Active mitigation system for protecting solid and/or liquid divertor PFCs from transient high heat flux events in fusion reactors

TECH 1003

NSTX-U

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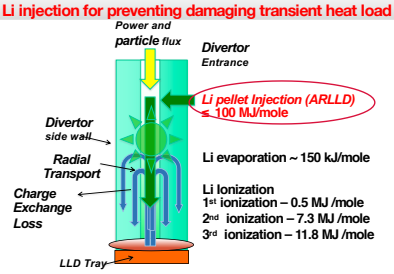
Abstract

- The transient heat flux could be as much as ~ 100 times the steady-state heat flux values which could for example damage the soild PFC surfaces.
- A solution we propose here is the timely injection of light impurities such as beryllium or lithium into divertor high heat flux region which would just balance the transient heat flux with appropriate radiative cooling leaving the actual divertor PFCs surface temperature unchanged.
- This active injection reduces the required amount of Li injection by a factor of x5 compared to the passive LM PFCs.
- A possible implementation technique using an inductive pellet injector with a rapid time response of a few msec is proposed here which can be tested on NSTX-U.

Radiative Cooling by Active impurity injection

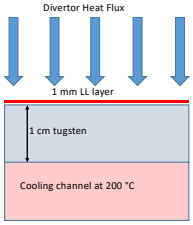
Active Li injection for preventing damaging transient heat load



M. Ono et al., RLLD – ISLA-2- NF 2013, ARLLD – ISLA-3 FE&D 2014

Active Li injection may also provide divertor plasma transport information

1-D Model of the Transient Divertor Heat Flux



- The base substrate is tungsten with 1 cm thickness with a cooling channel which is fixed at 200 °C.
- LL layer of 1 mm is added to simulate liquid Li divertor.
- Time dependent calculation with transient heat flux starting at t = 0 from the base steady-state heat load of 5 - 10 MW/m^2.

Transient heat flux:

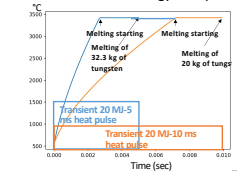
- 1% transient loss of 2 GJ fusion reactor plasma mean 20 MJ in ~ 5 - 10 msec.
- Results in 2 GW of power flux or ~ 1 GW/m^2 for ~ 2m^2 area.

M. Ono and R. Raman, Journal of Fusion Energy (2020)

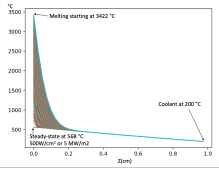
Solid tungsten divertor with Be injection

Transient Heat on Solid Tungsten PFC
20 MJ could melt ~ 20 kg of tungsten surface

Tungsten PFC surface temperature evolution with 20 MJ energy heat pulse



The evolving tungsten temperature profile as a function of depth Z.

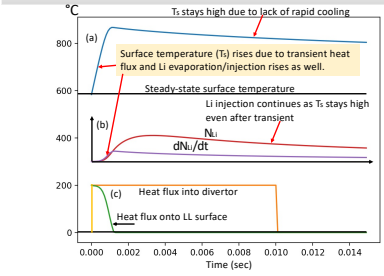


Melting clamps the tungsten surface temperature to 3422° C and cooling is a very slow process

Heat diffuses only ~ 3 mm depth So active cooling plays no role

Liquid Li divertor with Li injection

Passive Li radiation could protect divertor PFC from transient
However lack of rapid cooling causes excessive Li injection.

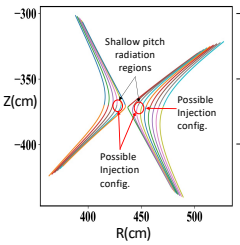


Active Injection Set-up and Injector

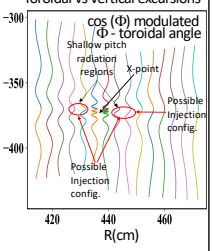
Active Injection in ITER-like Divertor

Shallow pitch regions near x-point looks suitable

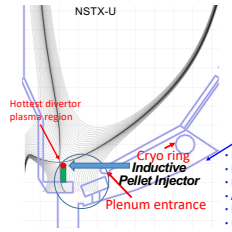
ITER-like Divertor flux surfaces

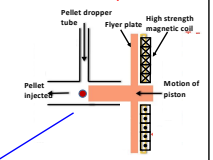


Toroidal vs vertical excursions



Injection location is highest divertor heat flux location
Inductive pellet injector can satisfy



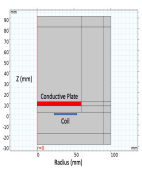


- Fast response time
- No high pressure gas involved
- No complicated vacuum seals
- A compact design possible
- No eroding parts
- Repetitive operations possible
- Double pancake design enables 0 net torque
- Can launch capsule such as TESPEL

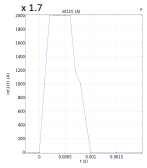
R. Raman, et al., IEEE Transactions on Plasma Science (2016)

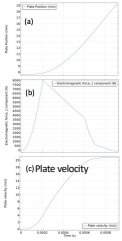
COMSOL Electromagnetic Simulation of Inductive Pellet Injector

Model Geometry



Coil Current Evoluation



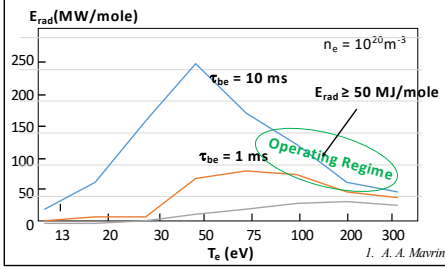


Up to 200 m/s would be possible with ~ 10x more current or 34 kA.

Non-coronal radiated energy per mole of injected Be

Possible radiative reactor divertor operating regimes

Be is 2.5 times more radiative than Li per mole



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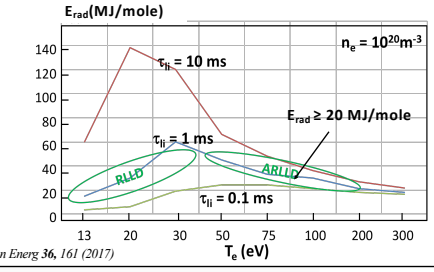
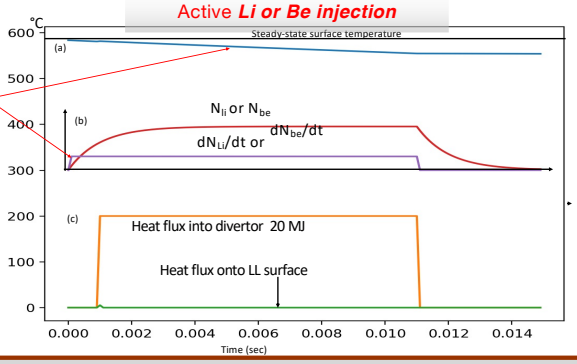


1. A. A. Mavrin, J Fusion Energ 36, 161 (2017)

Active *Li or Be injection*

PFC surface temperature can be kept low by active Li or Be injection to counter the transient heat pulse

20 MJ of transient power can be radiated by timely injection of 1 mole of Li or 0.4 mole of Be



Conclusions

- For next-step devices FNSF and DEMO, an acceptable divertor heat flux solution is needed for transient heat flux ~ x100 of SS heat flux
- Transient heat flux from ELM and other events could seriously damage divertor PFCs by melting ~ 20 kg of tungsten PFC surfaces.
- Solid tungsten PFC with Be injection and Liquid Li divertor PFC with Li injection investigated.
- Liquid Li divertor can prevent damage but may inject too much lithium due to lack of rapid cooling mechanism.
- Timely injection of light impurities such as Be and Li could reduce the transient heat flux. ~ 0.4 mole for Be and 1 mole for Li for 20 MJ heat pulse.
- Areas near the x-point would be a candidate location due to relatively low field line pitch for providing a “gap-less” radiative region.
- Injection from private flux could provide short paths for both outer and inner divertor strike points.
- Inductive Pellet Injector (IPI) with Li-D pellet could be a practical safe tool for a rapid response ~ few msec to the transient events.
- NSTX-U would be a good test bed for LL divertor research and ARLLD.