Recombination factor dependancy of high and low dose pulsed accelerators for electron beam energies

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Talk Overview

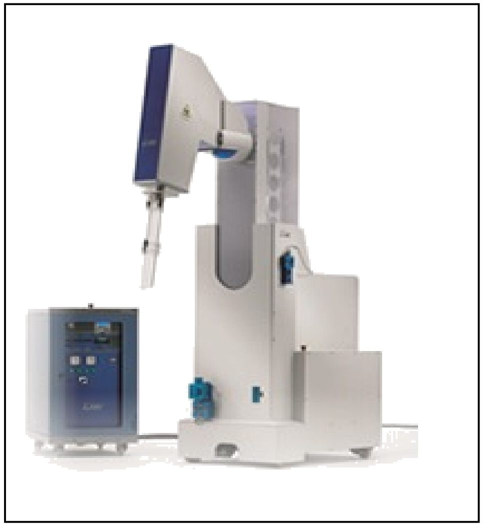
- Dose per pulse
    - ➢ what is the so called “ high dose per pulse” ?
    - ➢ Where does it comes from ?
    - ➢ Why IORT Linacs have a higher dose per pulse ?

- Dosimetric formalism and framework : IAEA TRS 398
    - ➢ The physics modelization of ion recombination
    - ➢ A different modelization for k_s
    - ➢ Calculus and examples

Low and high dose per pulse

EBRT LINAC

IORT LINAC



Dose Rate (DR) $\approx 10\,Gy/\text{min}$

Pulse Repetition Frequency (PRF) $\in [200\,Hz, 400\,Hz]$

Dose per pulse $(d_p) \equiv \dfrac{DR[Gy/\text{min}]}{PRF\,[Hz]\cdot 60} \approx 0.05\,cGy/p$

Dose Rate (DR) $\in [4\,Gy/\text{min}, 20\,Gy/\text{min}]$

Pulse Repetition Frequency (PRF) $\in [5\,Hz, 40\,Hz]$

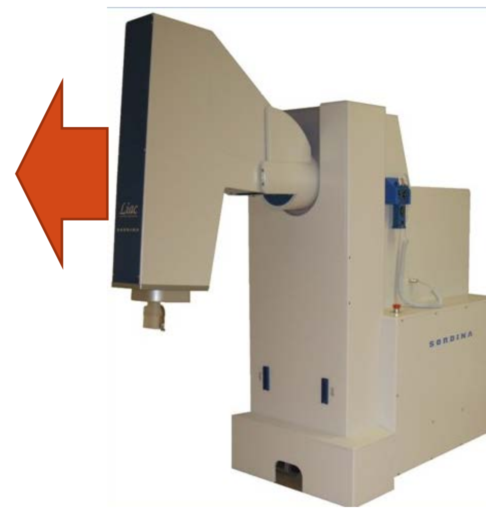
Dose per pulse $(d_p) \in [0.4\,\text{cGy/p},\ 5\,\text{cGy/p}]$

The dose per pulse generated by IORT linacs is up to 100 times higher respect to the standard

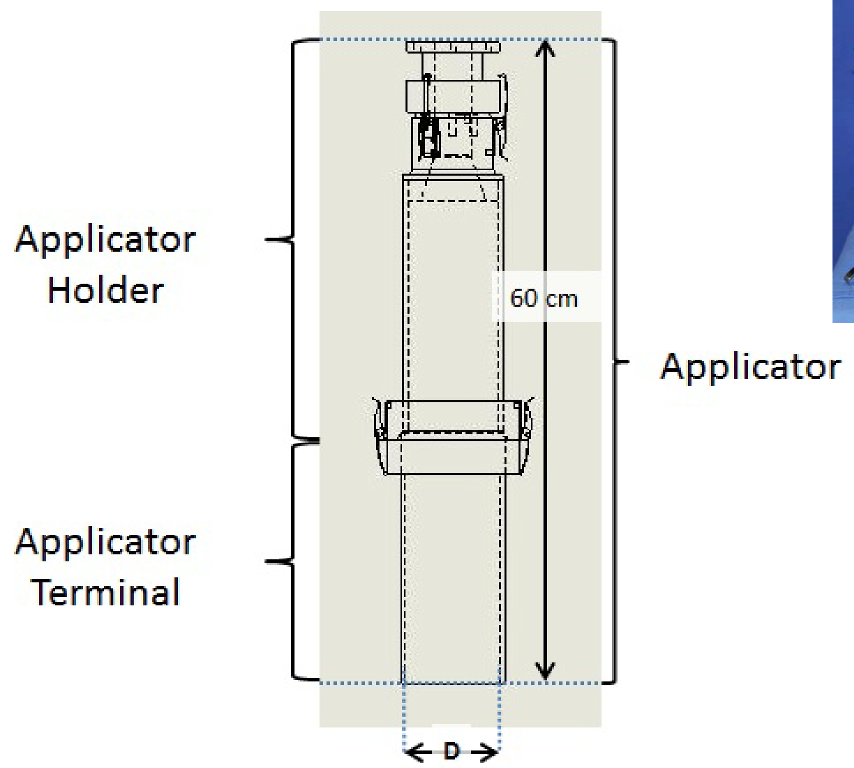
Where does the difference come from ?

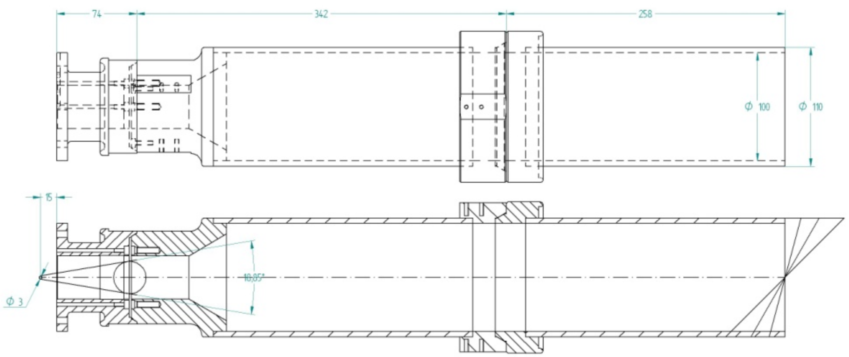
EBRT
LINAC

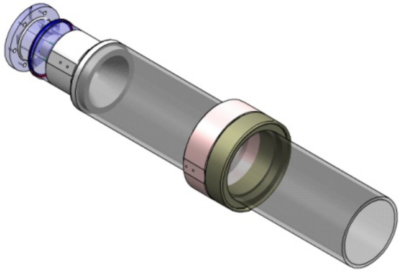
IORT LINAC



LIAC e-beam transport system is realized with low Z material



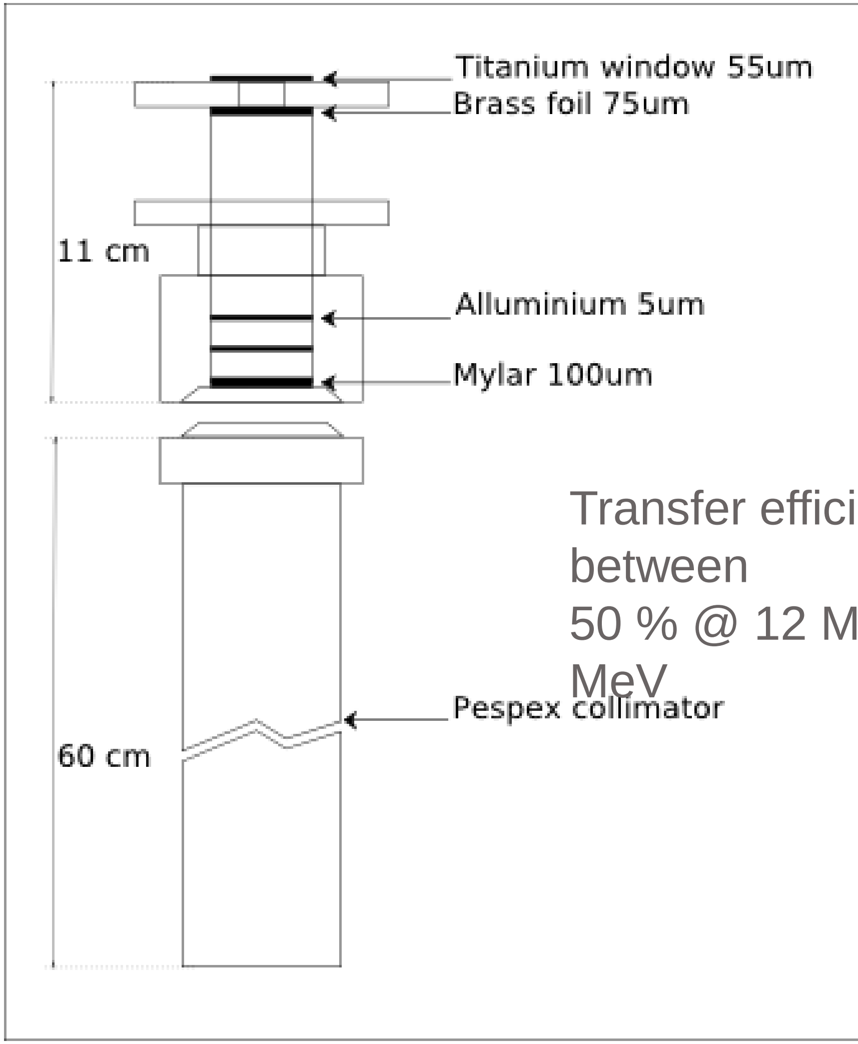


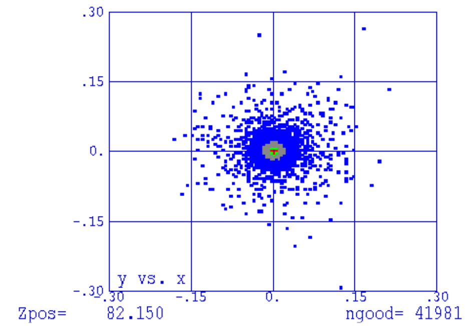


Nome file	Materiale	Massa	Quantitá
Naso liac allung-18mm.par	PMMA	0,369 kg	1
Partic.D applic-100-110-vB.par	pmma	0,283 kg	1
Partic.C applic-100-110 vers-2ganci-vB.par	PMMA	0,333 kg	1
Partic.A applic-100-110-vB.par	PMMA	0,483 kg	1
Tubo 100x110x00gr-vB.par	PMMA	0,950 kg	2

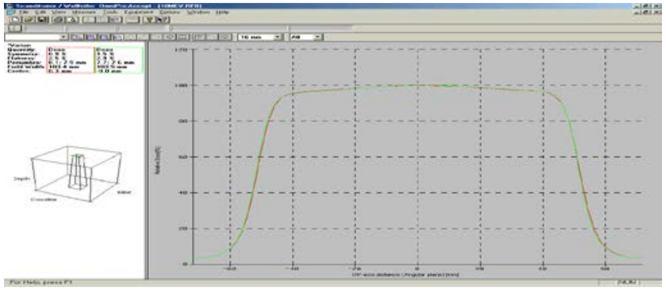
asm applic-100-vB-03-08.dft

Beam Optic Transfer efficiency is higher for IORT linacs





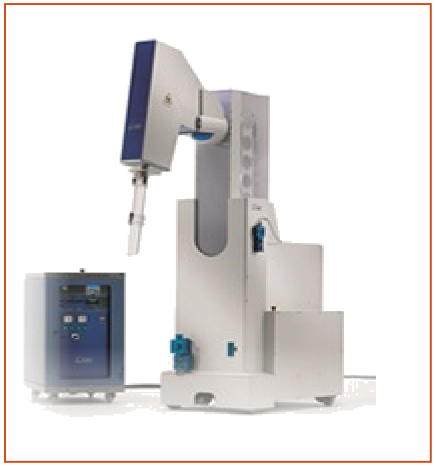
Transfer efficiency varies between
50 % @ 12 MeV and 8% @ 6 MeV



IORT Linacs design specs

1. Electron ONLY linac
2. Maximum mobility, able to move inside standard hospital space (elevators, doors…);
3. Not isocentric but capable of performing easily and safely docking process;
4. As small and light as possible;
5. Different energies, giving the possibility of irradiating a PTV with thickness ranging up to 3.5 cm inside the 90% isodse;
6. <u>It has to produce the minimum X rays possible, for radioprotection issues;</u>

Low stray radiation ⇄ High dose per pulse



Absorbed Dose to water according to IAEA TRS 398 formalism

Absorbed dose to water at the reference depth z_{ref} in water for a reference beam of quality Q_0

$$D_{w,Q} = M_Q \cdot N_{D_w,Q_0} \cdot k_{Q,Q_0}$$

$$M_Q = M' \cdot \prod_i k_i = M' \cdot k_{T,P} \cdot k_H \cdot k_{pol} \cdot k_s$$

M' measured signal

k_{Q,Q_0} *Factor to correct for the difference between the response of an ionization chamber in the reference beam quality Qo used for calibrating the chamber and in the actual user beam quality, Q.*

k_s *Factor to correct the response of an ionization chamber for the lack of complete charge collection (due to ion recombination).*

k_s modelization : from the definition of the problem to the solution

The saturation loss for plane parallel ionization chambers at high dose-per-pulse value

A. Piermattei, S. Delle Canne, L. Azario, A. Russo, A. Fidanzio, R. Miceli, A. Soriani, A. Orvieto, and M. Fantini

2000

Ion recombination correction for very high dose-per-pulse high-energy electron beams

F. Di Martino,[a)] M. Giannelli, A. C. Traino, and M. Lazzeri[b)]
U.O. Fisica Sanitaria—Sezione di Fisica Medica, Azienda Ospedaliera Universitaria Pisana, via Roma 67, 56126 Pisa, Italy

2005

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Charge collection efficiency in ionization chambers exposed to electron beams with high dose per pulse

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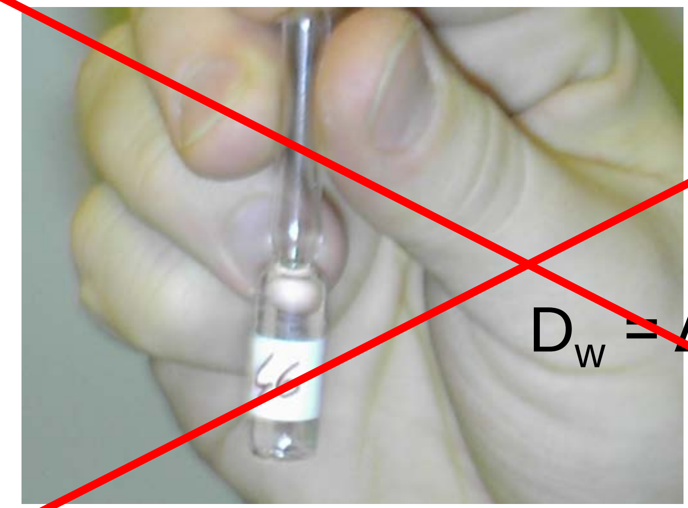
Abstract
The correction for charge recombination was determined for different plane-parallel ionization chambers exposed to clinical electron beams with low and high dose per pulse, respectively. The electron energy was nearly the same (about 7 and 9 MeV) for any of the beams used. Boag's two-voltage analysis (TVA) was used to determine the correction for ion losses, k_s, relevant to each chamber considered. The presence of free electrons in the air of the chamber cavity was accounted for in determining k_s by TVA. The determination of k_s was made on the basis of the models for ion recombination proposed in

- Laitano's paper allows TVA (Two Voltage Analysis) for determining k_s, eliminating the need of an external chemical dosimeter and greatly simplifying the dosimetric characterization
- Chemical dosimeter can be used for external audit



$$D_w = \Delta A \, N_w \, \Pi k_i$$

k_s the standard approach according to IAEA TRS 398

$$k_s = \frac{1}{f} \qquad f = \frac{1}{u}\ln(1+u) \qquad u = \frac{\mu d^2 r}{V}$$

- *d*(m) distance between chamber plates
- µ (mV/C) a constant depending on the gas in the cavity chamber
- *r* (C/m3) the charge liberated in air per unit volume and per pulse
- *V* (Volt) the voltage supply of the chamber.

This model is applicable only if the fraction of electrons escaping attachment to oxygen molecules and reaching the collecting electrodes is negligible.

The high-energy pulsed electron beams of interest in clinical dosimetry have usually a dose-per-pulse value of about 0.05 cGy/ pulse. This means that *r* and, consequently, *u* are small for the usually employed plane-parallel ionization chambers. Thus can be expanded to first order, giving

$$k_s \approx \frac{1}{\ln(1+u)} \approx 1 + \frac{u}{2}$$

If $k_s < 1.03$

This model fails for high dose per pulse !

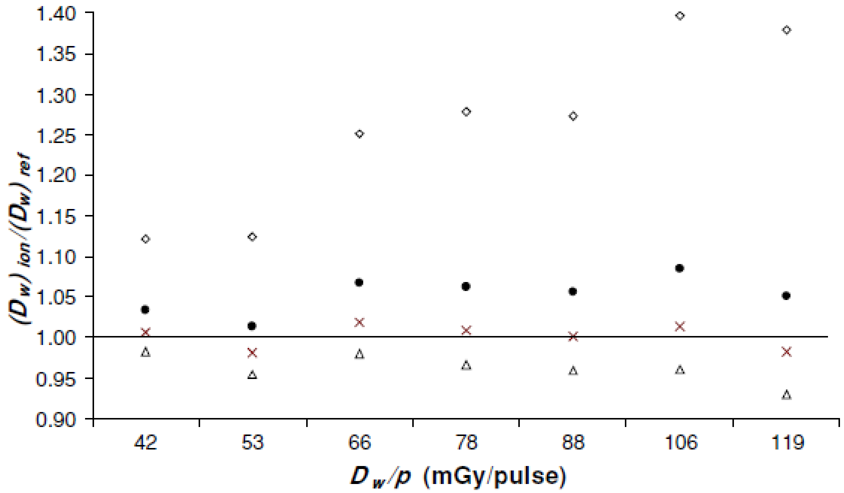


Figure 5. The $(D_w)_{\mathrm{ion}}/(D_w)_{\mathrm{ref}}$ ratios as a function of D_w/p for the Capintec PS-033 chamber. The symbols refer to the $(D_w)_{\mathrm{ion}}$ values corresponding to the different factors k_s^i that account for free electrons (circles, triangles and crosses according to the recombination model described by equations (3), (4) and (5), respectively). The data denoted by diamonds are the $(D_w)_{\mathrm{ion}}/(D_w)_{\mathrm{ref}}$ ratios corresponding to the factor k_s^c relevant to the conventional model not allowing for free electrons (equation (1)). The chamber is operated at the voltage $V_1 = 300$ V. The uncertainty on the $(D_w)_{\mathrm{ion}}/(D_w)_{\mathrm{ref}}$ values is 3.2% (1σ).

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k_s: Laitano's theory

$$f = \frac{1}{u}\ln(1+u) \quad \Rightarrow \quad f''' = \lambda + \frac{1}{u}\ln\left[1 + \frac{e^{\lambda(1-\lambda)u} - 1}{\lambda}\right]$$

$$\lambda = 1 - \sqrt{1-p} \qquad u = \frac{\mu d^2 r}{V}$$

p is the free electron fraction

$$p = \frac{w\tau}{d}\left(1 - e^{-\frac{d}{w\tau}}\right)$$

Boag, 1987

- *d* interelectrodic distance
- w free electrons migration velocity inside the air cavity
- τ electron mean life before recombination
- w ,τ can be calculated vs electric field intensity

Free electron fraction is independent from the dose per pulse and is always different from zero. Its effect becomes relevant when the dose per pulse is high, that means when u is increasing.

$$\lim_{u \to 0^+} f''' = f$$

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w electron drift velocity

$$w = a + b\left[\left(1 - e^{-cE}\right) - \frac{d}{n}\left(1 + \frac{c\,e^{-nE} - n\,e^{-cE}}{n - c}\right)\right]$$

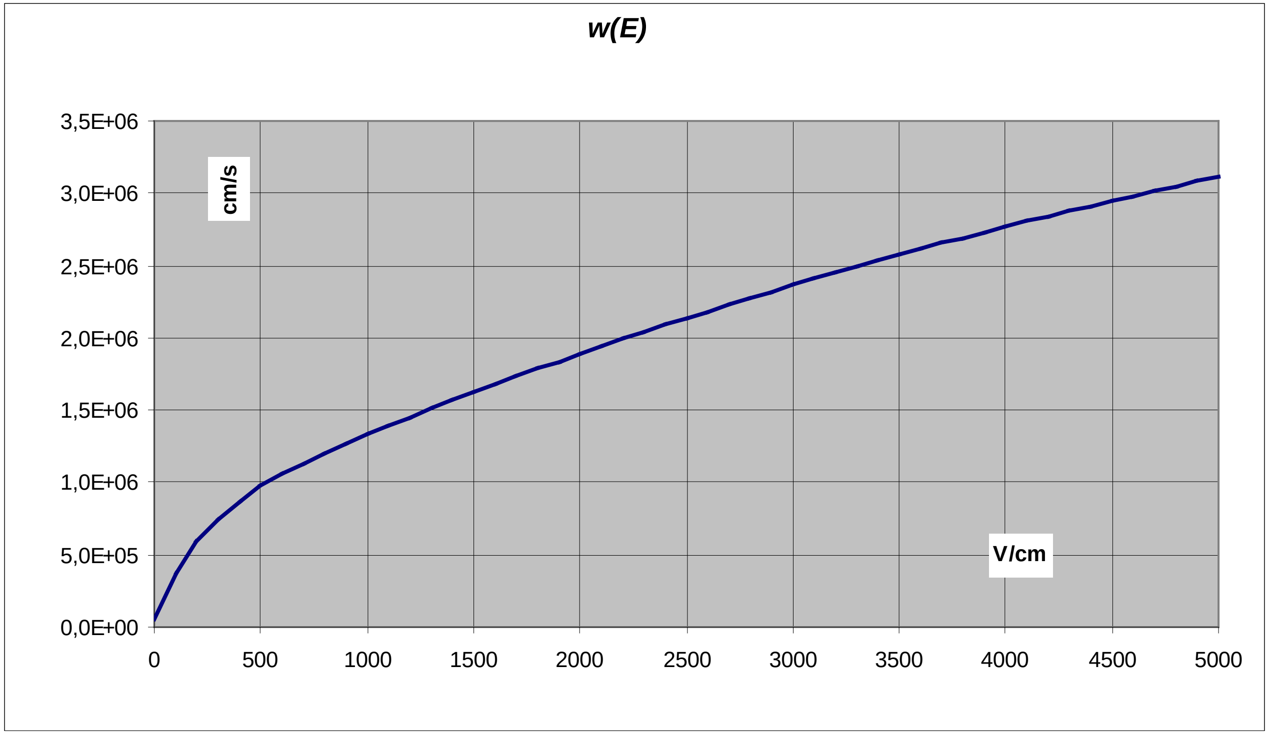
Hochhauser et al, 1997

parametres		mu
a	5,83535E+04	cm/s
b	2,41820E+07	cm/s
c	1,56809E-04	cm/V
d	3,86396E-03	cm/V
e	1,03039E-03	cm/V
n	4,89435E-03	cm/V

d (cm)
0,1

V_1 (V)
300
V_2 (V)
100

E (V/cm)	w (cm/s)
3000,0	2,36E+06
1000,0	1,33E+06



Electron Mean lifetime before attachment

$$\tau = a\left(1-e^{-bE}\right)+c\left(1-e^{-dE}\right)$$

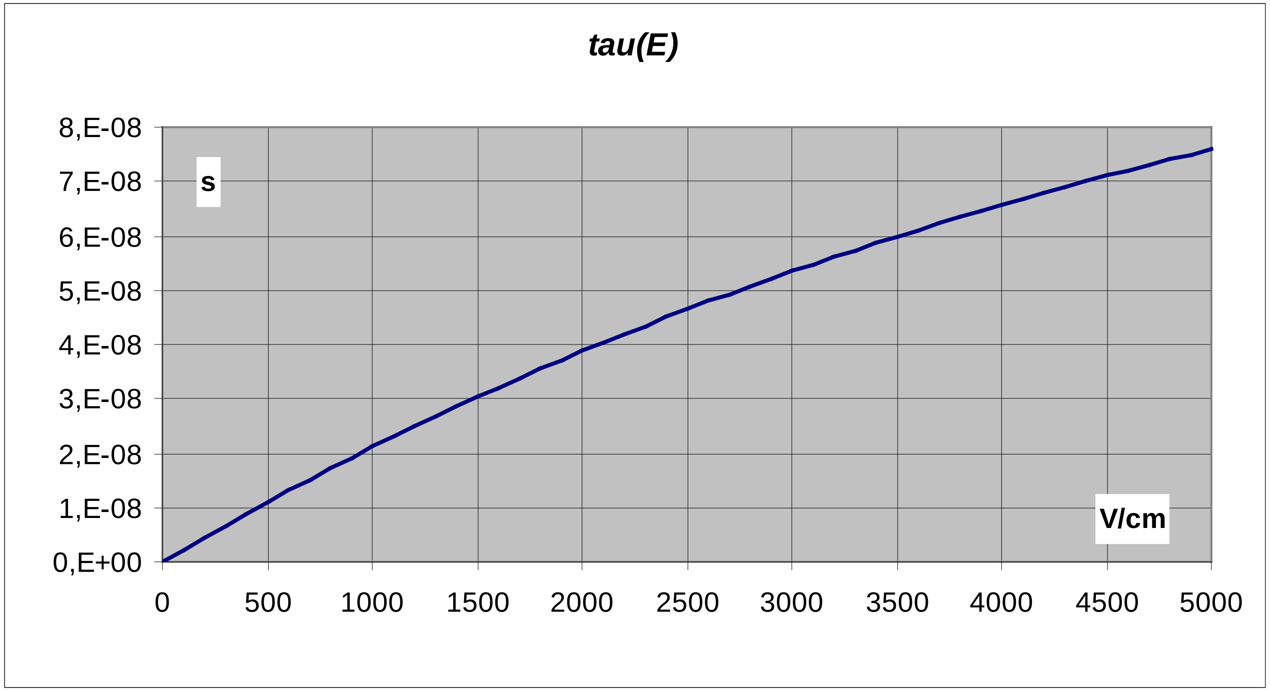
Hochhauser et al, 1997

parametres		mu
a	6,26950E-08	s
b	1,82679E-04	cm/V
c	6,44401E-08	s
d	1,8111E-04	cm/V

d (cm)
0,1

V_1 (V)	300
V_2 (V)	100

E (V/cm)	tau (s)
3000	5,35E-08
1000,0	2,11E-08



TVA :k_s determination

After w, tau have been determined p can be calculated ; now it is possible to calculate ks experimentally using TVA technique

$$\frac{Q'_1}{Q'_2}=\frac{f_1}{f_2}$$

$$u=\frac{\mu d^2 r}{V} \longrightarrow \mathrm{u}_2=\mathrm{u}_1\frac{V_1}{V_2} \longrightarrow \frac{Q'_1}{Q'_2}=\frac{f(p_1,u_1)}{f\left(p_2,\mathrm{u}_1\frac{V_1}{V_2}\right)}$$

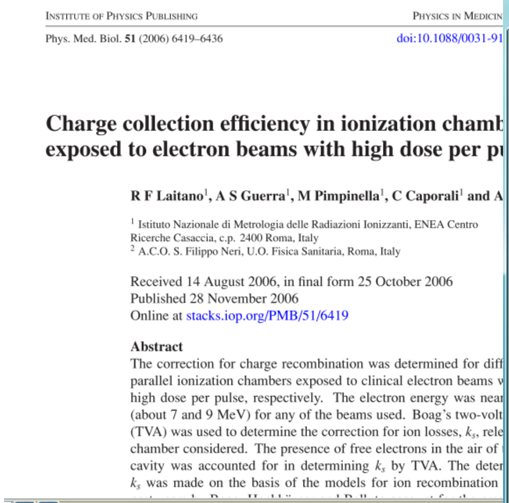
$$\frac{Q'_1}{Q'_2}=\frac{\lambda_1 u_1+\ln\left[1+\frac{1}{\lambda_1}\left(e^{\lambda_1(1-\lambda_1)u_1}-1\right)\right]}{\lambda_2 u_1+\frac{V_2}{V_1}\ln\left[1+\frac{1}{\lambda_2}\left(e^{\lambda_{12}(1-\lambda_2)\frac{V_1}{V_2}u_1}-1\right)\right]}^{1} \longrightarrow$$

It is resolved numerically respect to

Once u_1 is determined f is calculated with the corresponding voltage V_1

$$k_{sat}=\frac{1}{f\left(\lambda(p_1),\bar{u}_1\right)}$$

A specific calculus software has been developed by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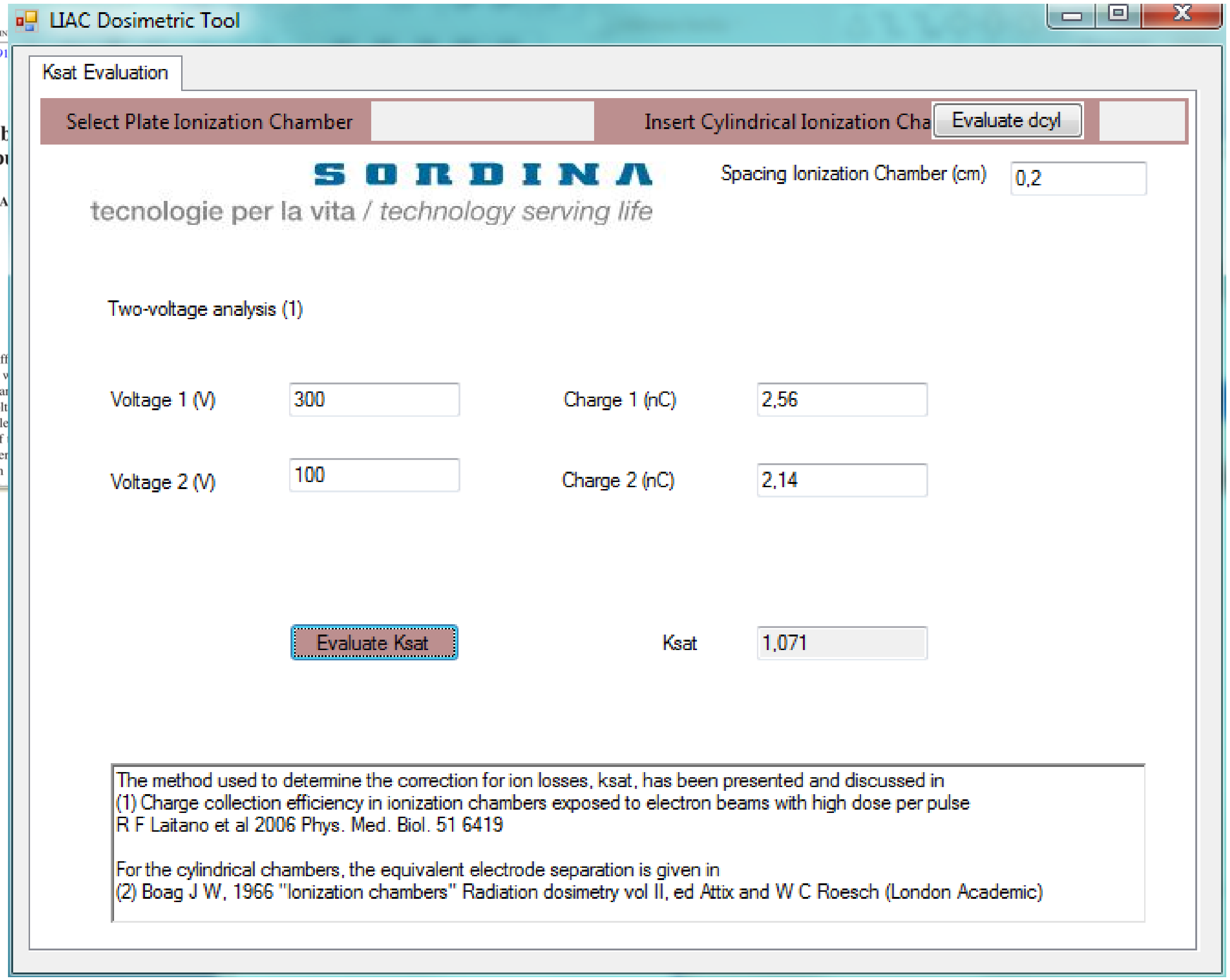
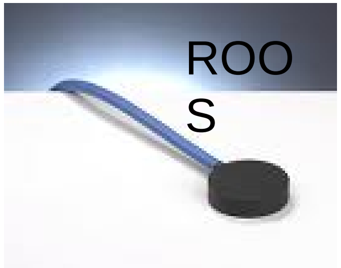


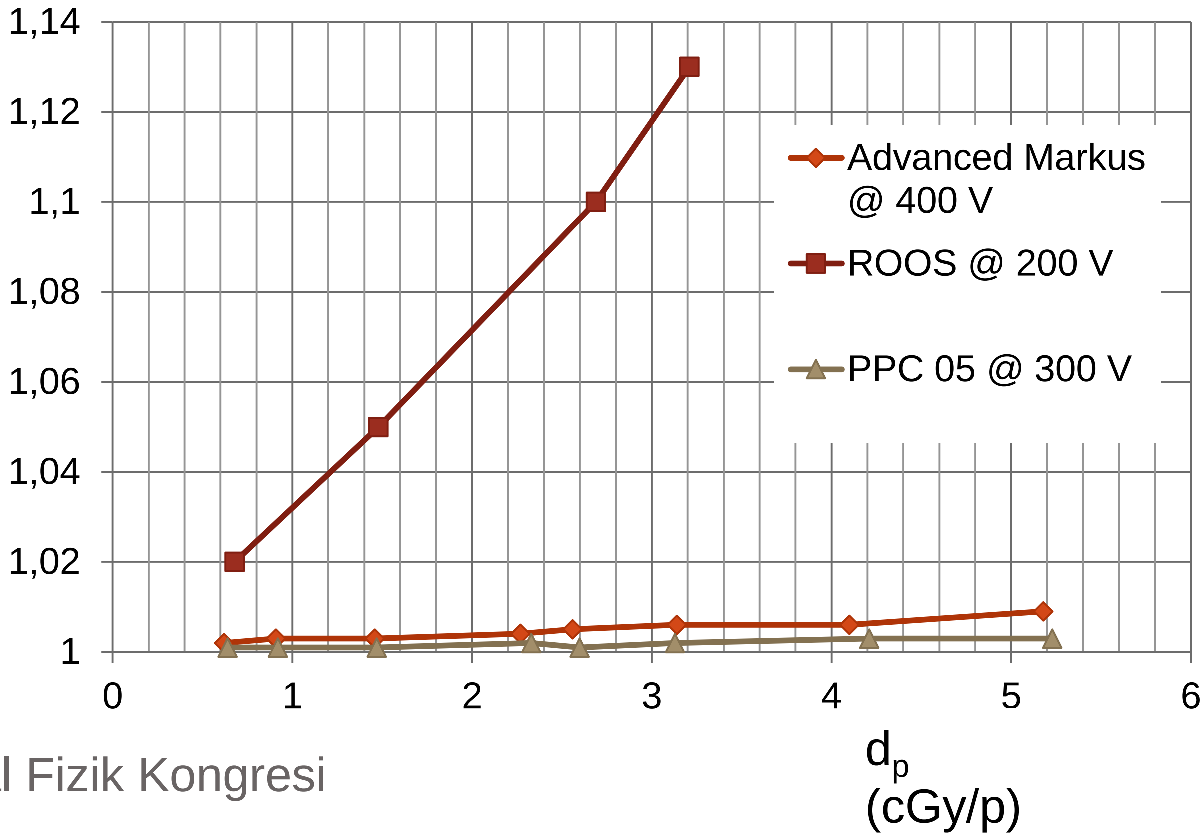
k_s : numerical examples

chamber type	interelectrodic spacing (cm)	polarization (V)
PTW Roos	0,2	200
PTW Adv. Markus	0,1	400
IBA PPC 05	0,06	300



$$u = \frac{\mu d^2 r}{V}$$

$$\frac{\partial k_s}{\partial d_p} > 0$$



Cylindical ionization chambers

It is possible to calculate ks also for cylindrical chambers using the Boag formula

$$d_{cyl} = (a-b)\left[\frac{a+b}{a-b}\cdot\frac{\ln(a/b)}{2}\right]^{1/2}$$

b	internal radius (mm)
a	external radius (mm)
d_{cyl}	equivalent electrode separation (mm)

Thanks !