Radiative Characteristics of Al Metal-Puff Z-Pinches in Experiments on the GIT-12 Generator at a Microsecond Implosion Regime

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SHCE

Study of K-shell plasma radiation sources operating at microsecond implosion times

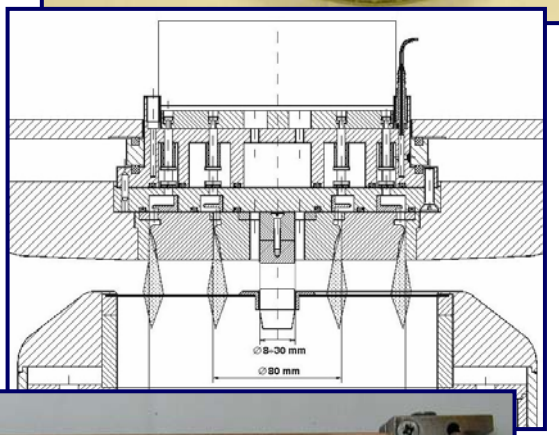
Multi-shell gas puff experiments (2003-2005)

Ne: 11 kJ/cm (I_{LOAD} = 3.6 MA, T_{IMP} = 1000 ns)

Ar: 500 J/cm (I_{LOAD} = 2.6 MA, T_{IMP} = 700 ns)

Gas-puff-on-wire-array experiments (2004-2005)

Al: 4 kJ/cm (I_{LOAD} = 3.4 MA, T_{IMP} = 950 ns)

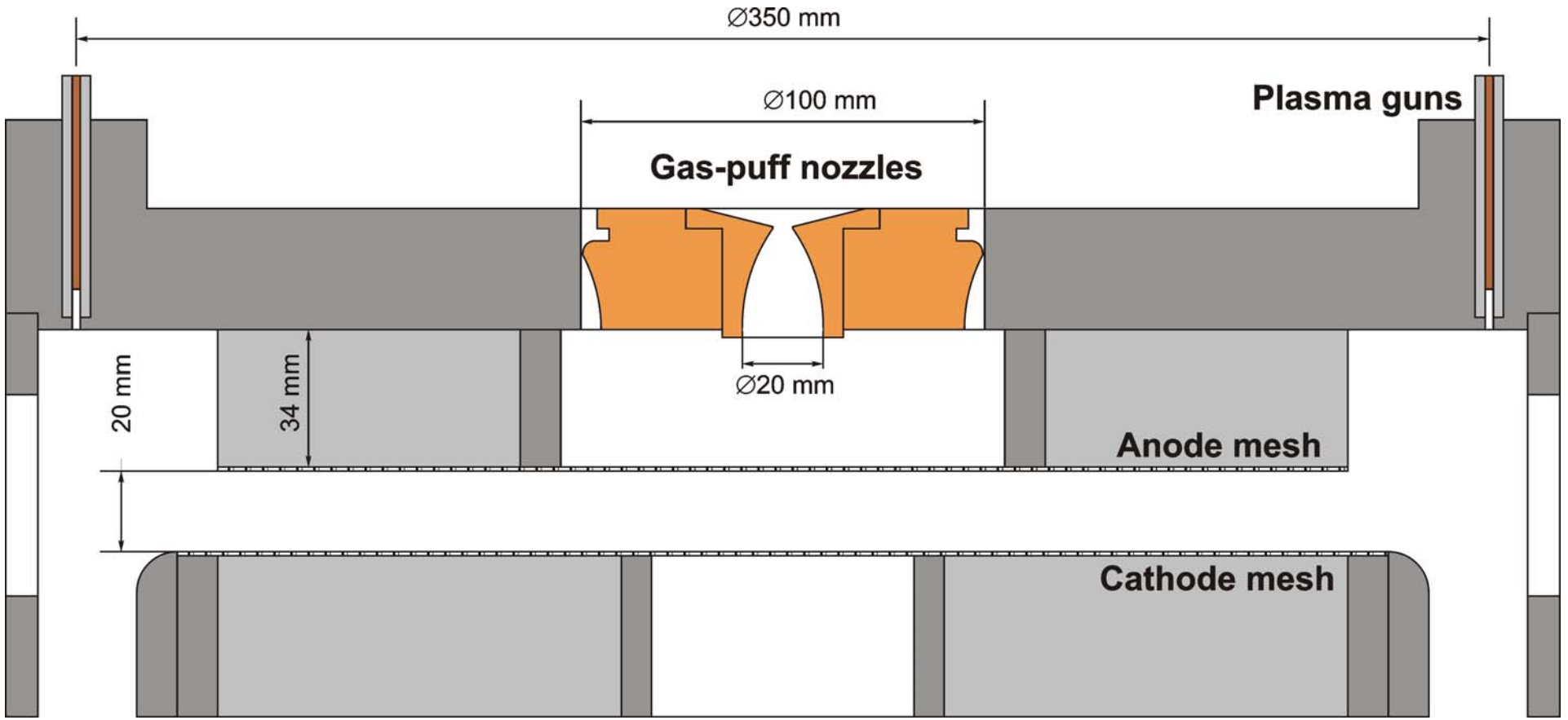


Planar wire arrays experiments (2006-2010)

Al: 6.5 kJ/cm

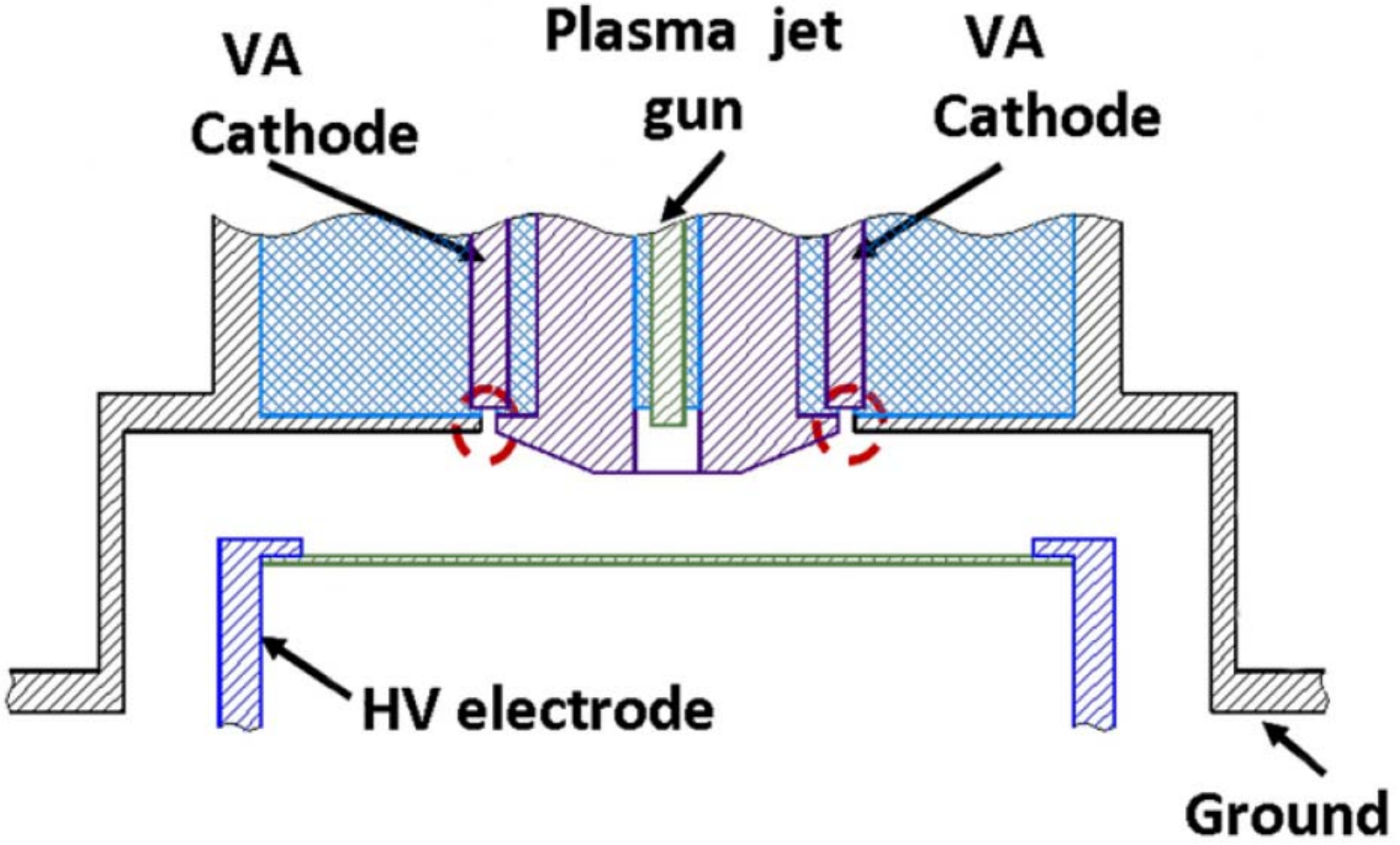
(I_{LOAD} = 3.8 MA, T_{IMP} = 1050 ns)

A new load type:
Gas-puff with an outer plasma shell



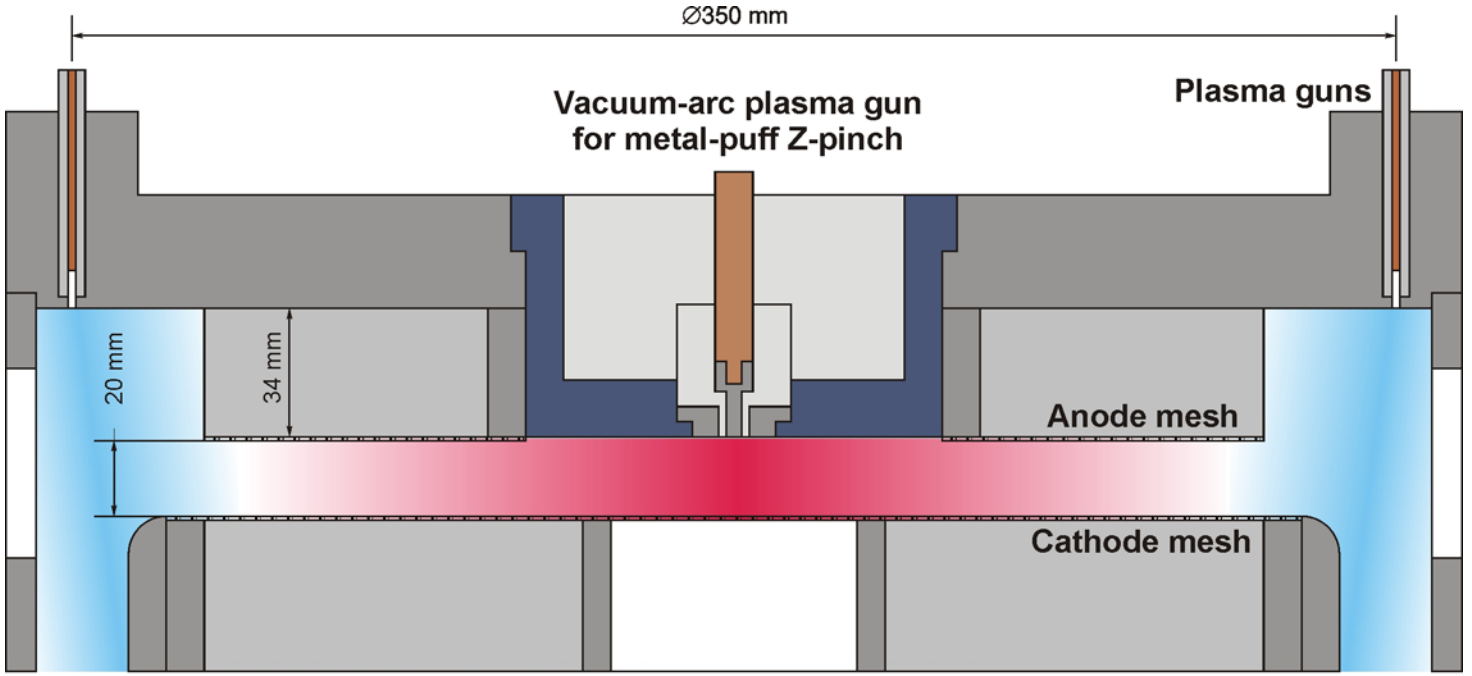
Kokshenev V.A., et al. // Proc. 14th Symp. on High Current Electronics, Tomsk, 2006, pp. 272-275
Klir D., et al. // Plasma Phys. Controlled Fusion. – 2015. – V.57, No. 4. – P. 044005
Shishlov A.V., et al. // Russ. Phys. J., vol. 62, no. 7, pp. 1243–1252, Nov. 2019.

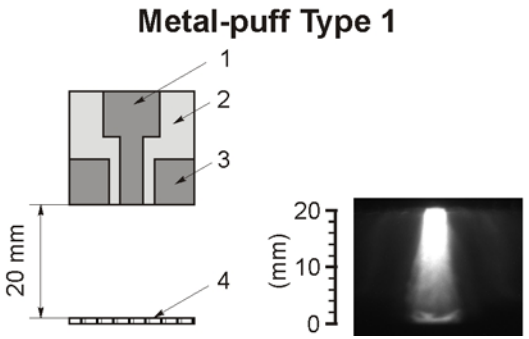
A new load type: Metal-puff Z-pinch

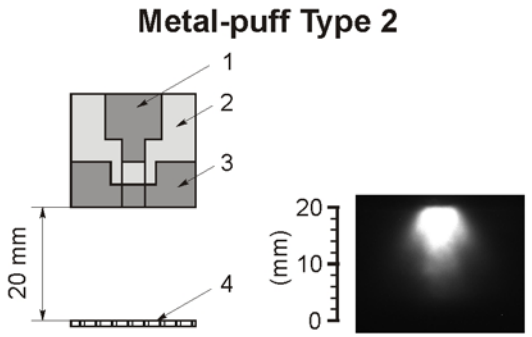


Baksht R.B., et al. // IEEE Trans. Plasma Sci., vol. 41, no. 1, pp. 182–186, Jan. 2013.
Rousskikh A.G., et al. // Physics of Plasmas 21, 052701 (2014)

A hybrid load:
Metal-puff Z-pinch with an outer plasma shell



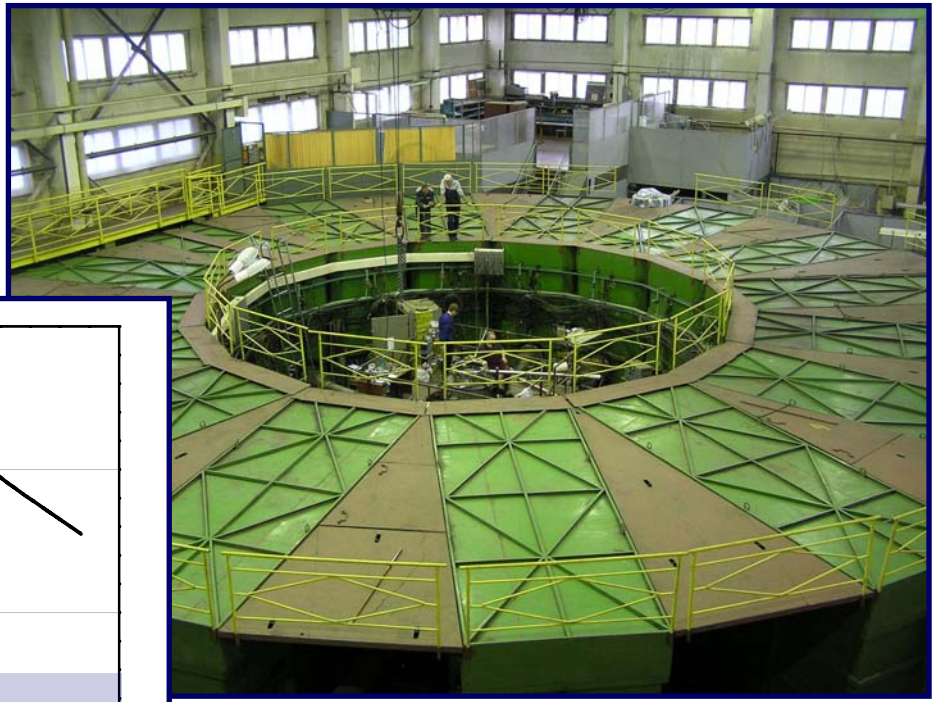


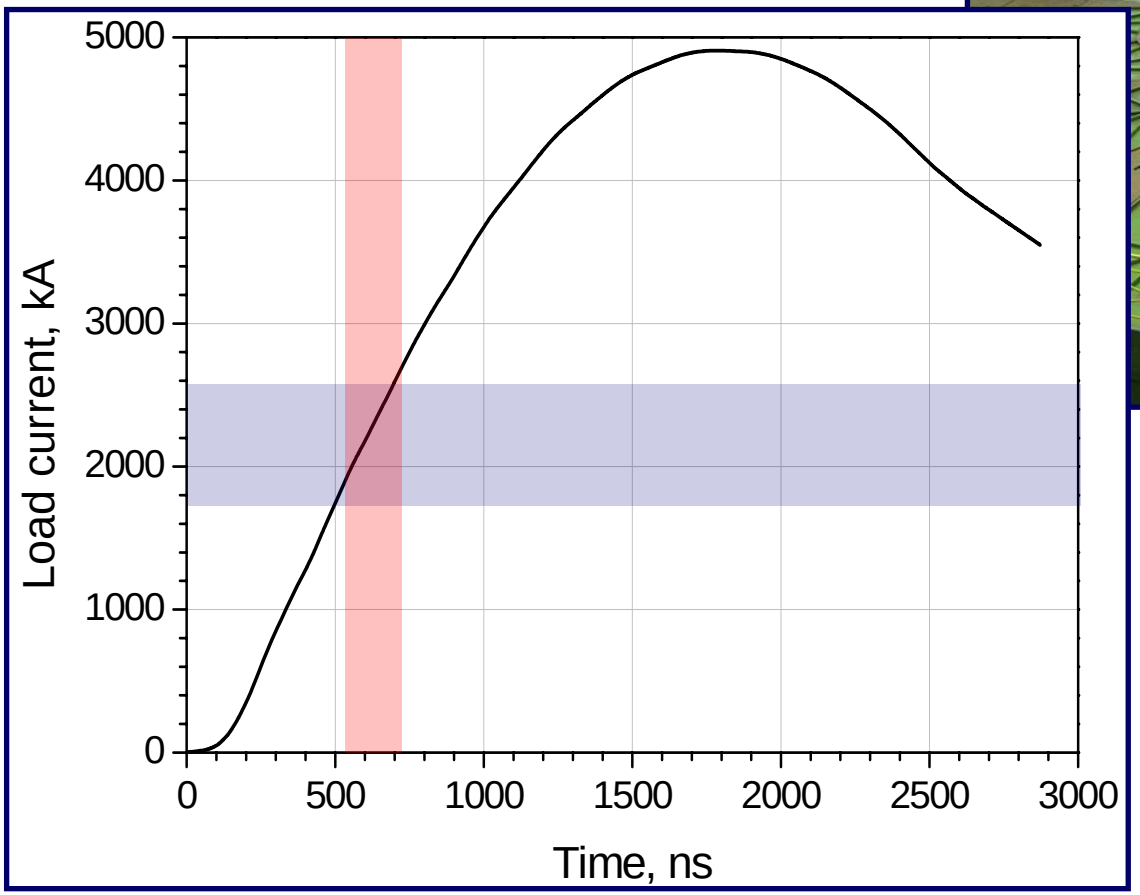


1 – an Al cathode of the vacuum arc plasma gun; 2 – a polyethylene insulator; 3 – an Al anode of the vacuum arc plasma gun; 4 – a cathode of the generator formed by stainless steel mesh

GIT-12 generator

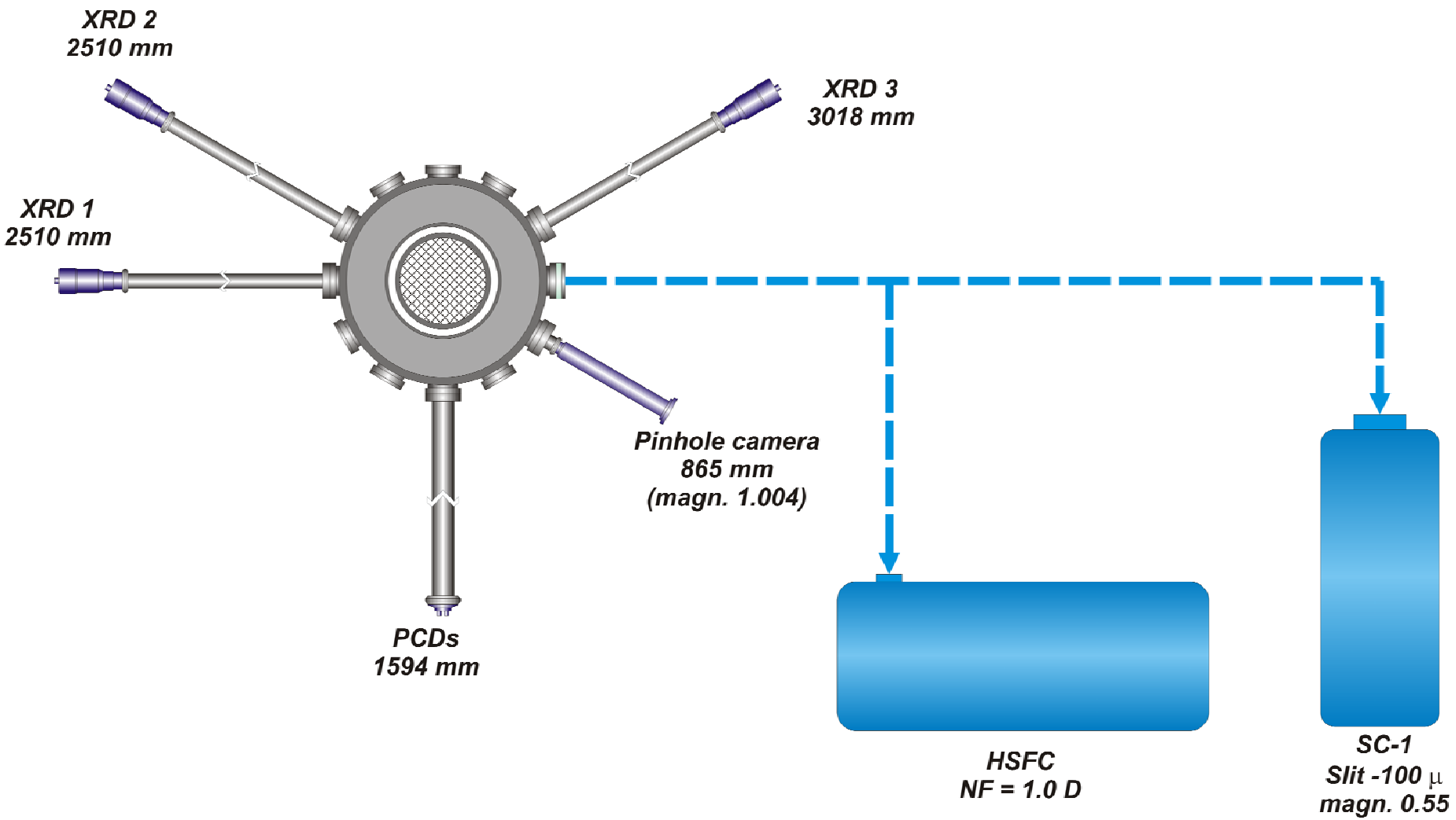
Charging voltage – 50 kV
Stored energy – 2.6 MJ



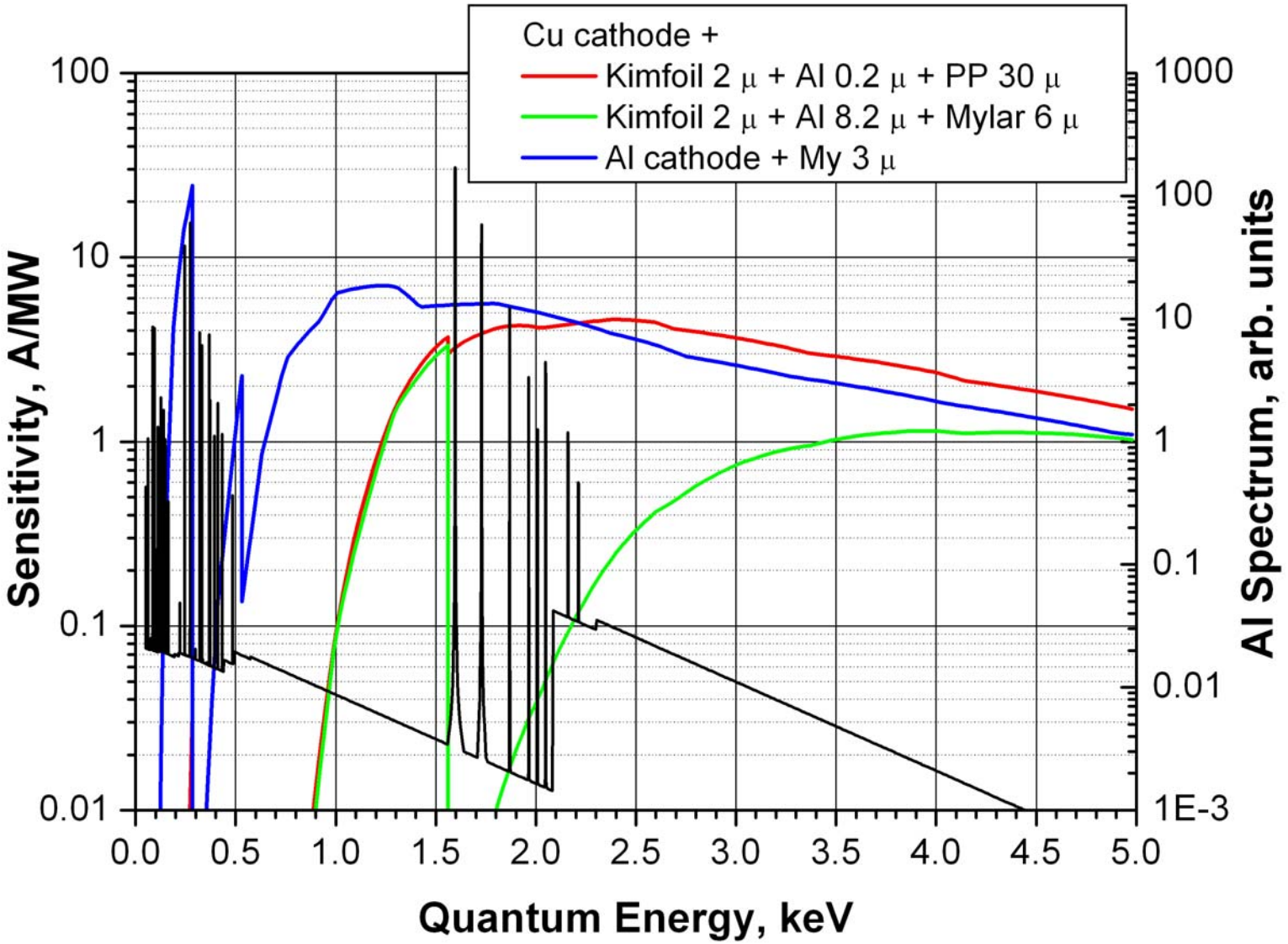


Operation w/o POS :
4.7 MA, 1.7 μs, 3 kA/ns

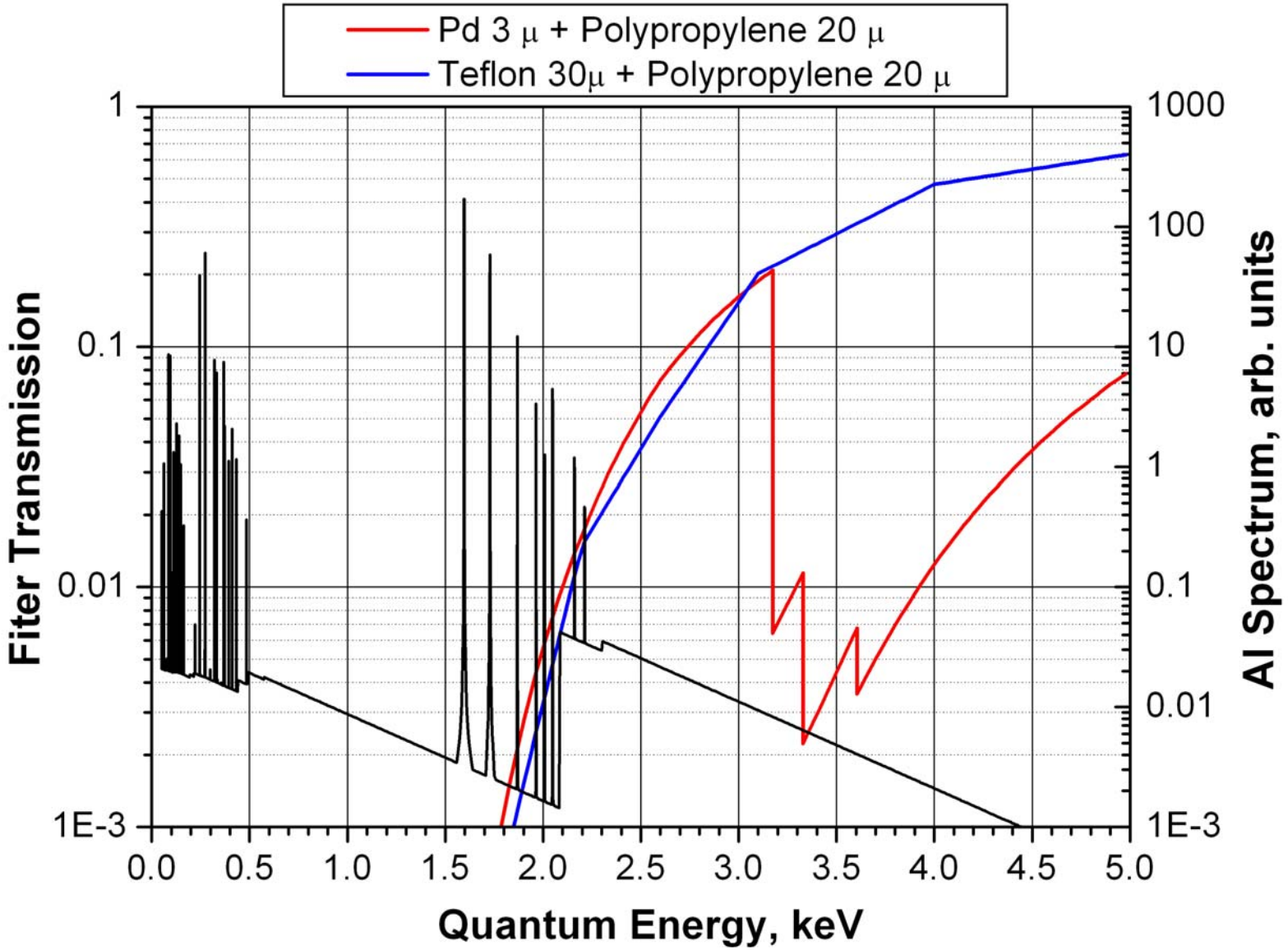
Z-pinch diagnostics



Sensitivity of X-ray diodes



Sensitivity of photoconducting detectors



Theoretical scaling of K-shell radiation yield

$$K = E_I + Y_K + E_P$$

$$K = \frac{\Delta L\, I^2}{2} = \ln\left(\frac{R_0}{R_f}\right) I^2$$

$$E_I = 4.7\times10^{-19} Z^{0.82} NT$$

$$Y_K = \frac{2.7\times10^{-31} ZN^2}{R_f T} \exp\left(-\frac{10.2Z^2}{T}\right)$$

$$\alpha \cdot K = E_I + Y_K$$

$$\alpha \le 0.5$$

$$K = \gamma \ln\left(\frac{R_0}{R_f}\right) I^2$$

$$K = 2000 I^2$$

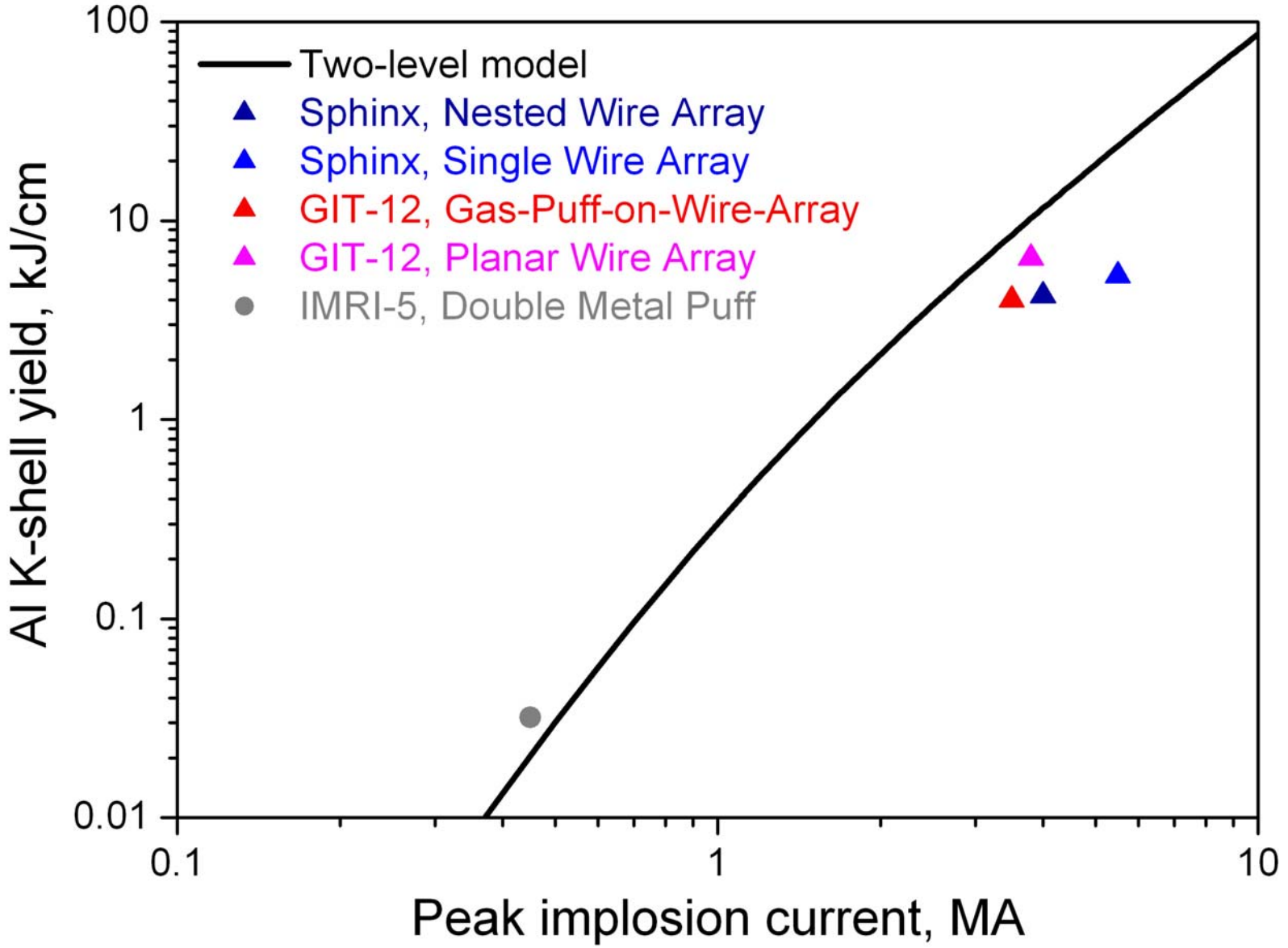
$Y_K \ll K,\ Y_K \sim I^4$ *inefficient regime*

$Y_K \approx K,\ Y_K \sim I^2$ *efficient regime*

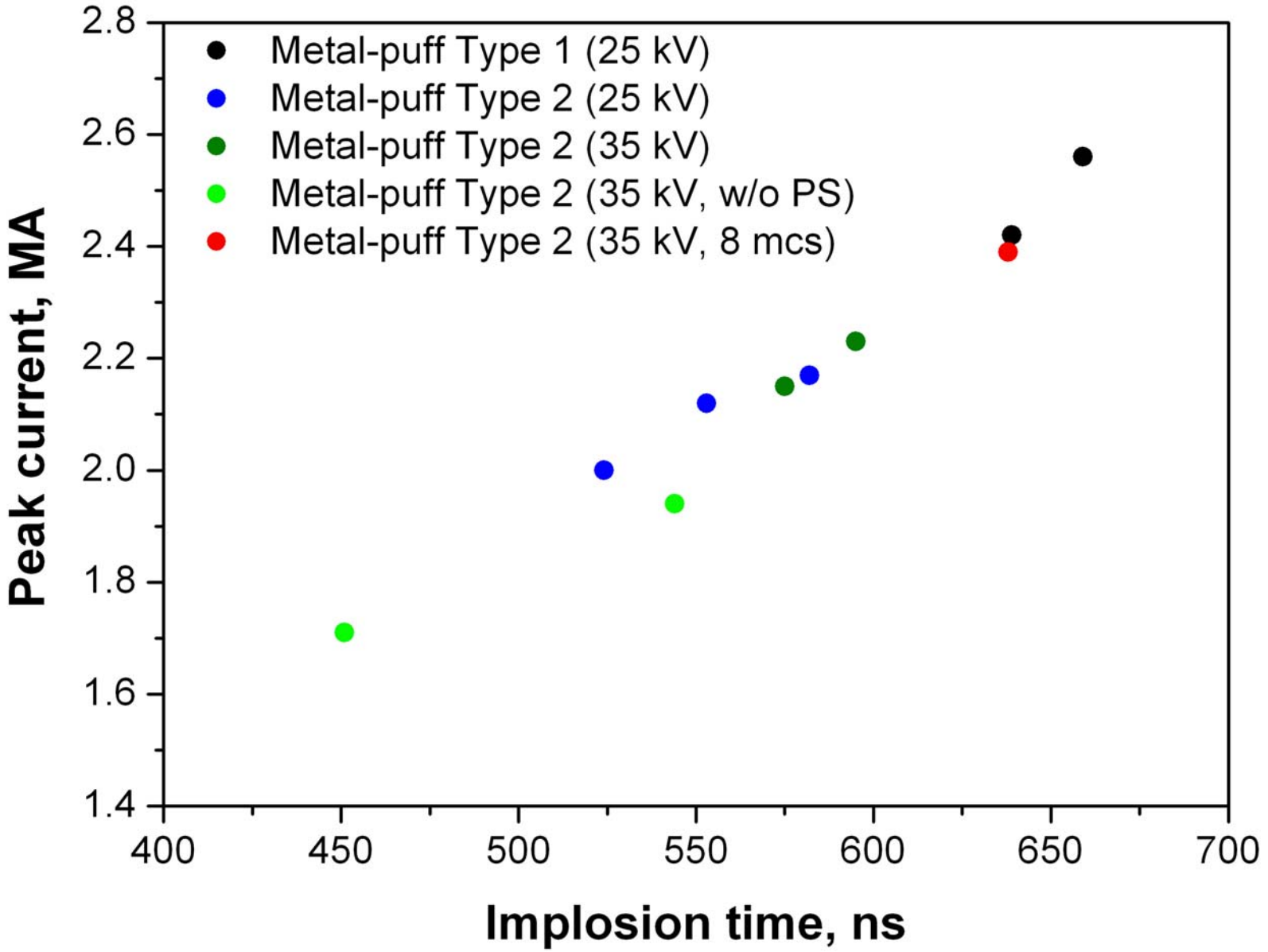
$$PRS\ Efficiency = \frac{Y_K(\exp)}{Y_K(theor)}$$

D. Mosher, et al. “A Two-Level Model for K-Shell Radiation Scaling of the Imploding Z-Pinch Plasma Radiation Source”, IEEE Trans. Plasma Sci., vol.26, No.3, June 1998, pp.1052-1061

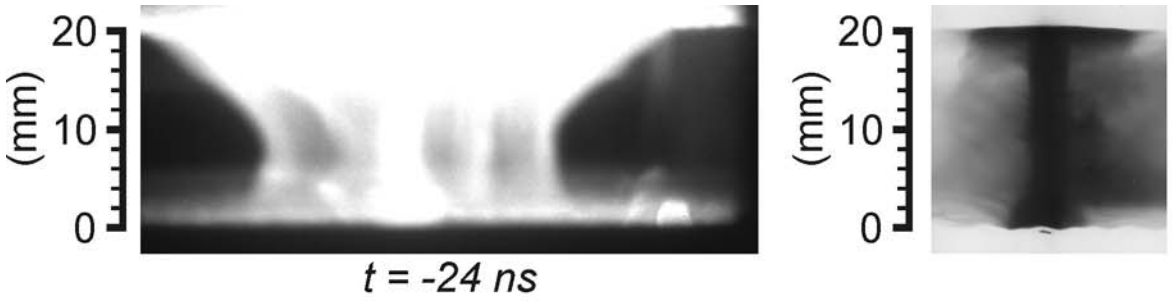
Al K-shell radiation yield at microsecond implosion times



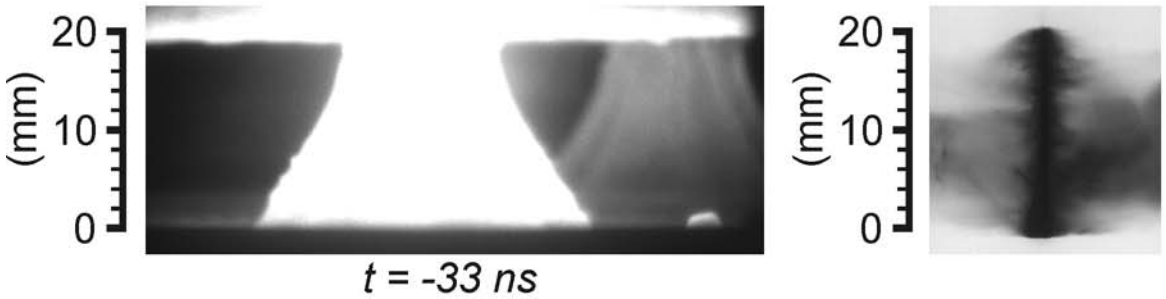
Metal-puff Z-pinch: Implosion times and peak currents



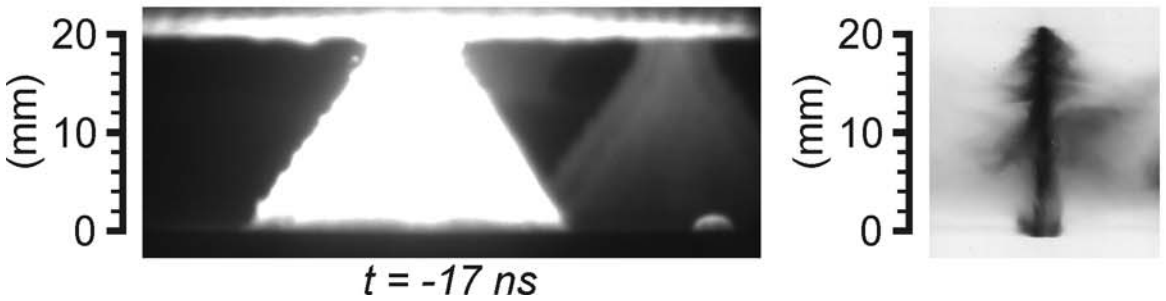
Metal-puff Z-pinch: Implosion stability



Shot #2539
Metal-puff Z-pinch Type 1

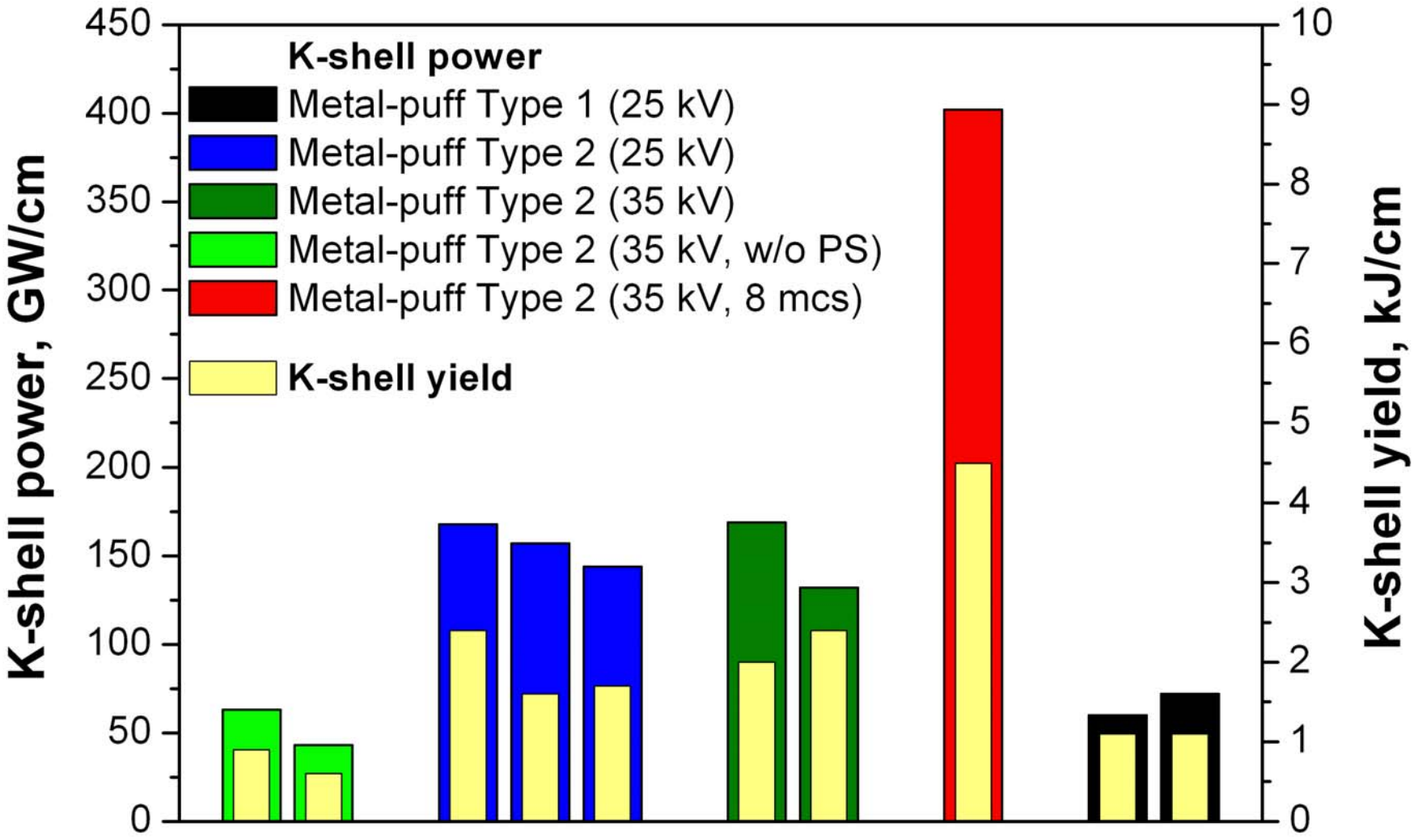


Shot #2544
Metal-puff Z-pinch Type 2

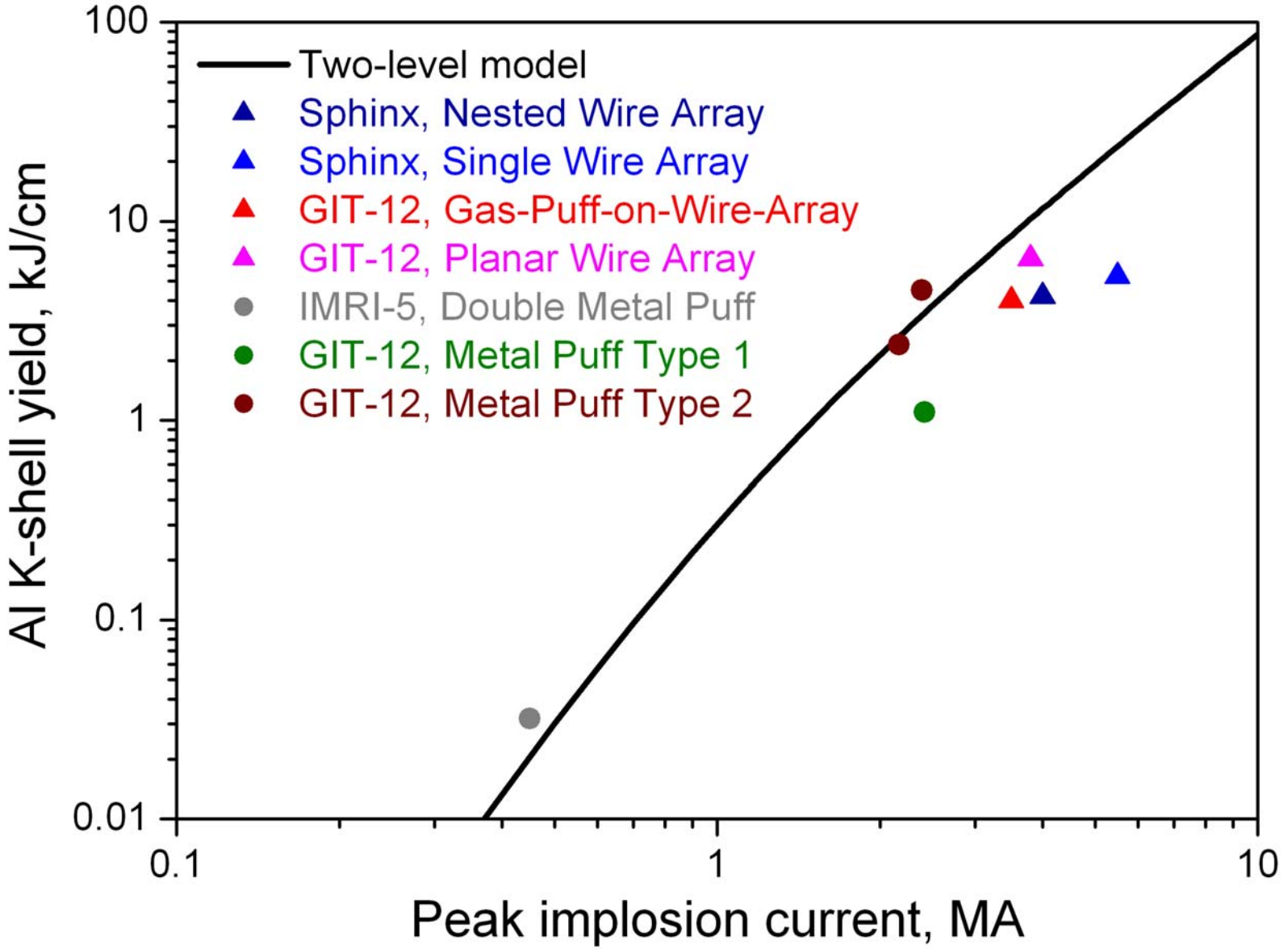


Shot #2547
Metal-puff Z-pinch Type 2
w/o the outer plasma shell

Metal-puff Z-pinch: K-shell radiation yield and power



Al K-shell radiation yield at microsecond implosion times



Summary

- ***Two load configurations of a new type of Z-pinch load – the metal-puff Z-pinch with the outer plasma shell – has been studied in the experiments on the GIT-12 generator in the microsecond implosion regime.***
- ***Both load configurations demonstrated the ability to provide stable implosions at microsecond implosion times, but… The configuration of metal-puff Z-pinch load with the discharge gap of the vacuum-arc plasma gun recessed into the anode produced four times higher Al K-shell radiation yield in comparison with another load configuration, where the discharge gap was located in the plane of the anode. This phenomenon requires further experimental and theoretical studies.***
- ***The maximum Al K-shell radiation yield registered in experiments was 4.5 kJ/cm at a peak implosion current of 2.4 MA. Comparisons with theoretical estimates of the expected radiation yield and with the results of early experiments carried out on various generators with different loads show that at present the metal-puff Z-pinch with the outer plasma shell is the most efficient load for generation of Al K-shell X-rays at a microsecond implosion regime.***