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Disruption mitigation by injection of massive Be and Li pellets

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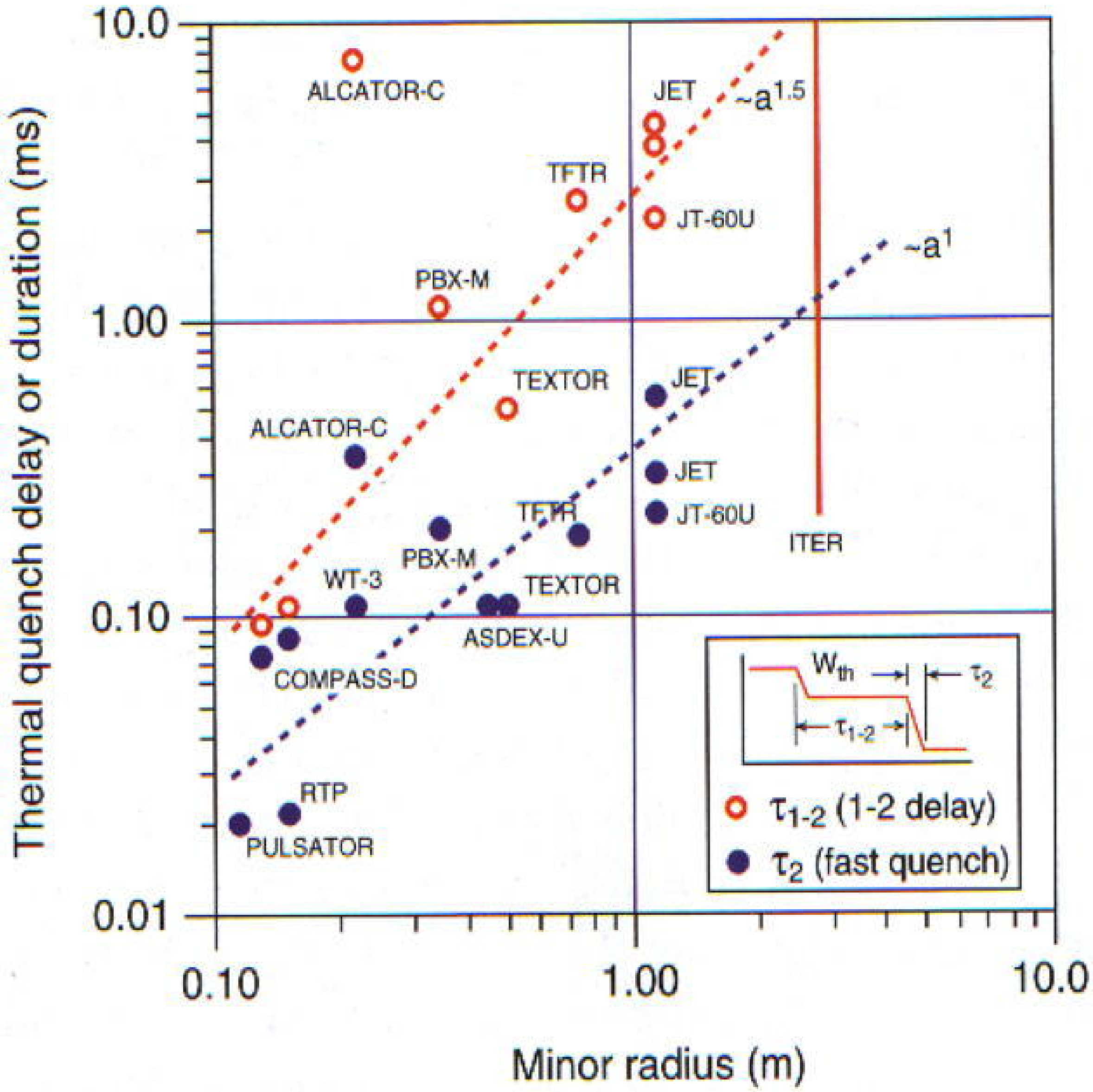
Motivation



Assumption of ITER major disruption scheme

(ITER Physics Basis)

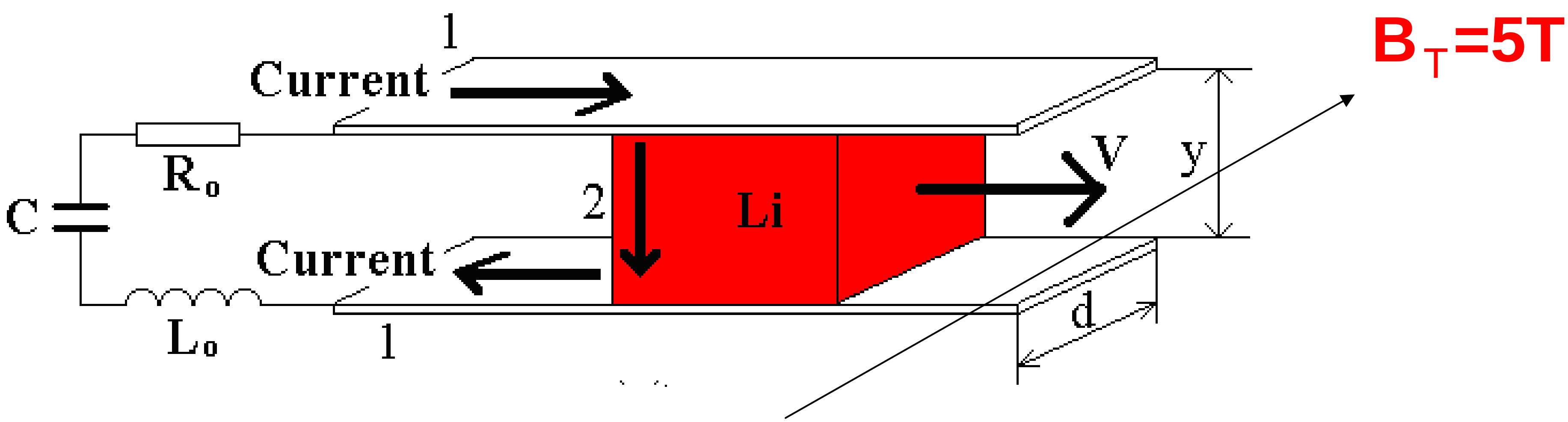
Duration of ITER major disruption stages:

t_{1-2} – slow (>10ms)

and

t_2-fast (1-3ms) thermal quench

Li (2x2x2cm^3) fast railgun injector



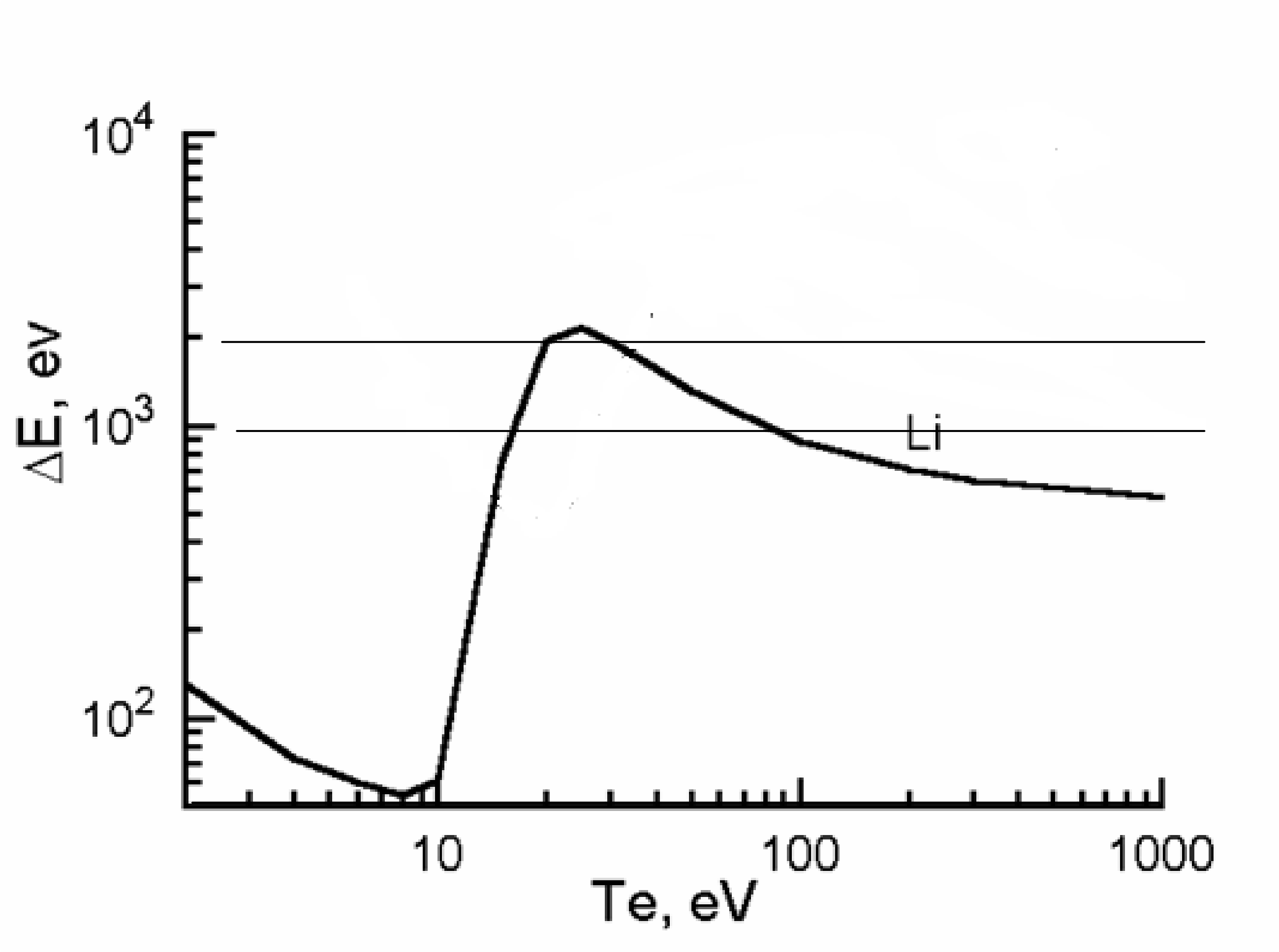
Railgun scheme: rail 1 L=1m, accelerated body 2 (Li 2x2x2cm^3), distance between rails y=2cm, rail width d=2cm, body velocity vector V.

The current communication is extension of authors previous activity in field of disruption mitigation by gun injection of massive low Z pellets .
Main aim of current communication is comparison of Li and Be efficiency as killer pellets during disruption mitigation.

1.S.V.Mirnov and D.Yu.Prokhorov. Plasma Control and MHD ITER Expert Group, San Diego, USA, 11-14 May 1998.
2. Yu.A.Kareev, S.V.Mirnov, D.Yu.Prokhorov «Proposal of ITER disruption mitigation by Li killer pellet injection» 10^{th} ITPA MHD Topical Group Meeting at IPP-Garching 10-12 October 2007
3. R.R. Khayrutdinov, S.V. Mirnov, Yu. A. Kareev, V.E.Lukash «Study of low Z pellets injection for disruption mitigation in ITER like tokamaks» 36 EPS Conf. on Plasma Phys. Sofia 2009 P4.170
4. V.E.Lukash, R.R.Khayrutdinov , Yu.A.Kareev, S.V.Mirnov "Modeling of Major Disruption Mitigation by Fast Injection of Massive Li Pellets in ITER Like Tokamak-reactor" FEC2010 THD/P2-01

How much lithium we need for ITER cooling?

“Energy cost” of Li ion before its transition to coronal equilibrium, as Te function



The lithium amount (N) used for 0.5GJ plasma cooling by fast Li-injection

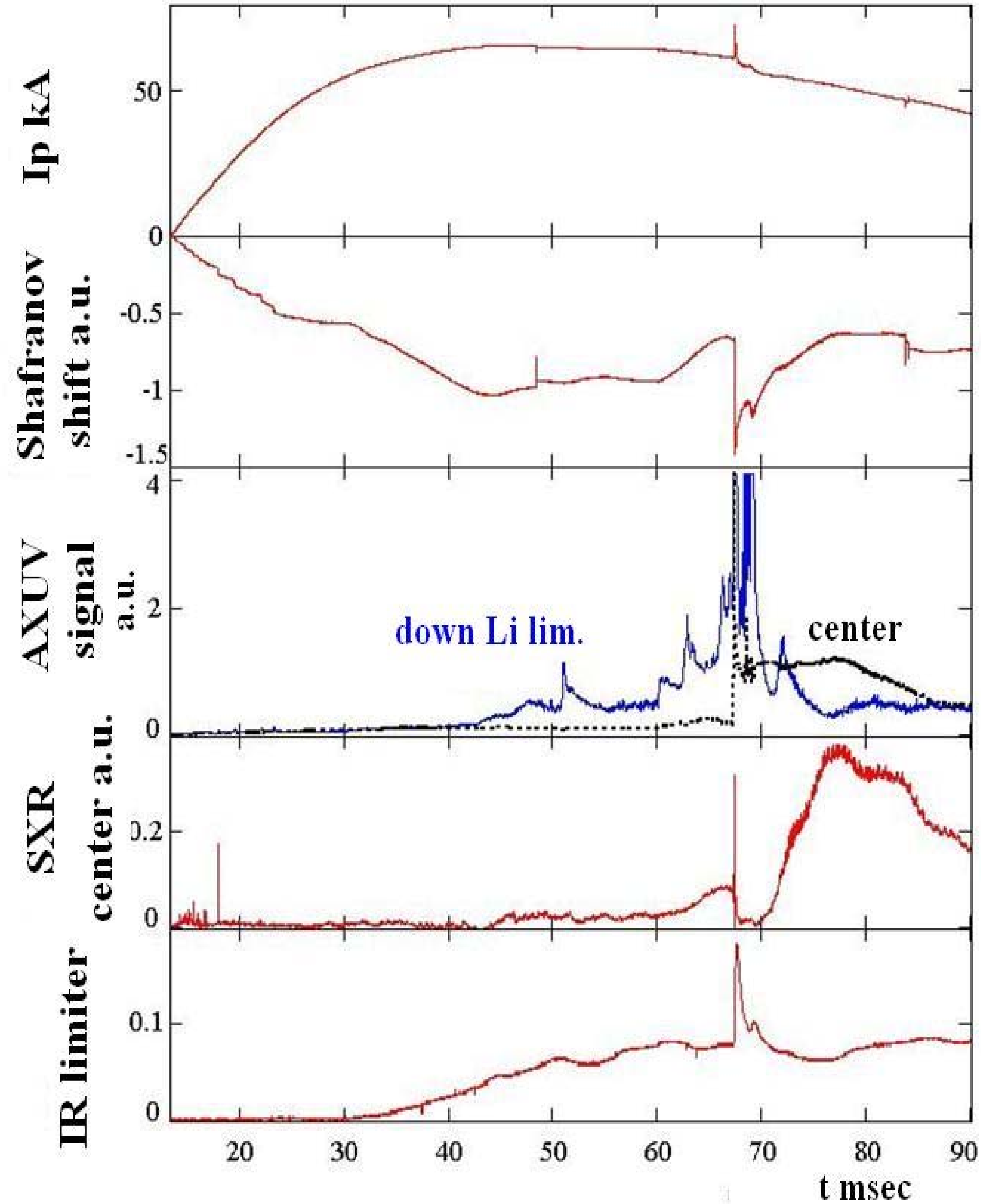
If the Li atom cost = 1500eV (Te=15-100eV),

$$5\times10^{8} = N\times2.4\times10^{-16}$$

$N\approx2\times10^{24}$ Li atoms ~ 23g of lithium

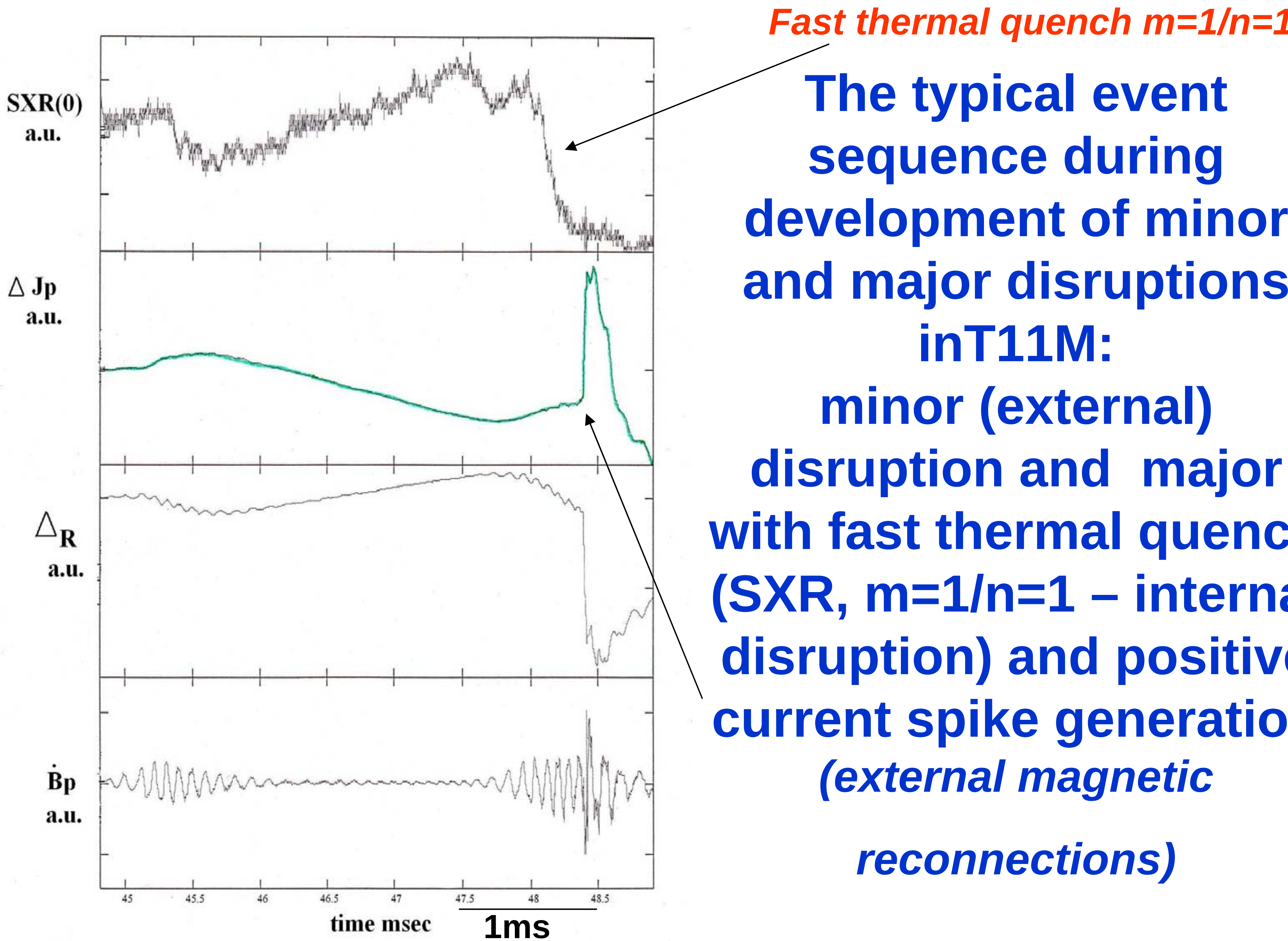
The total permitted amount of Li in ITER is 24kg. That is equivalent of 1000 permitted shots with use of Li pellets

Modeling of Li penetration into plasma center during major disruption in tokamak T-11M with lithium limiter



T-11M Tokamak 07/025m Ip=100kA with Li limiter

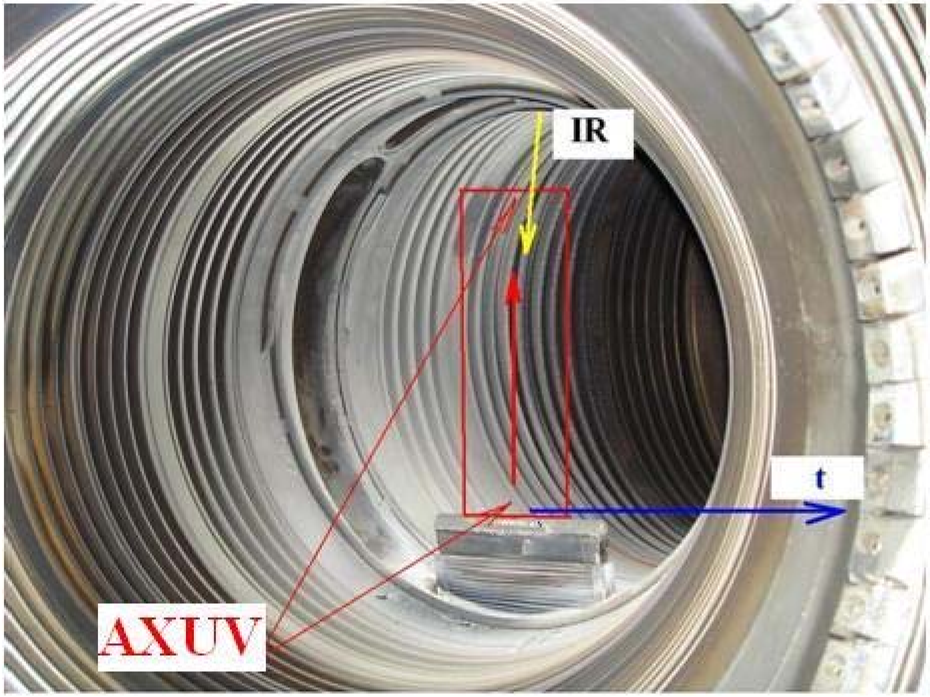
Typical disruption close density limit

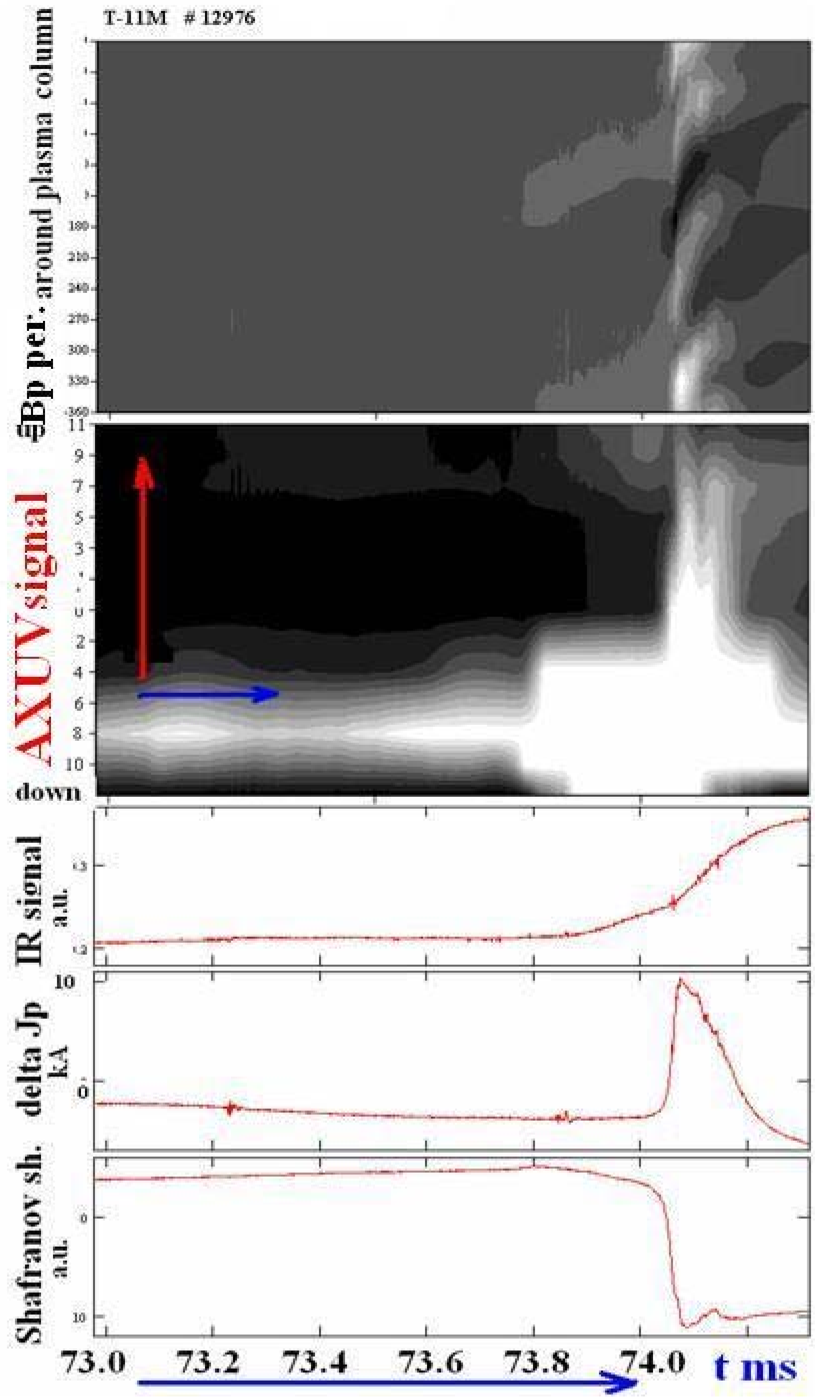


The typical event sequence during development of minor and major disruptions inT11M:
minor (external) disruption and major with fast thermal quench (SXR, m=1/n=1 – internal disruption) and positive current spike generation
(external magnetic

reconnections)

Lithium jump to the plasma center during major disruption

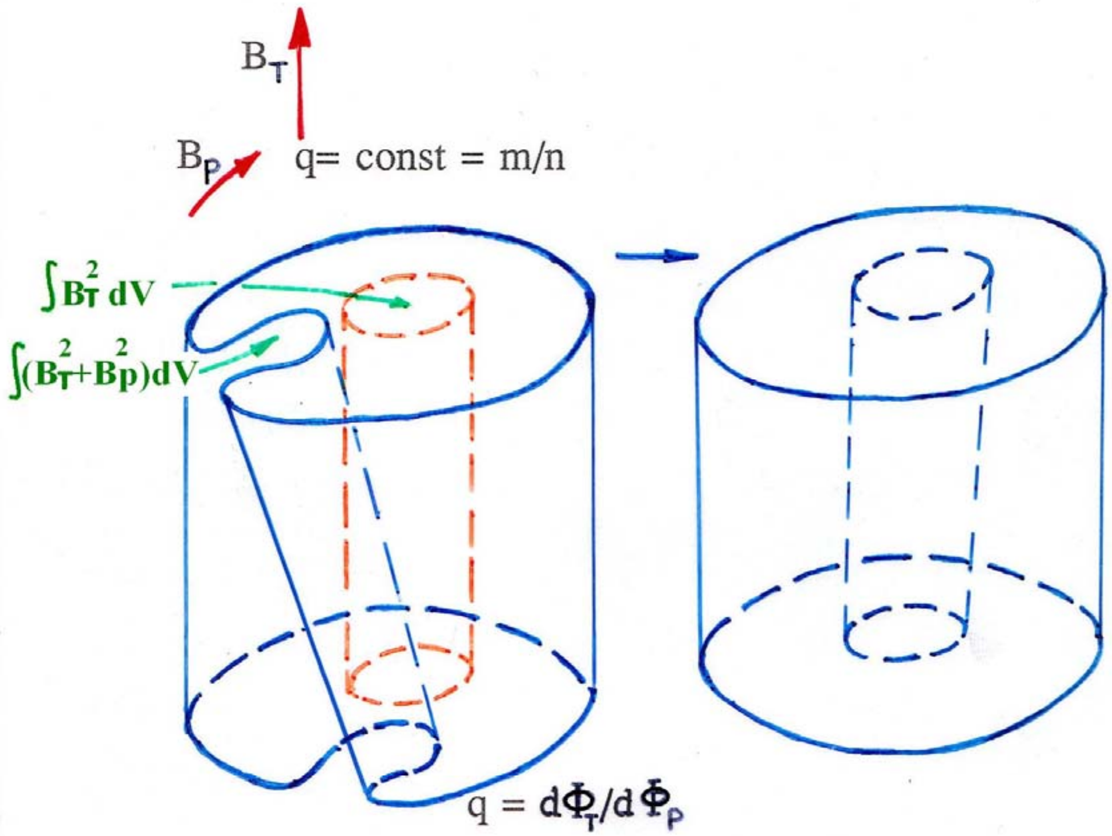


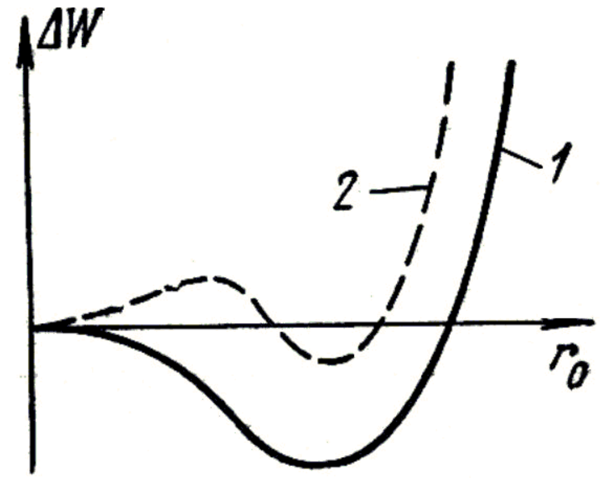


Li limiter in T-11M

Explanations of fast lithium convection

Vacuum bubble model (Kadomtsev-Pogutse 1973) [5,6]





Potential energy of babble as function of its radius. 1- dq/dr=0, 2 - dq/dr >0

(Kadomtsev B.B.,Pogutse O.P. J.Exp. &Theor. Phys. V65 1973 p.575)

Free motion of closed plasma tubes (q=m/n) can be real only when $\delta\Phi = \delta\Phi_p + \delta\Phi_T = 0$, but

$$\delta\Phi_p = 2\pi R\cdot B_p\cdot\delta r\cdot m\ ,\quad \delta\Phi_T = -\,2\pi r\cdot B_T\cdot\delta r\cdot n$$

$$2\pi R\cdot B_p\cdot\delta r\cdot m = 2\pi r\cdot B_T\cdot\delta r\cdot n$$

$$m/n = B_T\cdot r/B_p\cdot R \equiv q(r).$$

Electron runaway
(DINA calculation)

(V.E.Lukash, R.R.Khayrutdinov , Yu.A.Kareev, S.V.Mirnov “Modeling of Major Disruption Mitigation by Fast Injection of Massive Li Pellets in ITER Like Tokamak-reactor” FEC2010 THD/P2-01)

Runaway physical model.

In the simulations the energy balance equations for electrons and ions together with hydrogen and impurity ions density transport, and magnetic field diffusion equation are solved self consistently. For runaway electron current j_{run} simulation in DINA code an avalanche model of M.N.Rosenbluth and S.V.Putvinski ***(Nucl. Fusion 37 (1997) 1355)*** was used with a source S_{run} in form of Dreicer acceleration.

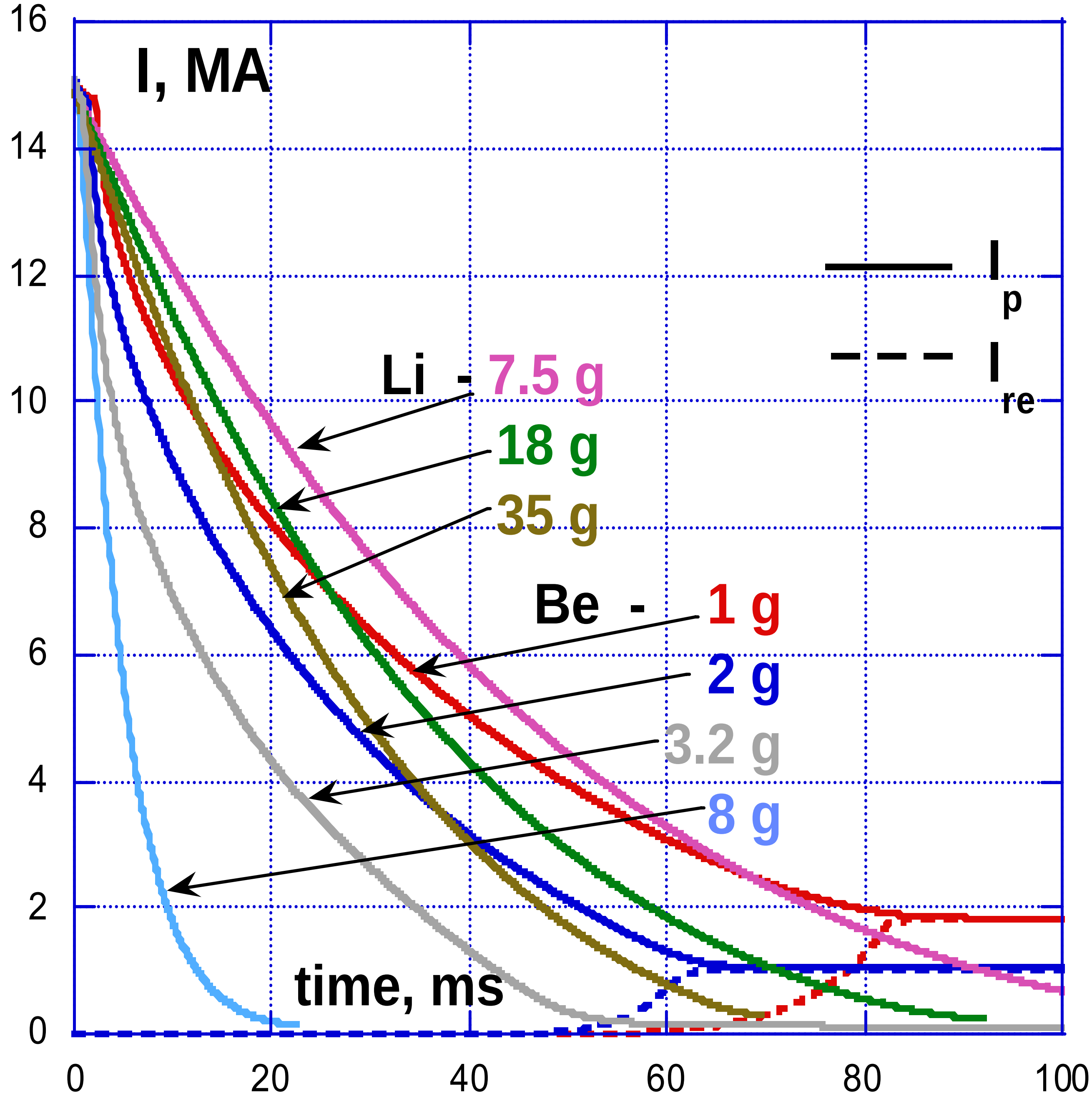
It is assumed that the runaway electrons are kept in each closed magnetic surface and due to plasma shrinking during limiter phase a part of runaway current contained in the scrapped plasma area can be lost on the first wall.

Impurity radiation model.

Model of dynamics of ionisation state of impurities was used for simulation of impurity ionisation states evolution. It has the same form for different types of impurities. The rate coefficients for ionization, recombination and charge exchange, taken from V.E. Zhogolev. 1992, ***(Preprint of Kurchatov Institute, IAE-5494)*** .

Radiation power for impurity represented as a sum of contribution from all ionisation states.

Effect of massive pellets injection



Ip decay during Be and Li injection with small hydrogen addition

(γ_{H0}=5e-3)

conclusions

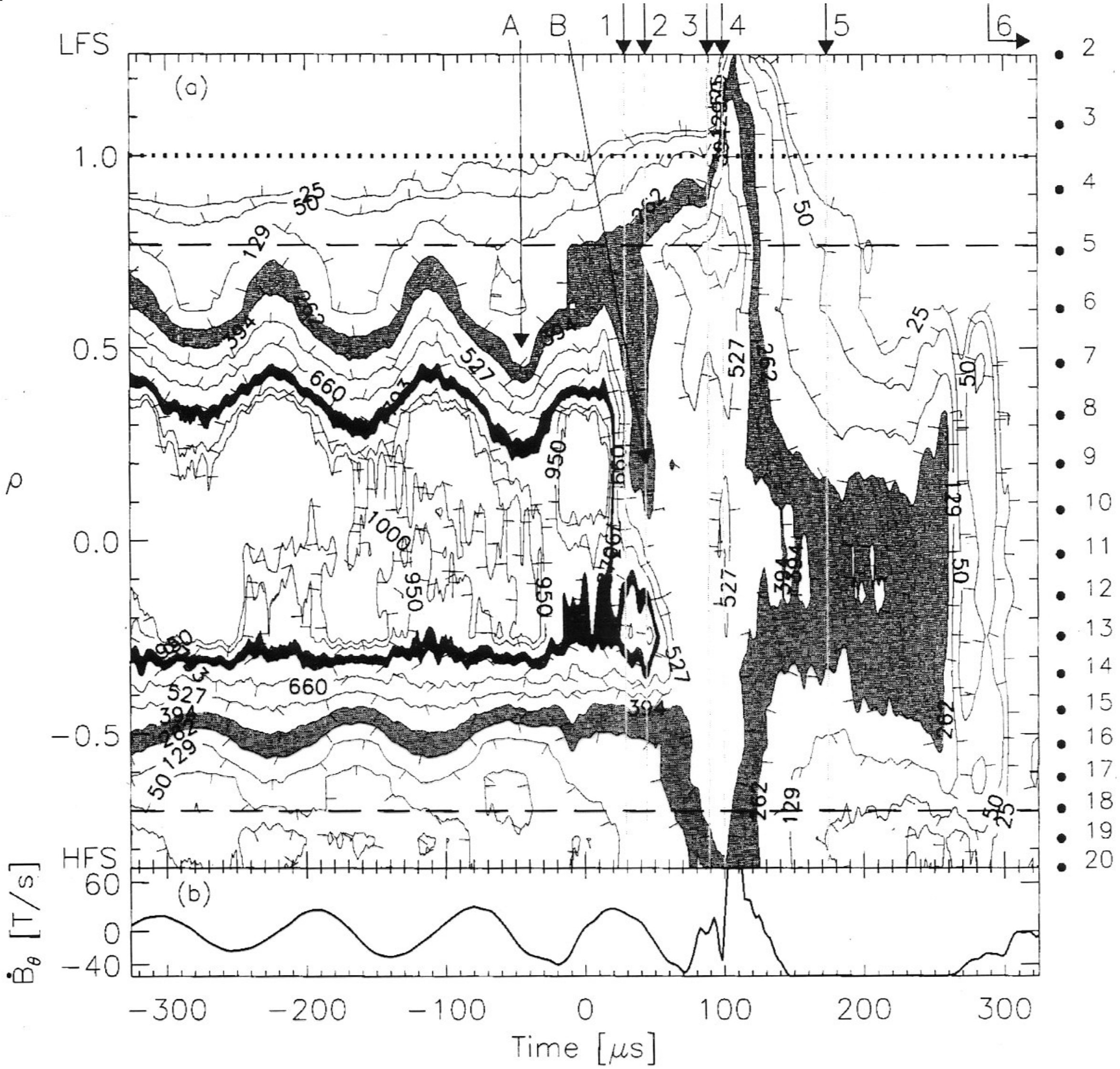
DINA numerical analysis of the high speed Li pellets injection during the fast thermal quench of major disruption in ITER-like plasmas shown that ~ 18g of Li is enough to radiate the thermal energy of ITER-like plasma and to shield the tokamak plasma facing components from the local high power loads.

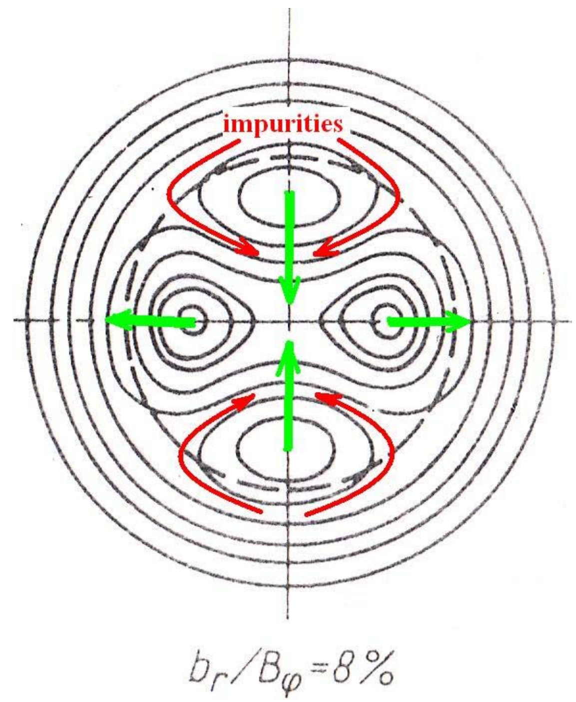
It was shown that in case of Be the counting of small hydrogen addition (n_{H0}) decreases drastically the electron temperature level during disruption and raises the probability of runaway electron generation.

Thank you for attention

Cold plasma (bubble?) penetration

(F. Salzedas, RTP, EC emission, 2001 28 EPS Conf.on CFPP)





(D.Robinson, K.MacGuire 1979)

Really should be:

b_r/B_p >(w/q) x (dq/dr)

(S.Mirnov 1998 [11])