Pellet sublimation and expansion under runaway electron flux*

D.I. Kiramov, B.N. Breizman

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Motivation

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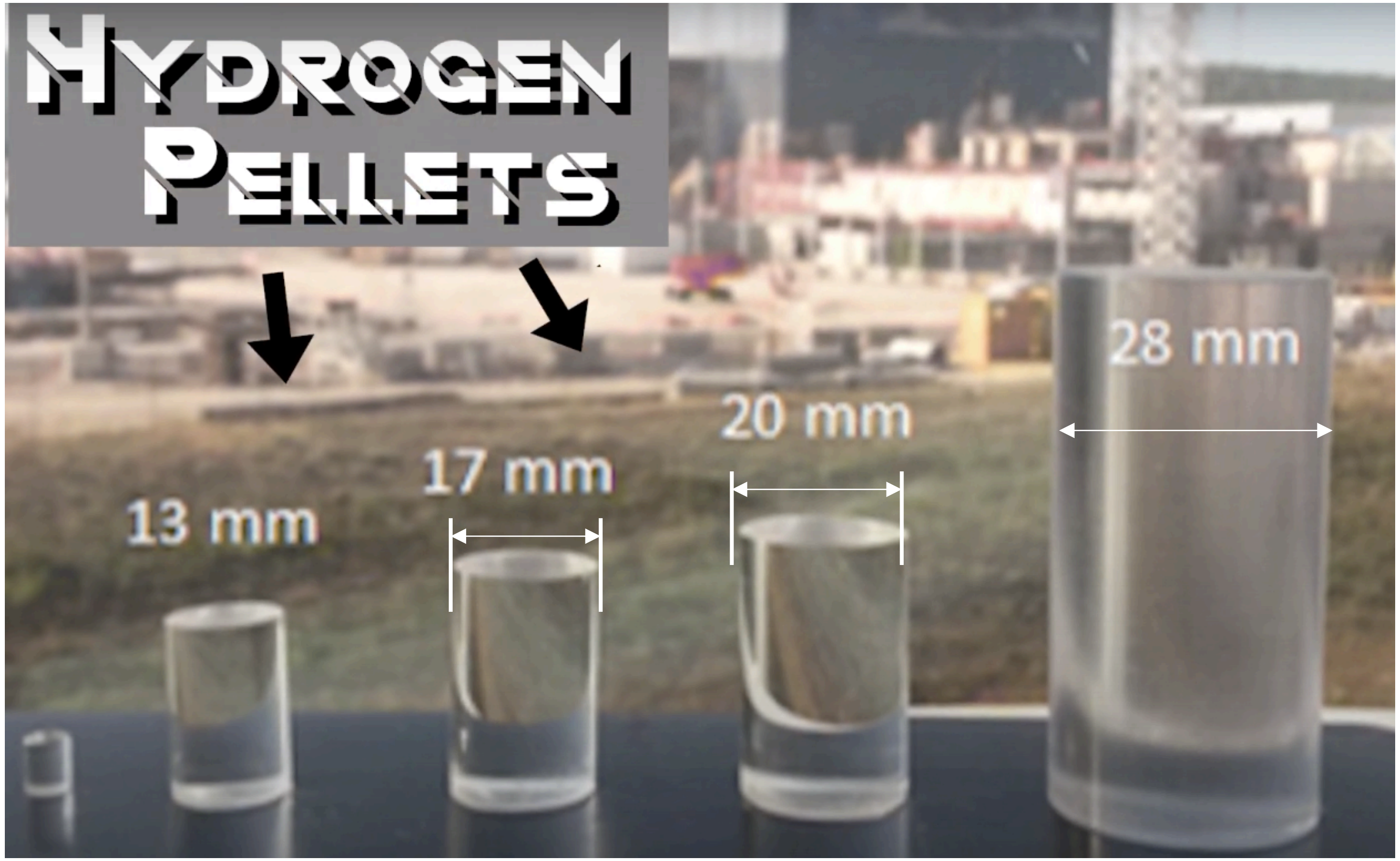
B.N. Breizman et al., Nucl. Fusion 59, 083001 (2019)

A total of up to 32 pellets can be injected from the equatorial ports with a diameter of 28 mm and length to diameter ratio of L/D = 2. Each of these pellets can deliver up to 10^{23} argon atoms.

Motivation



https://www.youtube.com/watch?v=WNpt1lFWchs&t=234s

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D. Shiraki et al., Nucl. Fusion 58, 056006 (2018)

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- Are the pellets available for mitigation of the RE current in ITER transparent for the REs with energies of the order of or larger than 10 MeV?
- Will the cryogenic pellet be sublimated instantly at the edge of the RE beam in ITER?

Runaway stopping distance

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Stopping power

$$\frac{d}{dt}\frac{\varepsilon_{RE}}{m_e c^2} = -4\pi r_e^2 c \ln\Lambda_{free}\left(n_{free} + \frac{1}{2}n_{bound}\right)$$

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Stopping distance

$$L \approx \frac{\varepsilon_0}{m_e c^2}\frac{1}{2\pi r_e^2 \ln\Lambda_{free} n_0 Z}$$

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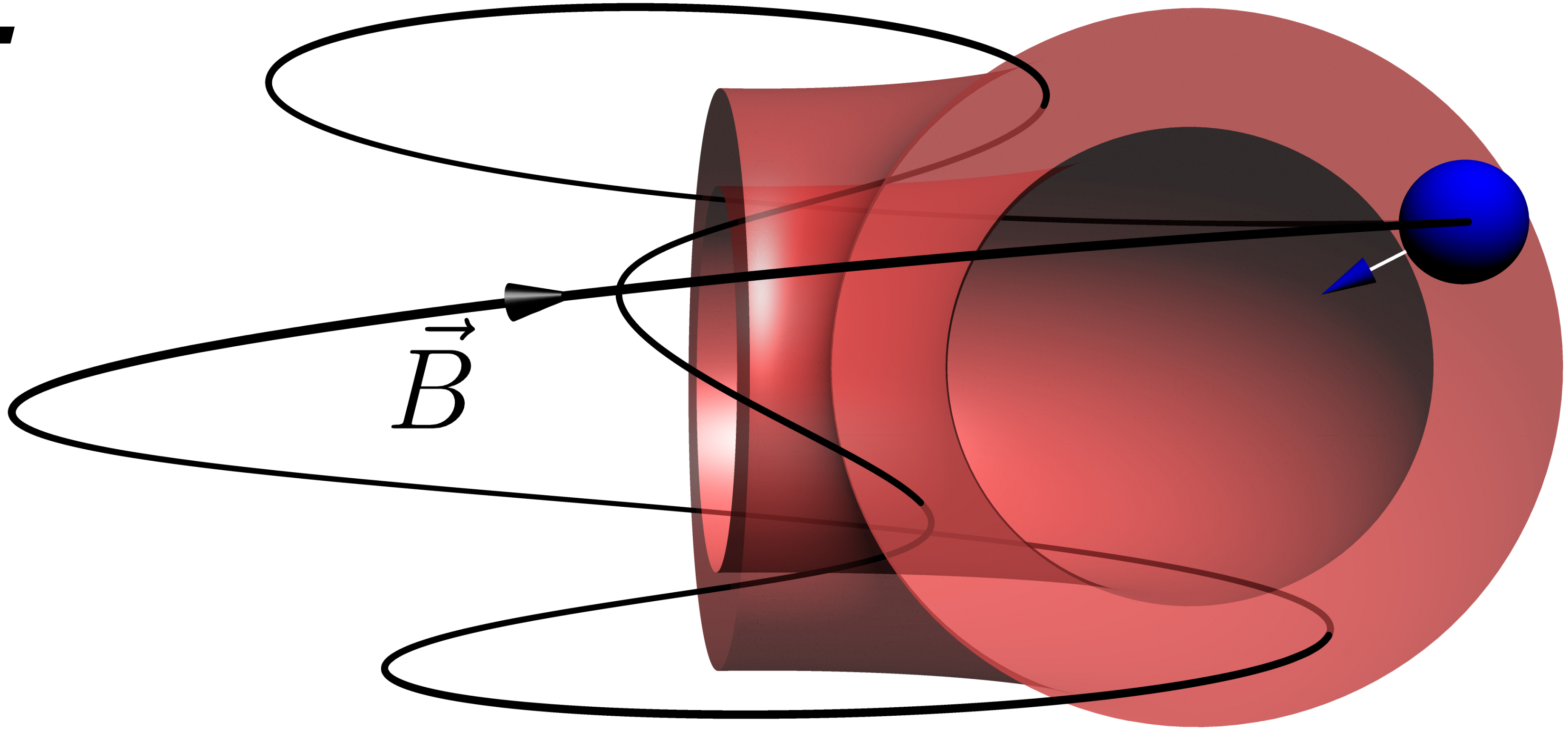
$L_{Ar} = 4$ cm, $L_{Ne} = 4$ cm, $L_{D2} = 30$ cm

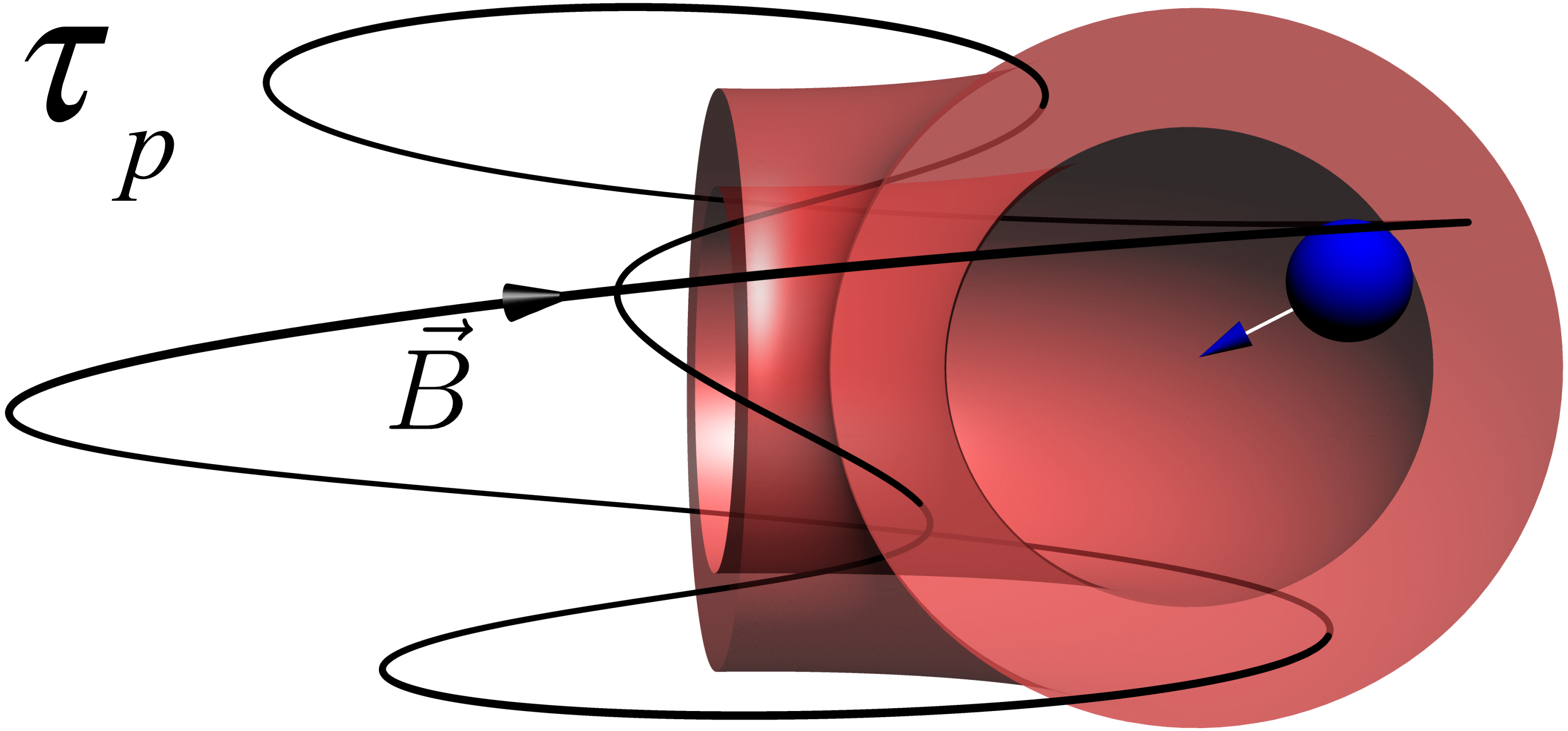
Pellet transit time

τ



Pellet transit time

$$\tau + \tau_p$$



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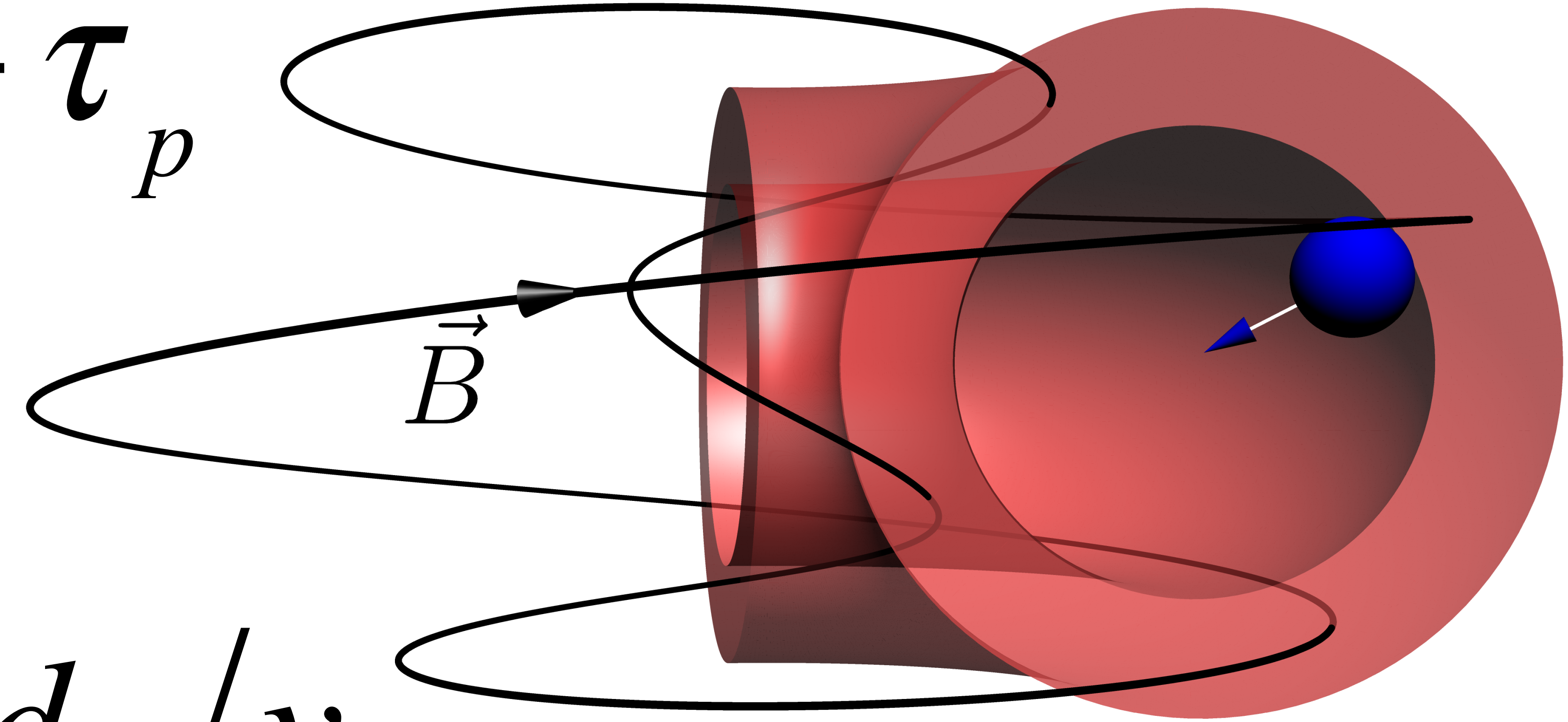

$$\tau_p = d_p / v_p$$

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For ITER

$$N_{\max} \approx 1 \div 2$$

Pellet sublimation

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Power input from the REs per individual atom

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It is apparent that the pellet will sublimate immediately if

$$\boxed{L_{sb} \leq d_p}$$

Pellet sublimation

Pellet sublimates immediately if

$$n_{RE\,sb} \geq \frac{1}{2\pi r_e^2 d_p \ln\Lambda_{free} Z_p} \frac{\varepsilon_s}{m_e c^2} \frac{v_p}{c} \qquad j_{RE\,sb} \geq \frac{ec}{2\pi r_e^2 d_p \ln\Lambda_{free} Z_p} \frac{\varepsilon_s}{m_e c^2} \frac{v_p}{c}$$

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	D_2	Ne	Ar
$j_{RE\,sb}$ [A/cm^2]	0.8	0.3	0.6
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In ITER

$$n_{RE\,uniform} = 0.95\times 10^{10}\ [\mathrm{cm}^{-3}]$$
$$j_{RE\,uniform} = 45\,[\mathrm{A/cm}^2]$$

Cloud expansion

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$$\frac{f_i^2}{1-f_i} = \frac{AT^{3/2}}{n_t}\exp\left(-\varepsilon_i / T\right)$$

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Rosseland mfp

$$L_R = B\frac{T^2}{n_t Z^2}\exp\left(\frac{\varepsilon_i}{T}\right)$$

Cloud expansion

Cloud expansion

ITER-relevant parameters

$$N_{atoms} = 9\times10^{23}$$

$$d_p = 2.8\,[\mathrm{cm}]$$

$$n_{RE} = 10^{10}\,[\mathrm{cm}^{-3}]$$

$$v_p \approx 10^4\,[cm/s],$$

$$v_{\exp} \approx 10^5 \div 10^6 [cm/s]$$

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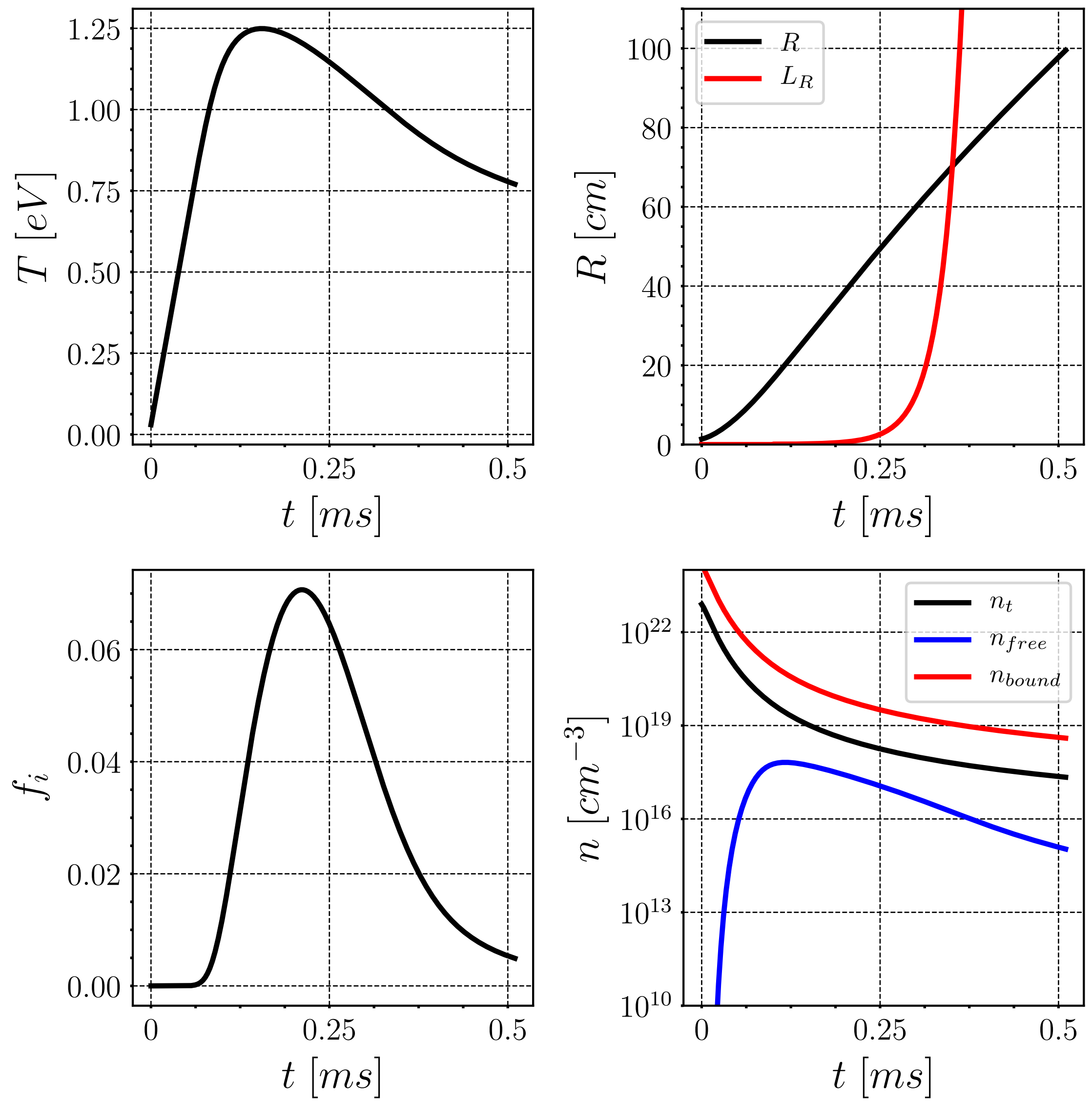

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- The cryogenic pellet will likely be sublimated instantly at the edge of the RE beam. This was already observed in recent experiments*;

- The sublimated pellet expands rapidly and spreads over the poloidal cross-section of a tokamak on a millisecond time scale. By the time it covers the poloidal cross-section, its temperature lies in a 1 eV range, and the ionization fraction stays low. Further ionization of the material is likely to occur during the toroidal expansion phase.

*D. Shiraki et al., Nucl. Fusion 58, 056006 (2018)