Assessment of beam-target interaction of IFMIF
A state of the art

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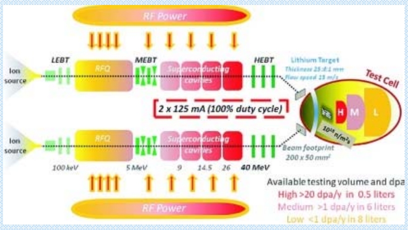
In the International Fusion Materials Irradiation Facility (IFMIF) two 40 MeV at 125 mA current deuteron beams will impinge on a liquid Li target, to generate a high energy neutron flux for the Test Cell.

The main requirement for an efficient and safe operation of the plant is the stability of the Li jet.
The stability is related to the thermo-hydraulic behaviour and can be affected by the beam–target interaction.

The thermo-hydraulic behaviour of the jet has been continuously studied in the last 30 years, theoretically and experimentally in consecutive different programs: FMIT, ESNIT, ISTC and IFMIF/EVEDA.

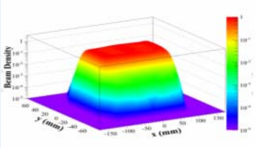
Concerns on the impact of the 10 MW beam power (1 GW/m² power density) and beam momentum transfer on the stability of the lithium screen are presented.



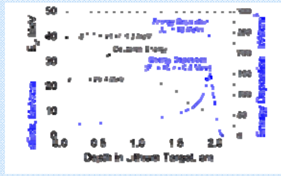
IFMIF scheme of main facilities: Linear Accelerator; Lithium Target; Test Cell

IFMIF beam characteristics

- 2 x 5 MW D^+ beams in CW (100% duty cycle) impinge the flowing Li screen with a beam footprint of 200 mm x 50 mm at an angle of ± 9º with a *flat-top* profile.
- Bragg's peak of D^+ at 40 MeV in Li is around 19 mm. All beam energy is absorbed at 21 mm.



Beam density



Beam energy deposition

Pressure effects

Wave pressures can appear in the flowing Li by:

1) Thermal gradients
   Maximum expansion velocity due to thermal effects occurs on the free surface at the center of the beams footprint and results of about **0.05 m/s,** with 40 MeV of energy and 25 A/m² of current density.
2) Beam momentum transfer
   The forces induced on the Li by the beam momentum transfer generate a pressure gradient and a velocity field:
   - The pressure field induced in beam direction, maximized cancelling the velocities, results

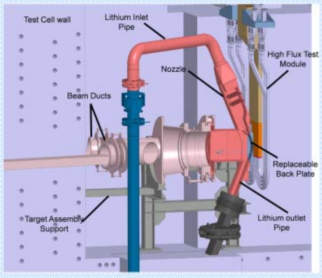
     $$P(x,y,z) = \frac{I(x,y)}{e}\sqrt{2m}\left(\sqrt{E_o} - \sqrt{E_z}\right)$$

     where E is the deuteron energy, *I(x,y)* the current density, *e* the unit of charge and *m* the deuteron mass; and give a maximum value of **32 Pa**, which would be damped by the about 9 kPa of centrifugal pressure at 19 mm depth.
   - The maximum velocity in beam direction, neglecting transversal components and cancelling the pressure, results

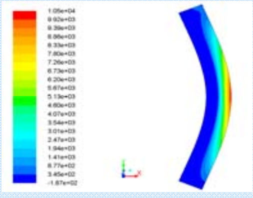
     $$v_z = \sqrt{2\frac{I}{\rho e}\sqrt{2m}\left(\sqrt{E_o} - \sqrt{E_z}\right)}$$ and yield a value of **0.5 m/s**.

IFMIF target characteristics

- Two step nozzle with a reduction rate 10:2.5:1 to obtain a stable Li flow with a velocity of 15 m/s in a concave channel open to the beam vacuum chamber.



Lithium Target section

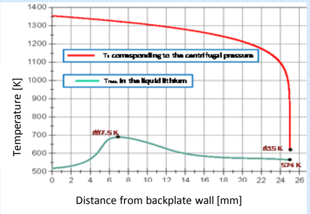


Pressure profile along the channel [Pa]

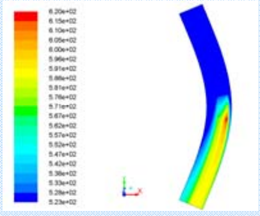
- Channel curvature radius gradually decreasing from nozzle exit (6 m) to beam center (0.25 m)
- Li jet width 260 mm and thickness 25 mm
- Jet thickness variation accepted +/- 1 mm

Thermal effects

- Flowing Li is exposed to beam during 3.3 ms . The temperature rises in downstream direction reaching maximum at lower edge of the beam footprint.
- Centrifugal pressure (~kPa) raises saturation temperature in the bulk of the liquid preventing nucleation.



T_{max} and T_{sat} at beam footprint lower edge



Temperature profile along the channel [K]

- The 15 m/s speed evacuates the heat preventing heating of the backwall and guarantee a margin bigger of **41 K** at operational target pressure of 10^{-3} Pa.

Experimental validation

RIA project (Argonne Lab.) carried out experimental validation of 1 MeV e-beam interacting with cross-flowing Li. Power densities were modulated up to 25.4 GW/m² and flowing speeds up to 6 m/s with no instabilities. Positive ΔP were observed in Li free surface during beam operation due to ion induced gas desorption.

Conclusions

Analysis performed and experiments available show that the 1GW/m² beam power density will not induce instabilities in the flowing Li screen of IFMIF.

- The maximum theoretical transversal velocities due to thermal expansion of the jet (0,05 m/s) and to momentum beam transfer (0,5 m/s) are of some order of magnitude lower than the average jet velocity (15 m/s), the jet thickness variation induced in the foot print area will be lower of the tolerance accepted (+/- 1 mm).
- The maximum theoretical pressure gradients due to momentum beam transfer (32 Pa) are of some order of magnitude lower than centrifugal pressures of ~kPa, constructive interferences are not expected.