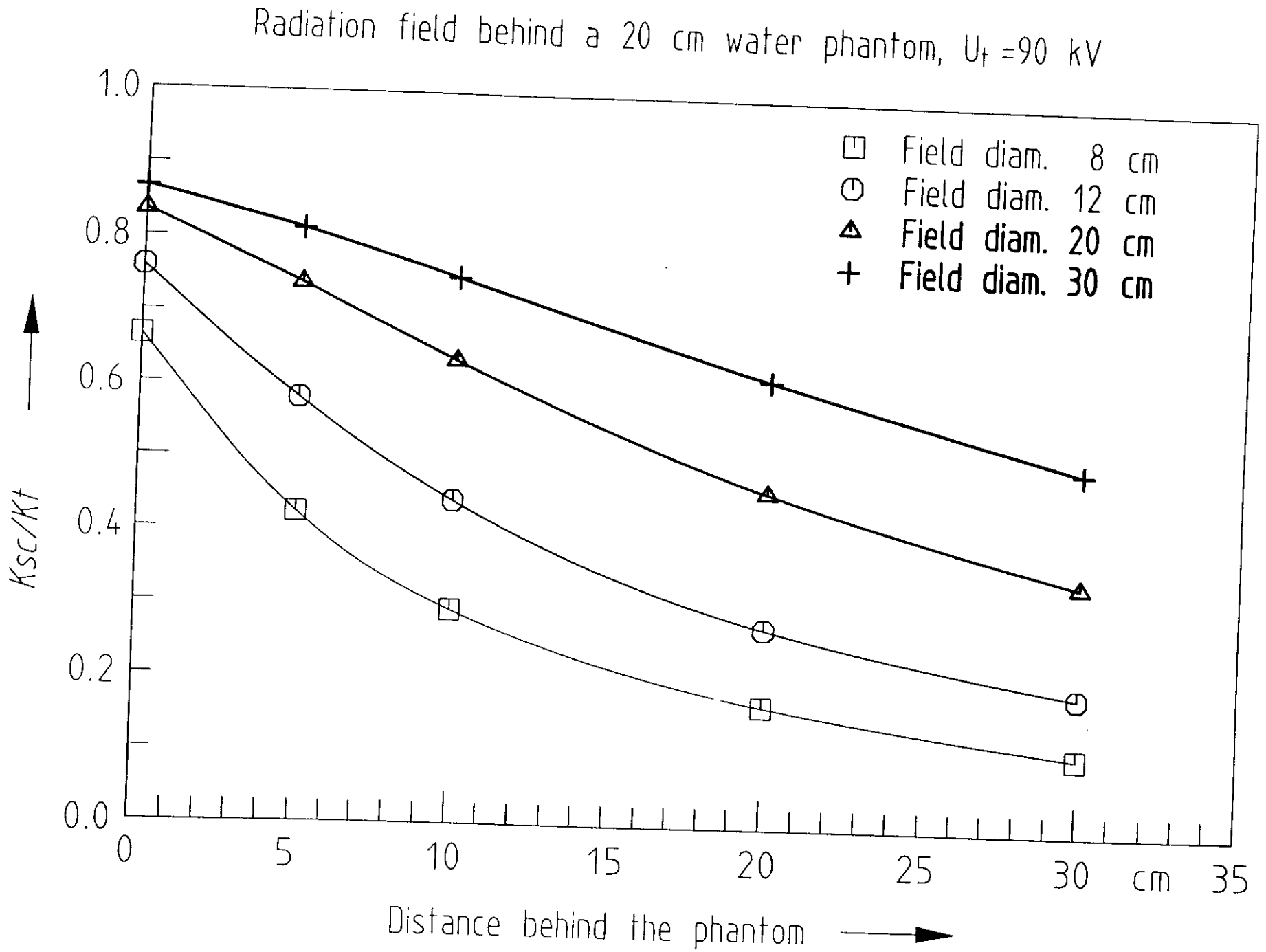

Relative frequency of interactions
1.0
0.8
0.6
0.4
0.2
0.0
w
absorption
H2O
Al
scattering
H2O
Al
1
2
5
10
20
50
100
200
keV
1000
energy

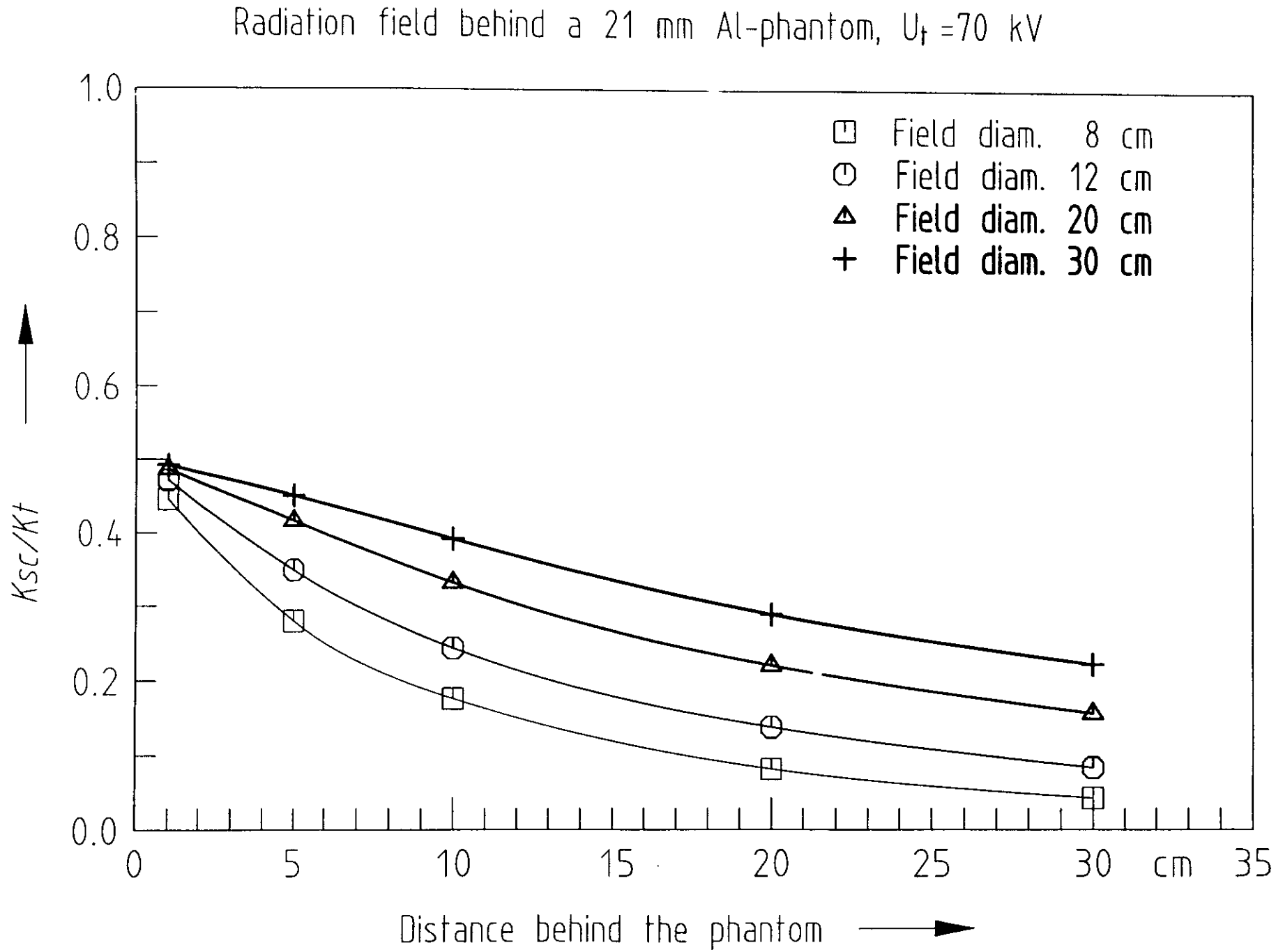
Beam hardening vs. attenuation

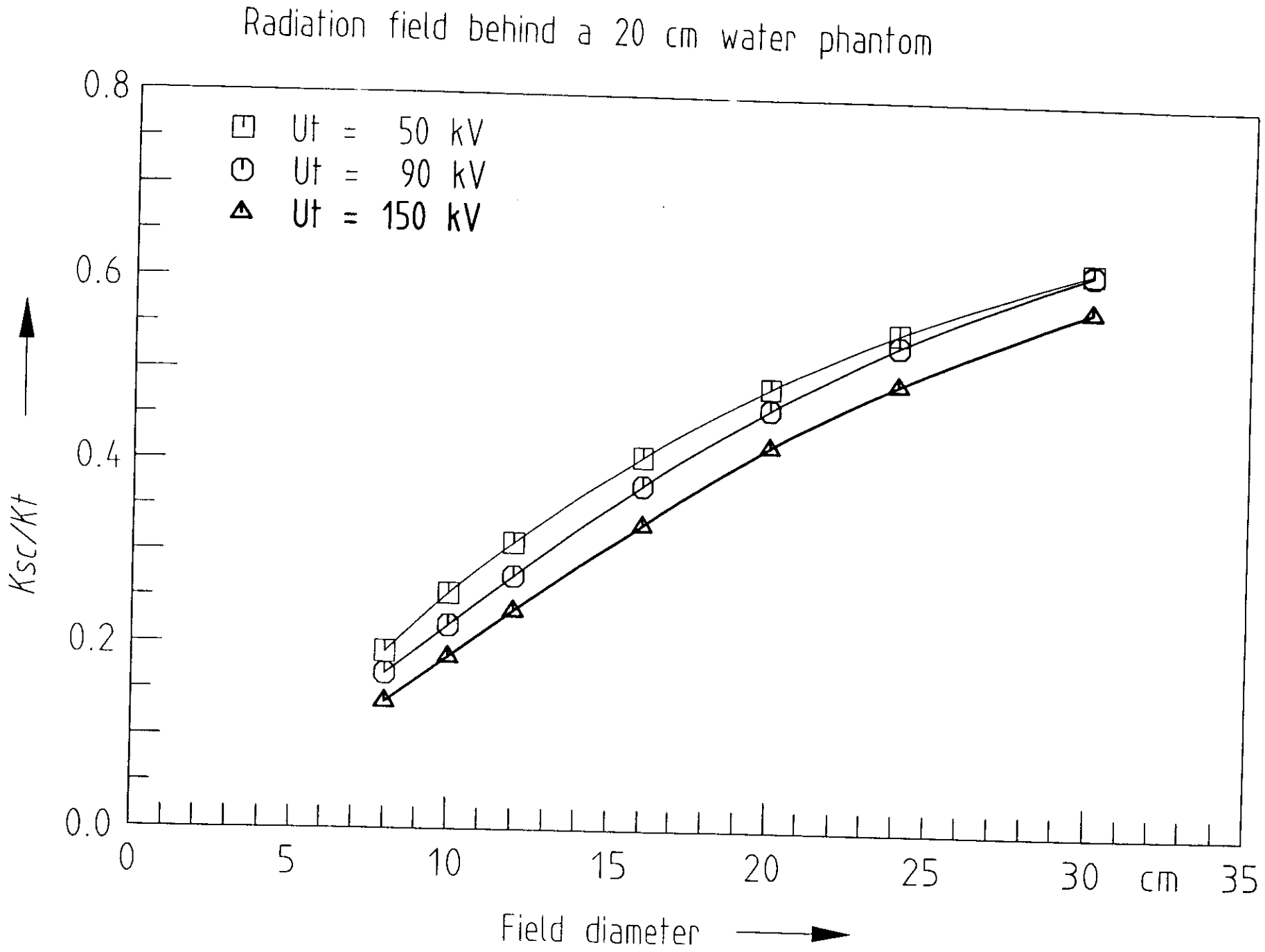
U_t/kV	phantom	HVL in mm Al	$\bar{E}$ / keV	rel. K_a
70	20 cm H_2O	6.24	48.4	1
	16 mm Al	6.25	48.4	19.2
	46.5 mm Al	8.19	55.4	1
	21.5 mm Al	6.76	50.2	11.2

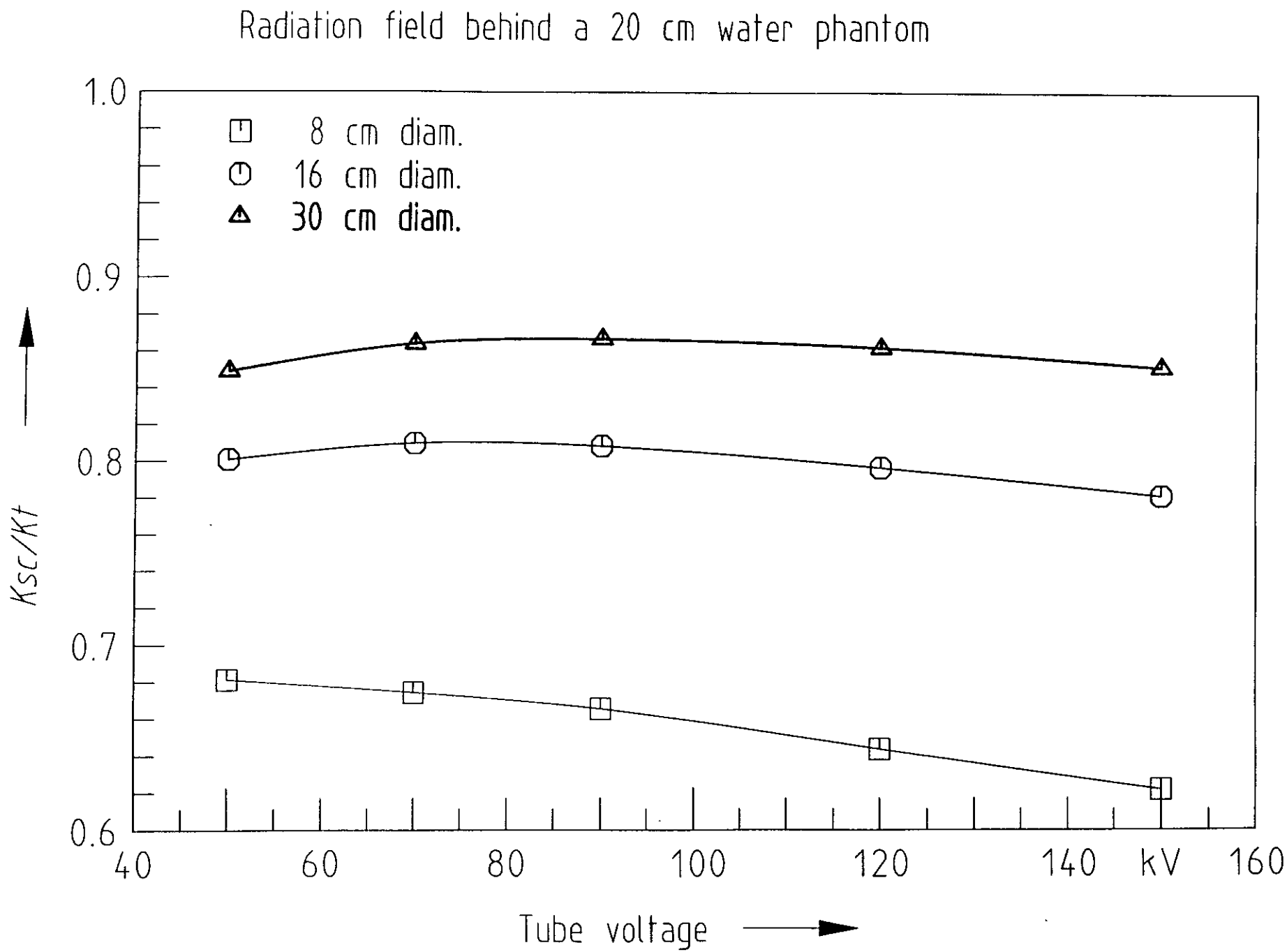

spectra behind 20 cm of water (distance = 0 cm)
primary spectrum
sum
scattered radiation
direct radiation
300
keV⁻¹
200
100
0
φE(E)
0
20
40
60
80
keV
100
E

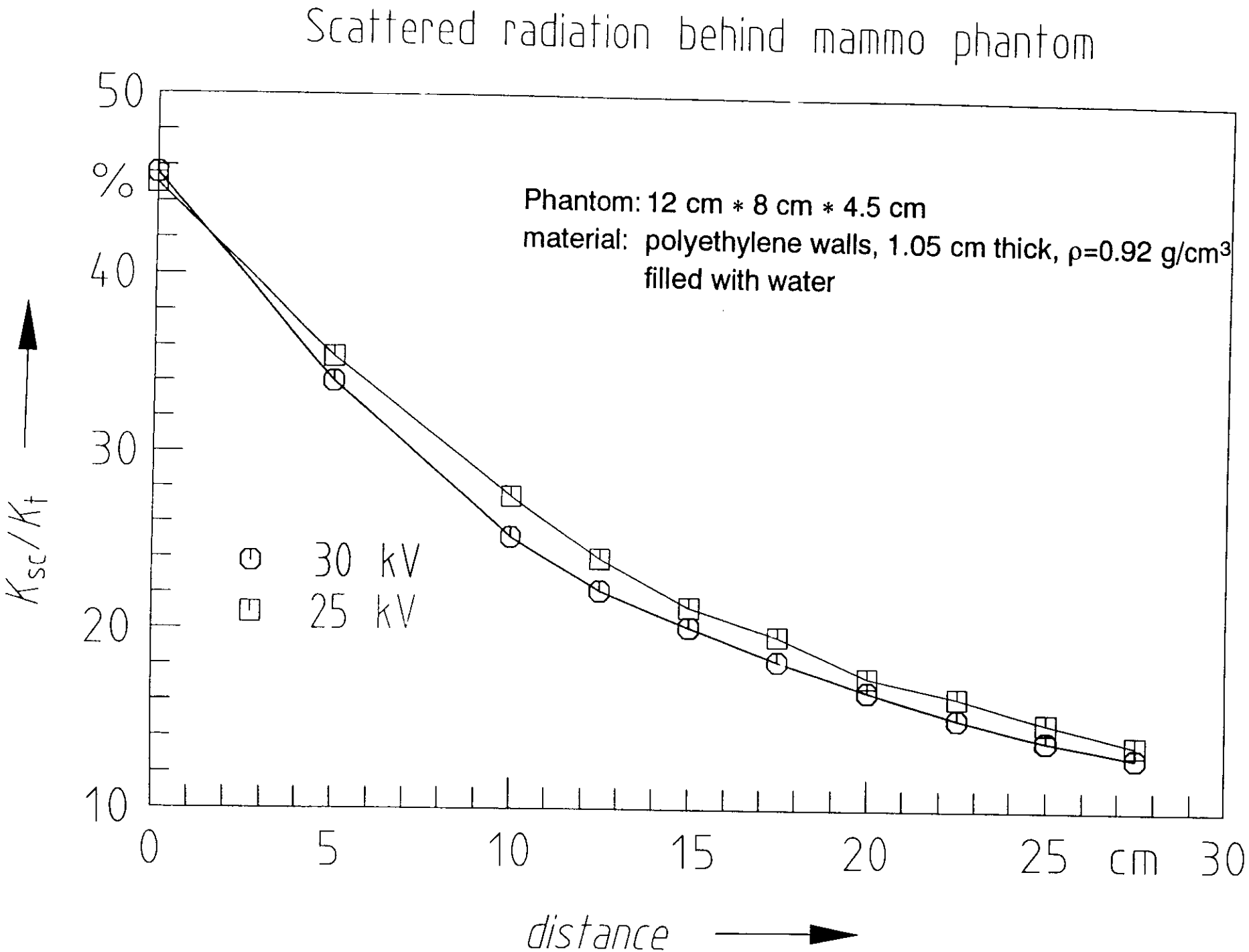

spectra behind 20 cm of water (distance = 40 cm)
sum
scattered radiation
direct radiation
80
keV⁻¹
60
40
20
0
φE(E)
0
20
40
60
80
keV
100
E


Radiation field behind a 20 cm water phantom, U_t =90 kV
Field diam. 8 cm
Field diam. 12 cm
Field diam. 20 cm
Field diam. 30 cm
Ksc/Kt
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
cm
35
Distance behind the phantom

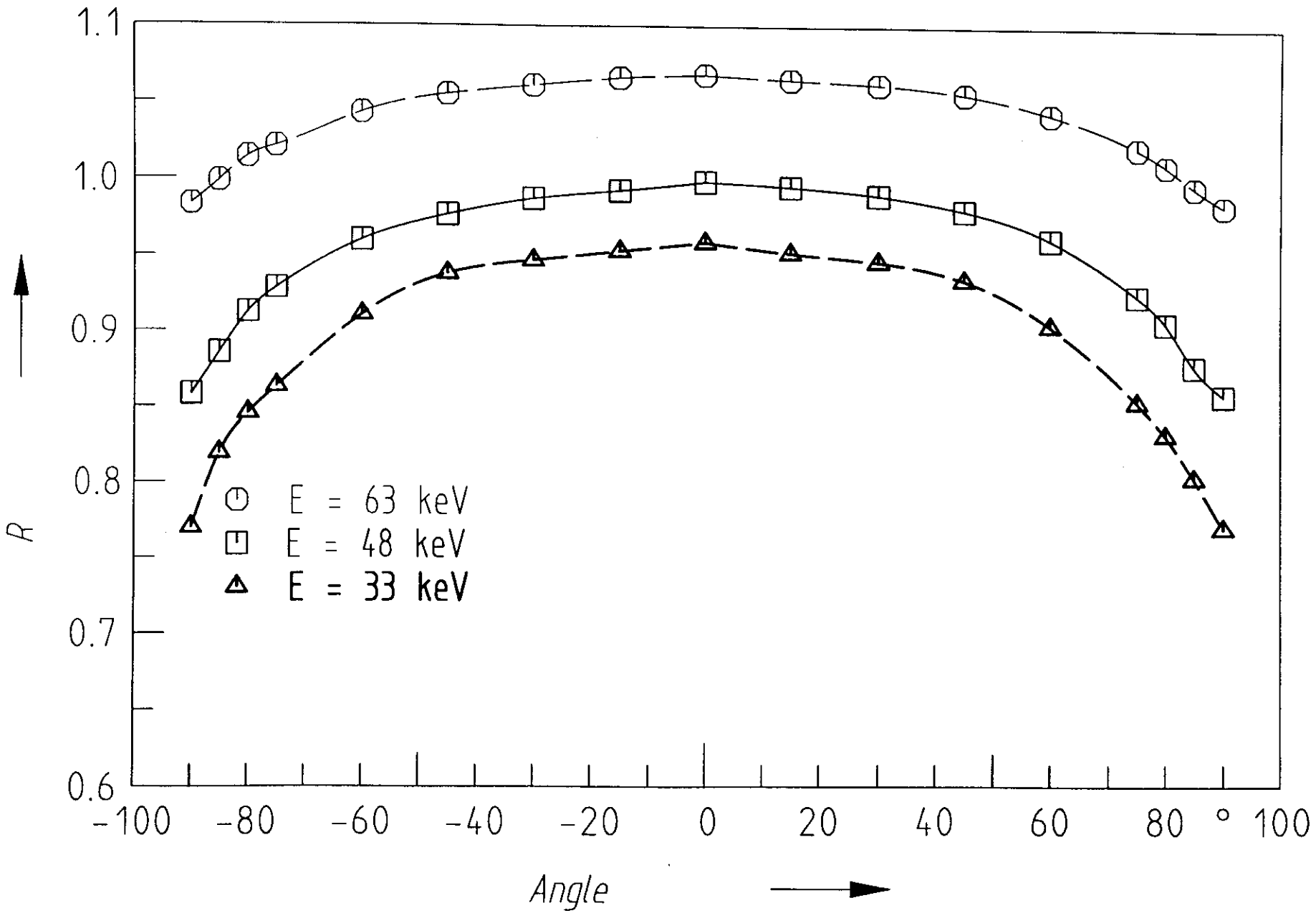

Radiation field behind a 21 mm Al-phantom, U_t =70 kV
Field diam. 8 cm
Field diam. 12 cm
Field diam. 20 cm
Field diam. 30 cm
Ksc/Kt
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
cm
35
Distance behind the phantom

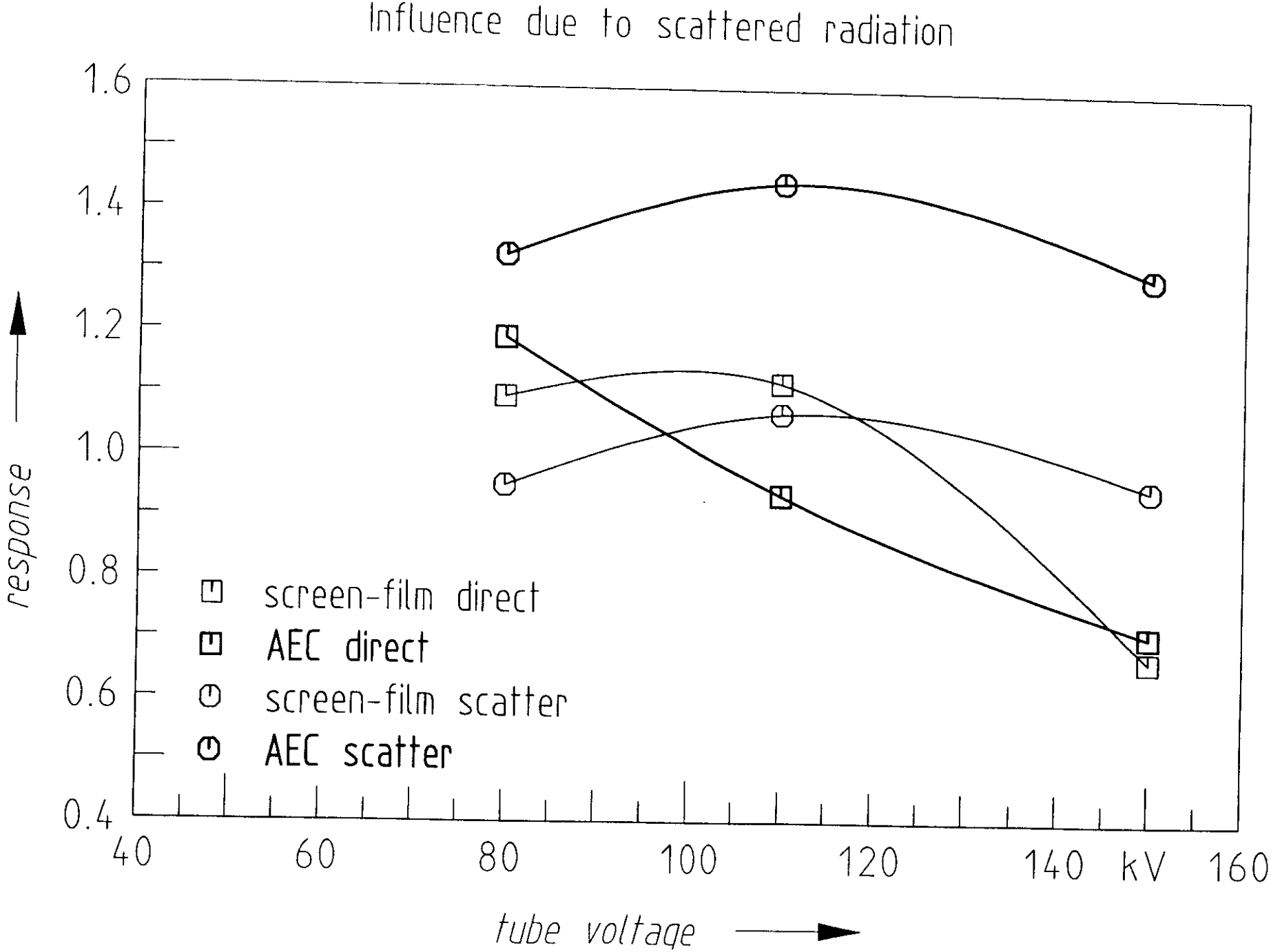

Radiation field behind a 20 cm water phantom
Ut = 50 kV
Ut = 90 kV
Ut = 150 kV
0.8
0.6
0.4
0.2
0.0
Ksc/Kt
0
5
10
15
20
25
30
cm
35
Field diameter


Radiation field behind a 20 cm water phantom
8 cm diam.
16 cm diam.
30 cm diam.
1.0
0.9
0.8
0.7
0.6
Ksc/Kt
40
60
80
100
120
140
kV
160
Tube voltage


Scattered radiation behind mammo phantom
50
%
40
30
20
10
0
5
10
15
20
25
cm
30
K_{sc}/K_f
distance
Phantom: 12 cm * 8 cm * 4.5 cm
material: polyethylene walls, 1.05 cm thick, ρ=0.92 g/cm³
filled with water
30 kV
25 kV

Variation of response with direction of radiation incid.




Influence due to scattered radiation
1.6
1.4
1.2
1.0
0.8
0.6
0.4
response
screen-film direct
AEC direct
screen-film scatter
AEC scatter
40
60
80
100
120
140
kV
160
tube voltage