Self-consistent non-stationary 1-D theory of multipactoring in DLA structures

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Outline

- Introduction
- Dispersion characteristics of cylindrical DLA structures
- Non-stationary 1D-model
- Numerical results
- Summary and conclusions

Introduction

- Multipactor (MP) may occur in many situations: one- and two-surface MP, resonant and poly-phase MP, on the surface of metals and dielectrics etc.
- Below we consider only dielectric loaded accelerator (DLA) structures.
- The starting point for our work is experimental and theoretical studies of such structures jointly done by Argonne National Lab and Naval Research Lab (J. G. Power et al., PRL, 92, 164801, 2004).
- In the theoretical model developed during those studies, the space charge field E_{dc} due to the total number of particles is taken into account as a parameter. We offer a simple non-stationary model where the DC field is taken into account self-consistently.

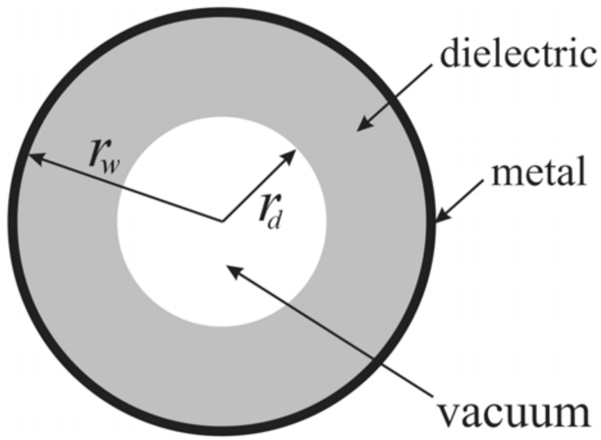
Dispersion characteristics of DLA structures

- So far, dispersion characteristics were calculated for structures with given geometrical parameters. It is possible to analyze them in a more general way.
- Azimuthally symmetric TM-waves (TM_{0n}- waves). From boundary conditions,
  - Fast waves in the vacuum:

$$\frac{1}{\tilde{\rho}_1}\frac{J_1(\tilde{\rho}_1)}{J_0(\tilde{\rho}_1)} = \varepsilon \frac{1}{\rho_2 \tilde{r}} \frac{Y_0(\rho_2)J_1(\rho_2\tilde{r}) - J_0(\rho_2)Y_1(\rho_2\tilde{r})}{Y_0(\rho_2)J_0(\rho_2\tilde{r}) - J_0(\rho_2)Y_0(\rho_2\tilde{r})}$$

  - Slow waves in the vacuum:

$$\frac{1}{\rho_1}\frac{I_1(\rho_1)}{I_0(\rho_1)} = \varepsilon \frac{1}{\rho_2 \tilde{r}} \frac{Y_0(\rho_2)J_1(\rho_2\tilde{r}) - J_0(\rho_2)Y_1(\rho_2\tilde{r})}{Y_0(\rho_2)J_0(\rho_2\tilde{r}) - J_0(\rho_2)Y_0(\rho_2\tilde{r})}$$

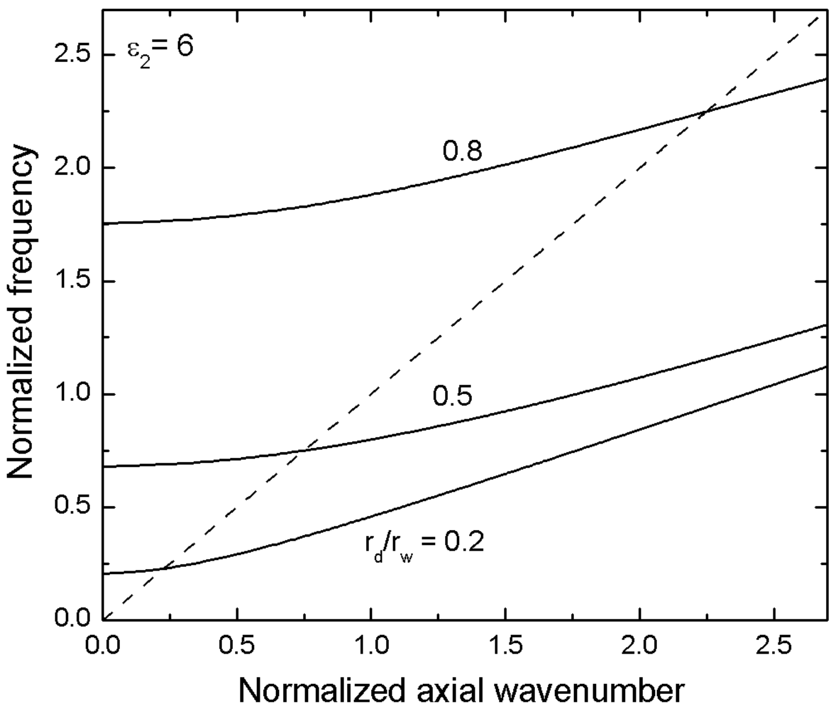


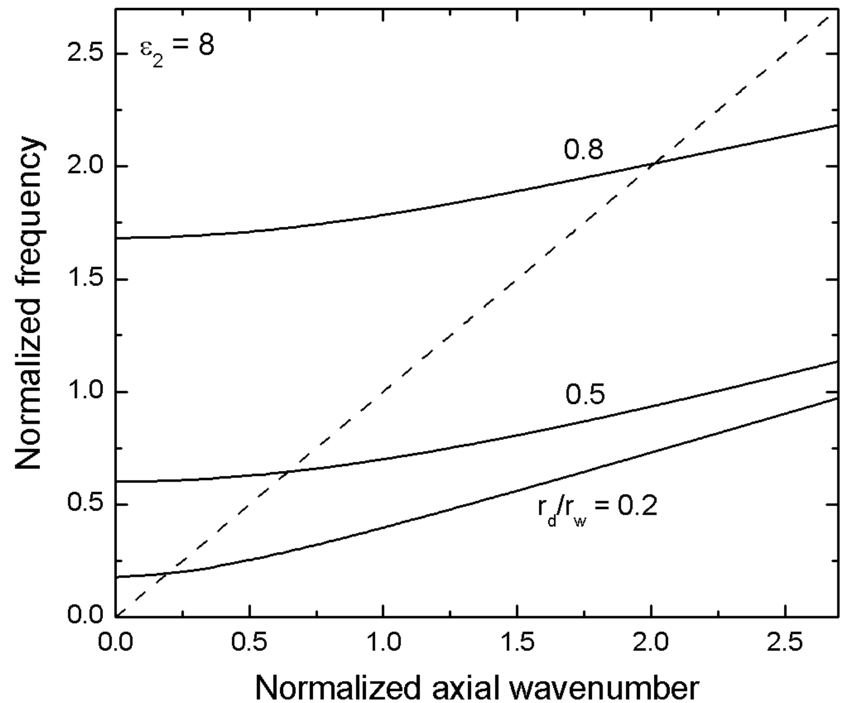
Here $\rho_1 = |k_{\perp 1}| r_d$, $\tilde{\rho}_1 = k_{\perp 1} r_d$, $\rho_2 = k_{\perp 2} r_w$ are normalized transverse wave numbers in the dielectric and vacuum; $\tilde{r} = r_d / r_w$, r_d and r_w are the radii of the dielectric and waveguide, respectively.

Normalized wave frequency $\tilde{\omega} = (\omega / c) r_d$ and the normalized axial wave number $\tilde{k}_z = k_z r_d$ can be expressed via these transverse wave numbers as

$$\tilde{\omega}^2 = \frac{1}{\varepsilon - 1}\left(\rho_1^2 + \tilde{r}^2 \rho_2^2\right), \quad \tilde{k}_z^2 = \frac{1}{\varepsilon - 1}\left(\varepsilon\rho_1^2 + \tilde{r}^2 \rho_2^2\right)$$

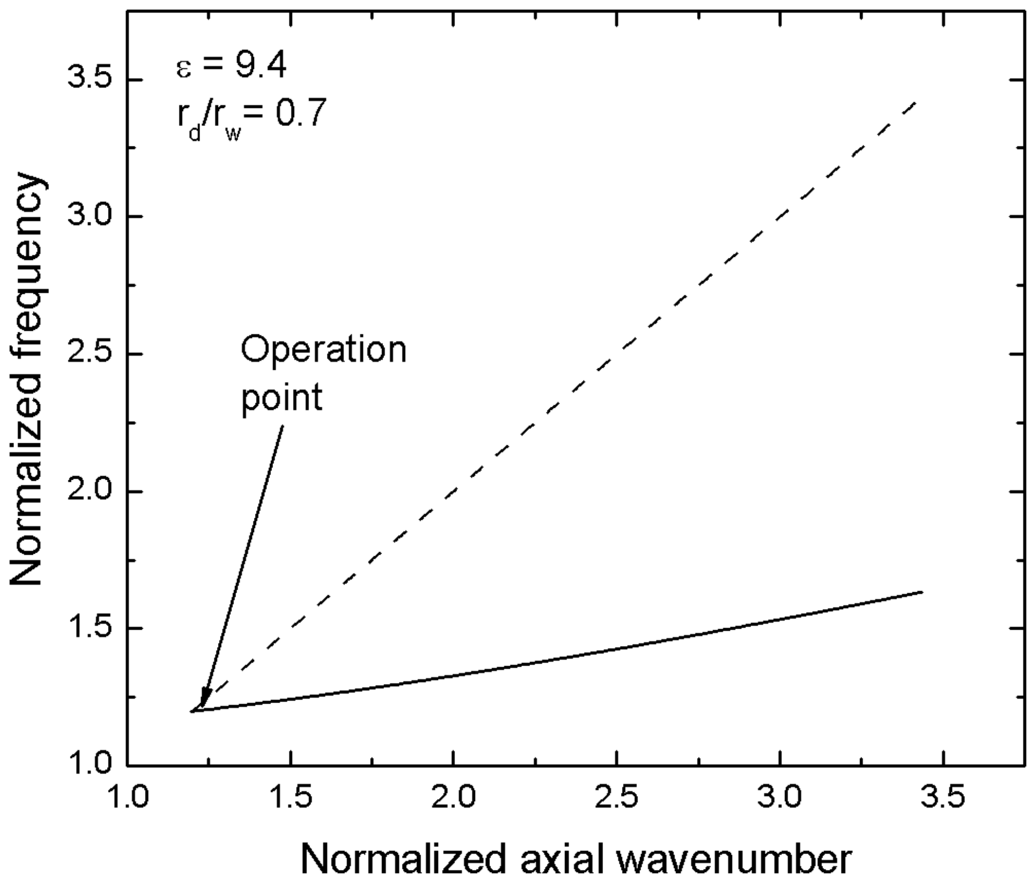
Dispersion characteristics (cont.)





- Solutions of the dispersion equation. Results are shown for two values of the dielectric constant and several values of the ratio of the dielectric radius to the wall radius. The dashed line shows the light line $k_z = \omega / c$.

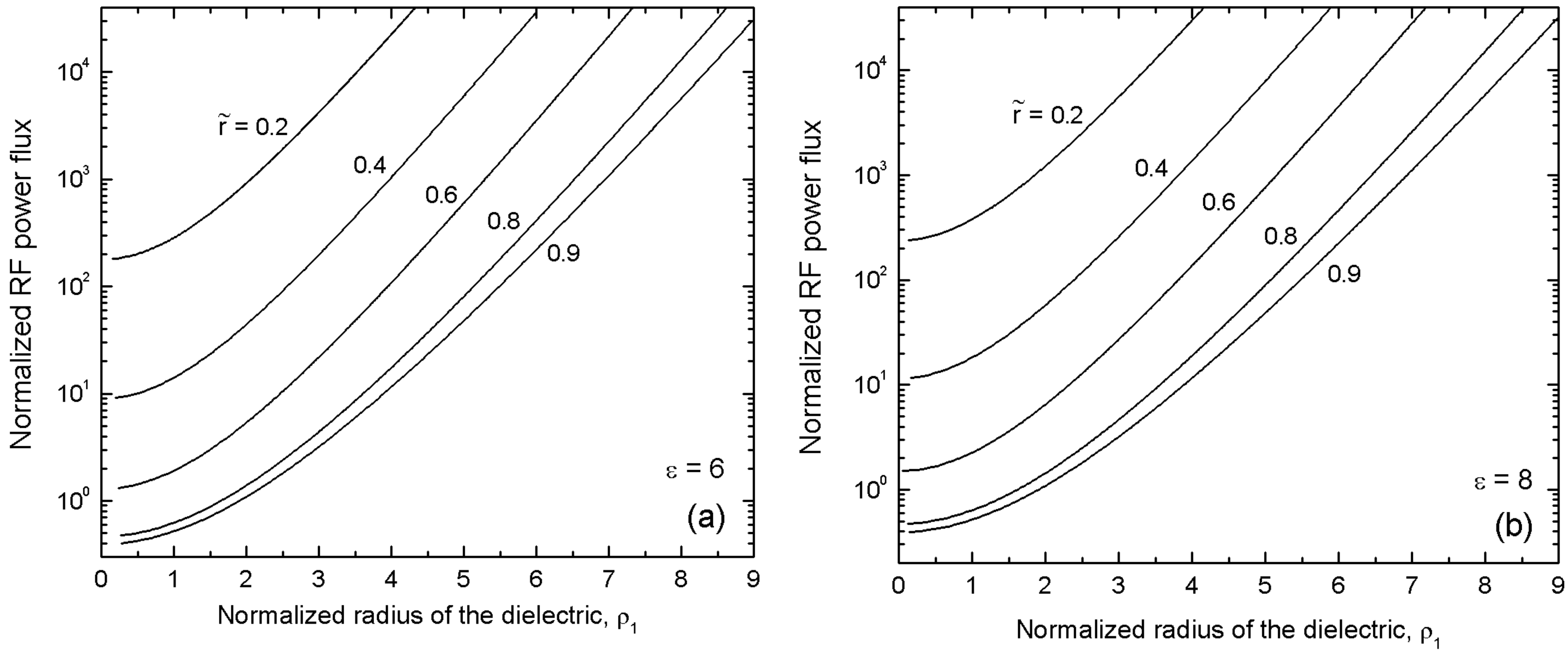
Dispersion diagram, experimental parameters



- The operation frequency f = 11.424 GHz, radius of dielectric r_d = 5 mm, wall radius r_w = 7.185 mm.

Normalized RF amplitude and power flow

- A relation between the propagating power and the normalized wave amplitude $\alpha = eA/mc\omega$ can be given as: $P(MW) = 1088\alpha^2 \tilde{k}_z \tilde{\omega}^3 \tilde{P}$
- Normalized RF power flux $\tilde{P}$ as function of the normalized radius of dielectric and the ratio r_d/r_w for two values of the dielectric constant:



1D-model of multipactoring in a DLA structure

- The physical insight to the effect of multipactoring can be obtained from consideration of a 1D radial motion of electrons. Such motion near the surface of dielectric can be described by a simple equation of electron motion:

$$m\ddot{r} = -eE_{dc} - eA\left(\frac{\pi r_d}{\lambda_z}\right)\sin\left(\omega t + \theta\right)$$

θ is the rf phase at the instant of emission, $\lambda_z = 2\pi / k_z$ is the axial wavelength.

- The DC field acting on the electron with radial coordinate r is created by charges located at $r' < r$. Correspondingly, it can be determined as

$$E_{dc}\left(r\right) = -\frac{4\pi e}{r}\int_0^r n\left(r'\right)dr'$$

When the height of electron trajectories is much smaller than the radius of the dielectric we may neglect the cylindricity and calculate DC field as

$$E_{dc} = -4\pi e\int_y^h n\left(y'\right)dy'$$

1D-model (cont.)

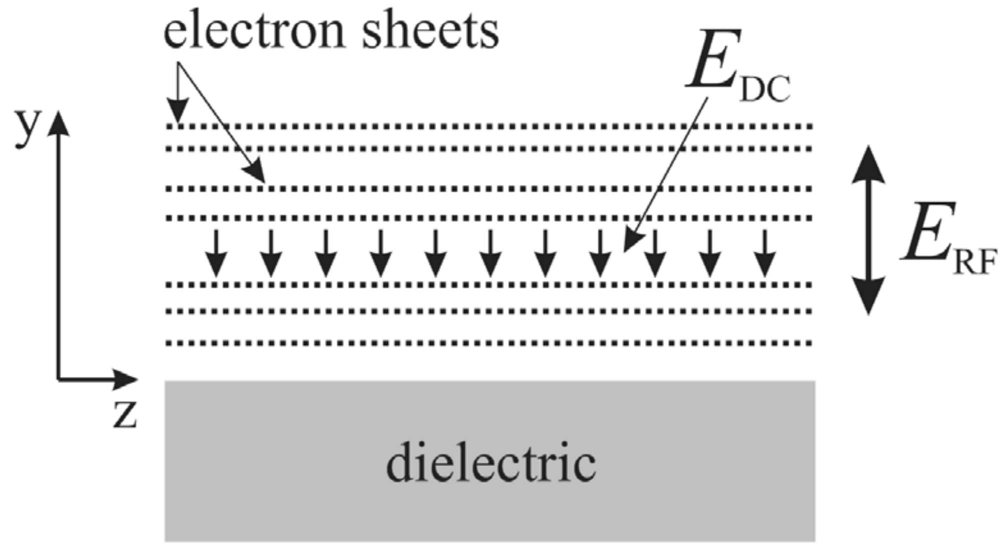
Equation of electron motion in normalized variables for this case can be written as:

$$\frac{d^2 y'}{dt'^2} = -\alpha \sin t' - \nu^2 \int_{y'}^{h} n'(y'')\, dy''$$

Here $y' = (\omega / c) y$, $t' = \omega t$,

$\alpha = (eA / mc\omega)(\pi r_d / \lambda_z)$,

$\nu^2 = (4\pi e^2 n_{\max} / m) / \omega^2$, $n' = n / n_{\max}$,
where $n_{\max}$ is the maximum electron density.



•Equation should be supplemented by initial conditions at the dielectric surface for the particle coordinate y: $y(t_0) = 0$ and particle velocity: $dy' / dt'|_{t=t_0} = \beta_0$.

•We assume that initially all electrons are uniformly distributed over the emission phases.

• Initial velocities of true secondaries, which are emitted from the dielectric surface in the process of multipactoring are **randomly** distributed in the interval which corresponds to kinetic energies from 0 to 20 eV.

1D-model, code block diagram

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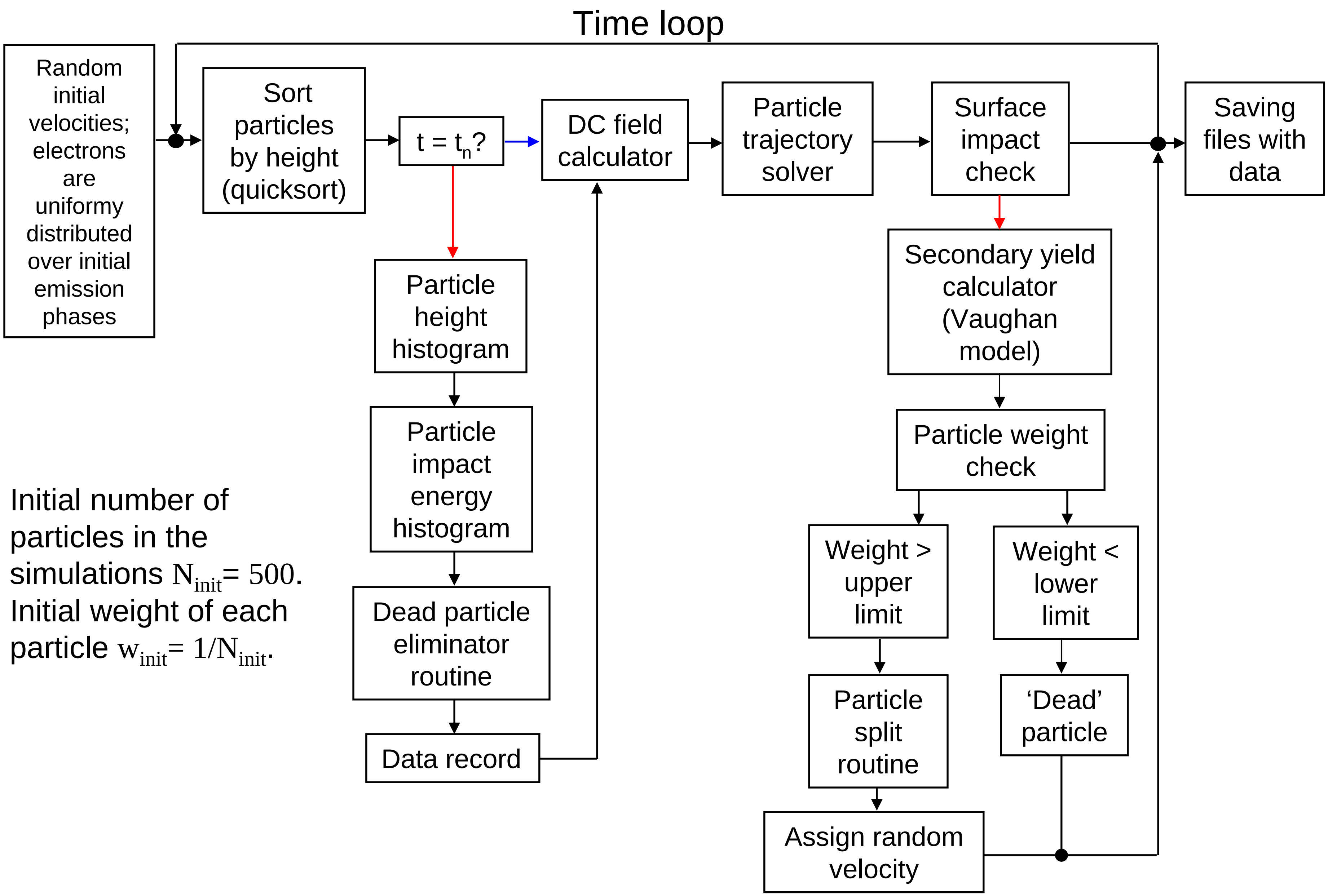
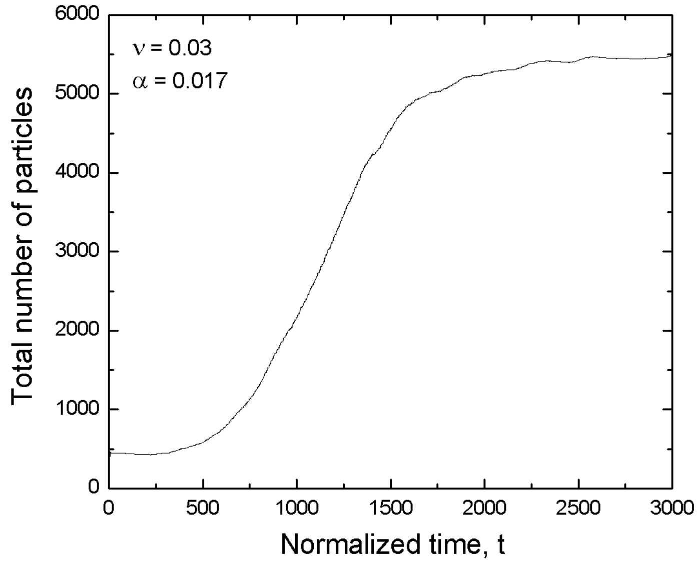
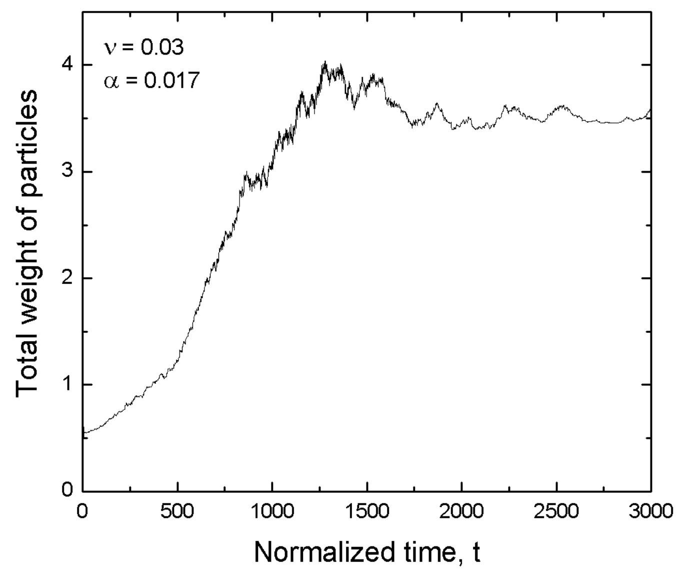
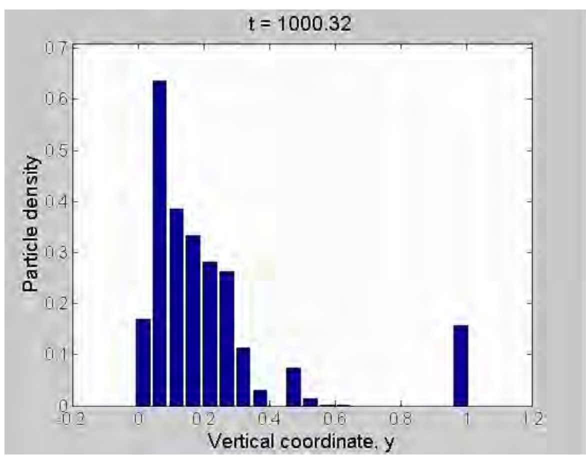


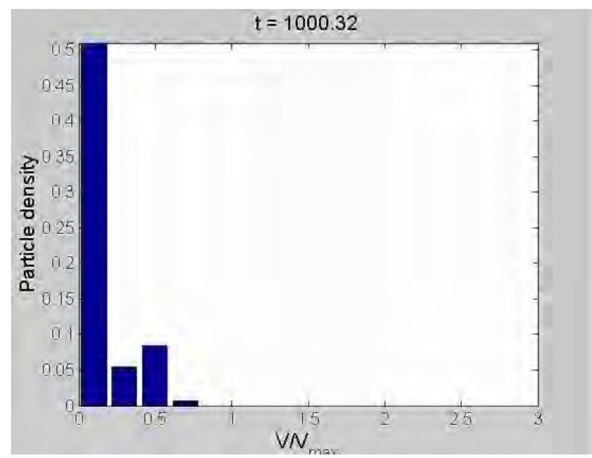
Initial number of particles in the simulations $N_{init} = 500$. Initial weight of each particle $w_{init} = 1/N_{init}$.

Results of simulations



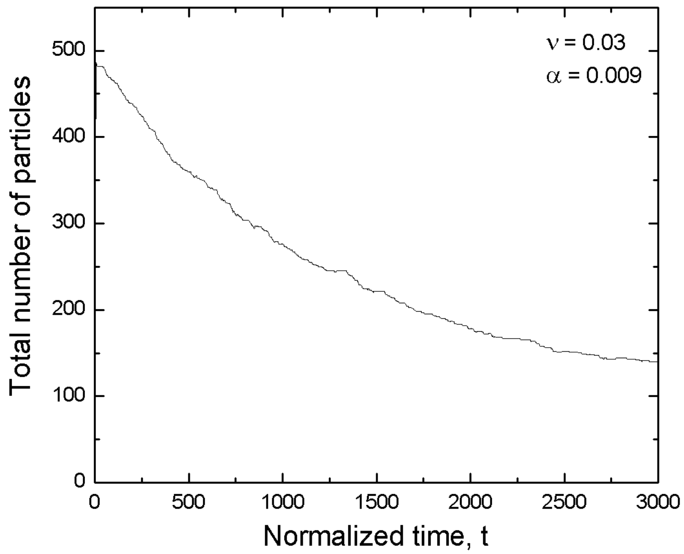


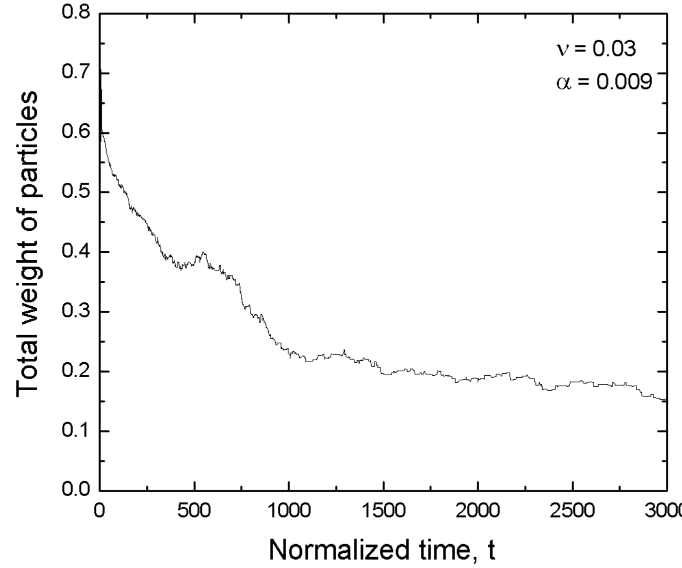


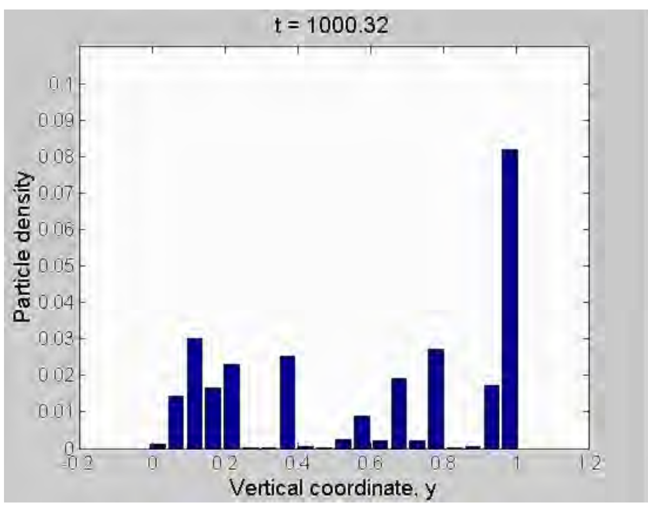


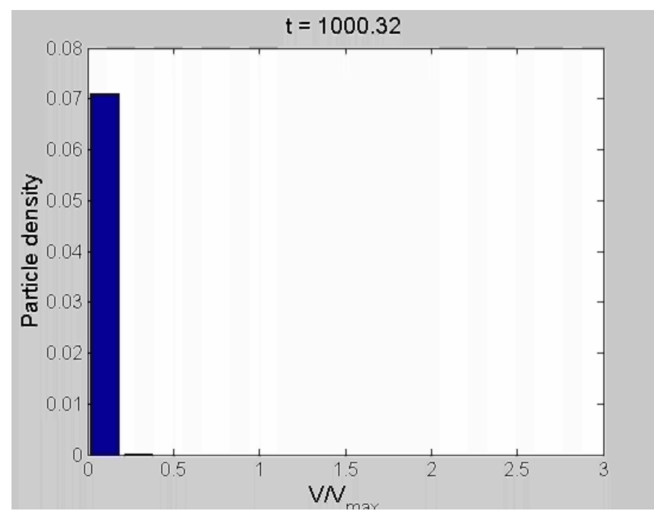
- Results are obtained for the maximum secondary yield value $\delta_{\max} = 2$, t = 3000 corresponds to 477 RF periods. The shape of the RF pulse is square.

Results of simulations (cont.)



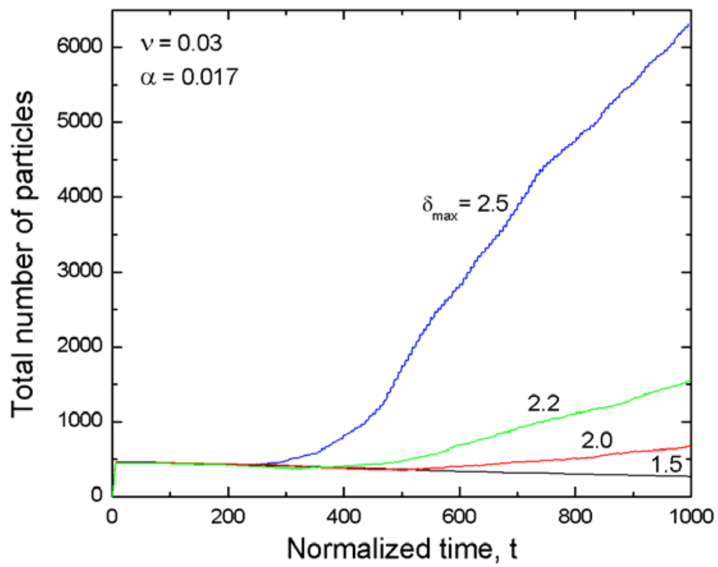


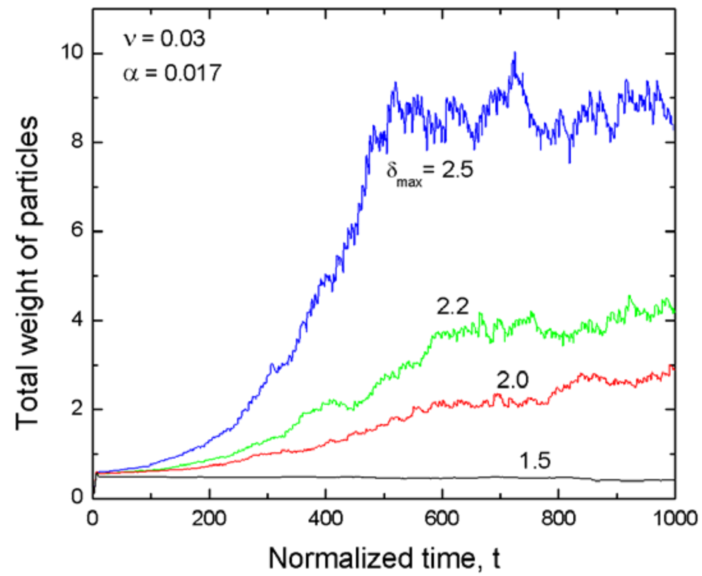




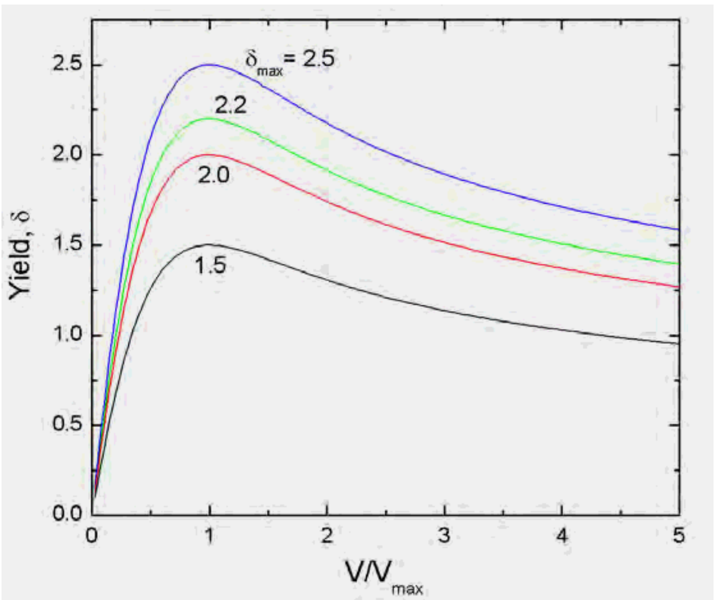
- No multipactor can be observed at lower RF amplitudes.

Results of simulations (cont.)

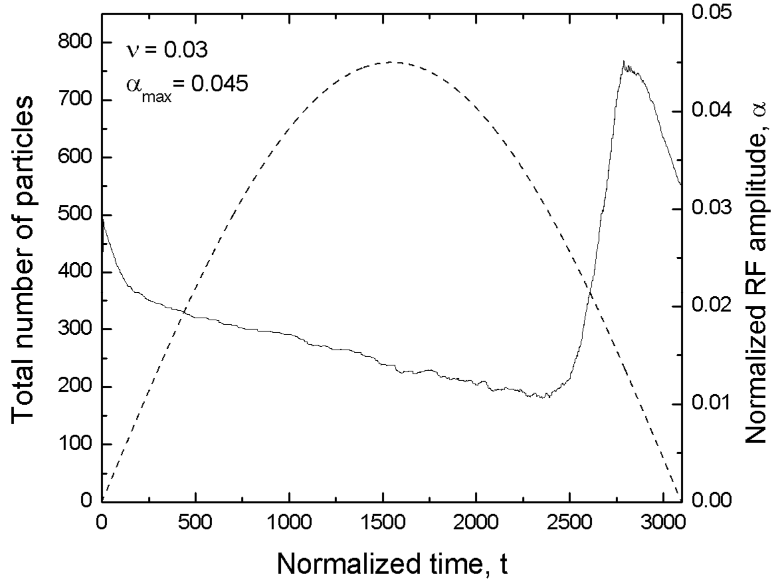


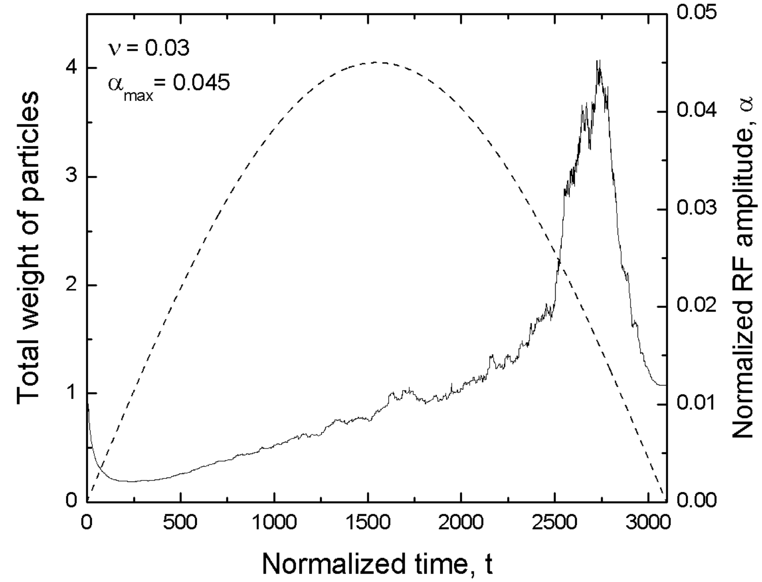


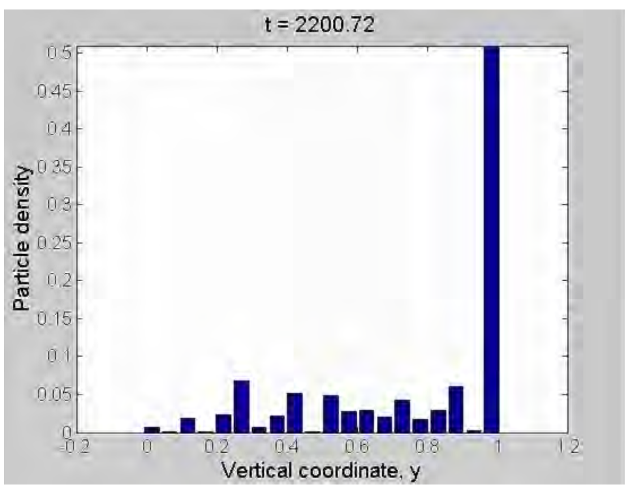
Effect of the secondary electron yield value on the multipactoring process. δ_{max} varies between 1.3 and 2 for most metals. V_{max} varies between about 200 and 1000 V. In our calculations V_{max} = 250 V.

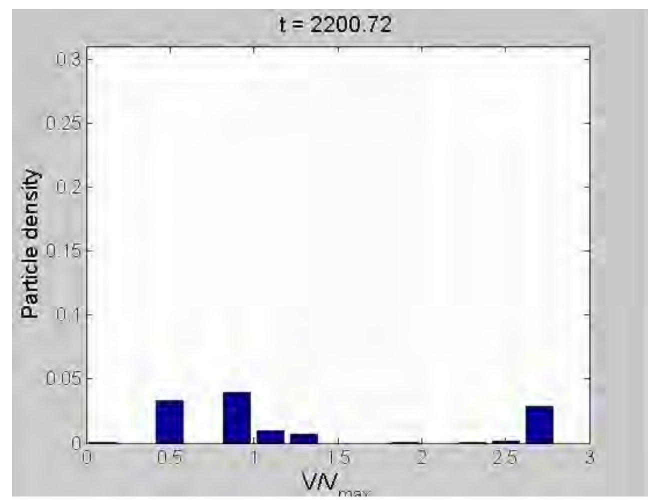


Results of simulations (cont.)









Results are obtained for the maximum secondary yield value $\delta_{max} = 2.2$. The shape of the RF pulse is represented as $\alpha(t) = \alpha_{max} \sin(\pi t / t_{max})$.

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Summary and conclusions

- Initial results for the 1D non-stationary model have been obtained
- The effects of the RF pulse amplitude and shape, and secondary emission yield value on the multipactoring process can be analyzed
- It is planned to include effects of cylindricity.

Acknowledgment

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