Target choice for SARAF TNS (Thermal Neutron Source)

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on behalf of SARAF team

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INFN Laboratori Nazionali di Legnaro

Talk Layout

- System requirements for the Thermal Neutron Source (TNS) at Soreq Applied Research Accelerator Facility (SARAF)
- Review of technologies for the neutron converter
- Recent results with a liquid lithium neutron converter

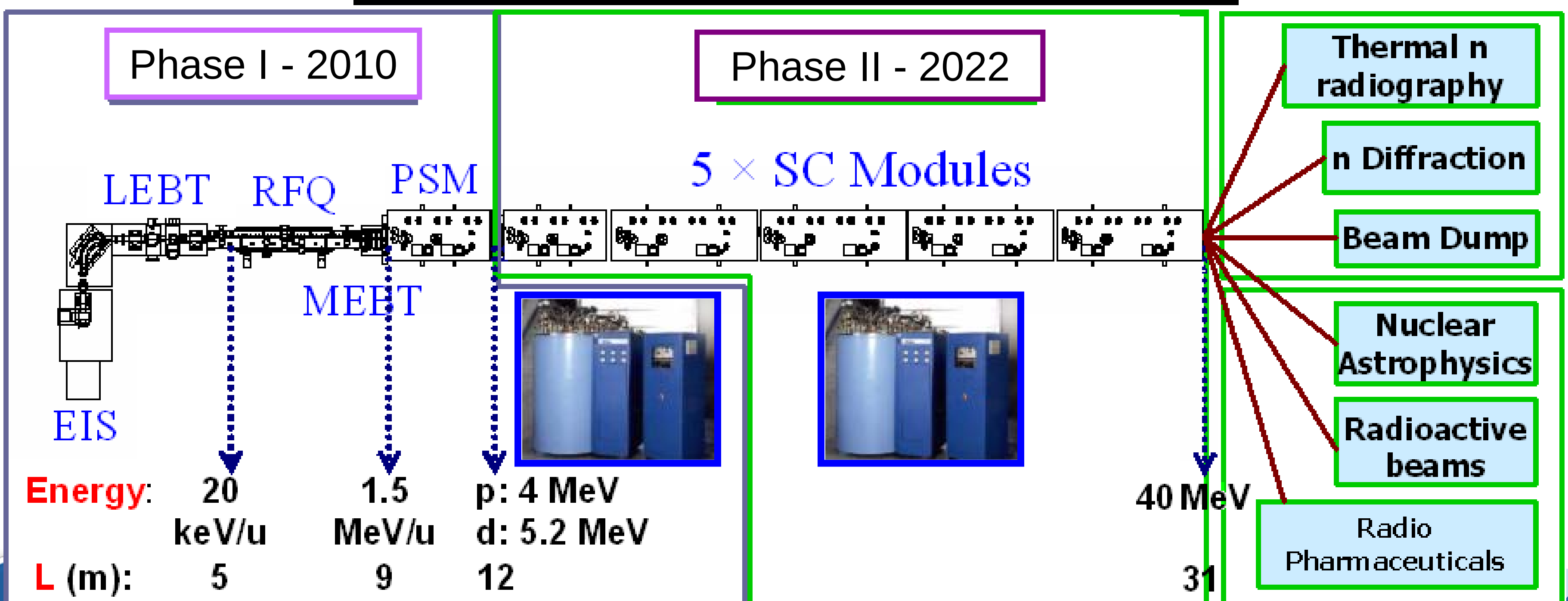
Background

- Soreq nuclear reactor (IRR-1) is in operation since 1961

- It provides:
    - Neutron radiography
    - Neutron diffraction
    - Samples irradiation
- Soreq infrastructure should be modernized to support experimental nuclear physics research in Israel

SARAF Accelerator Complex

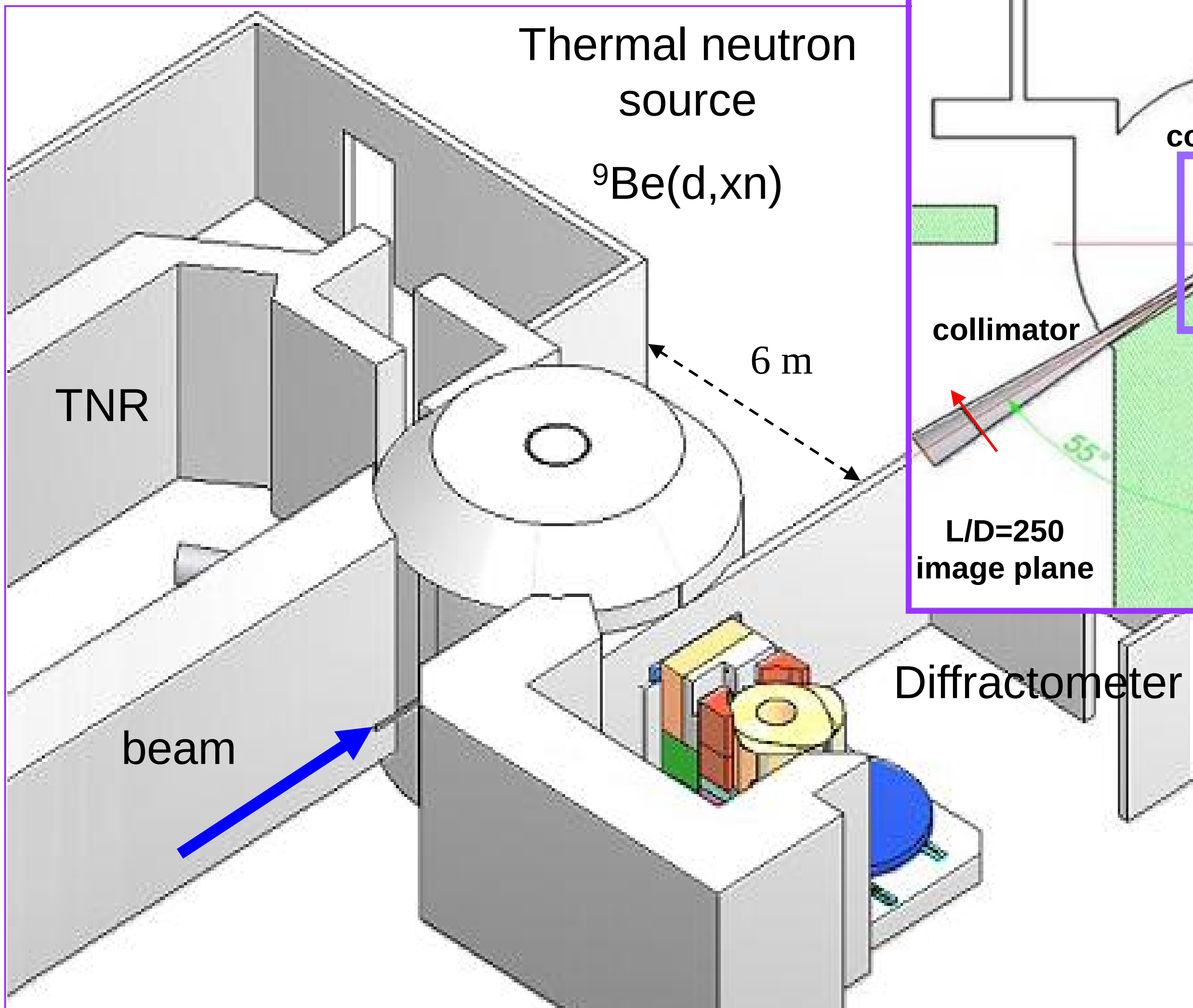
Parameter	Value	Comment
Ion Species	Protons/Deuterons	M/q ≤ 2
Energy Range	5 – 40 MeV	Variable energy
Current Range	0.04 – 5 mA	CW (and pulsed)
Operation	6000 hours/year	
Reliability	90%	
Maintenance	Hands-On	Very low beam loss

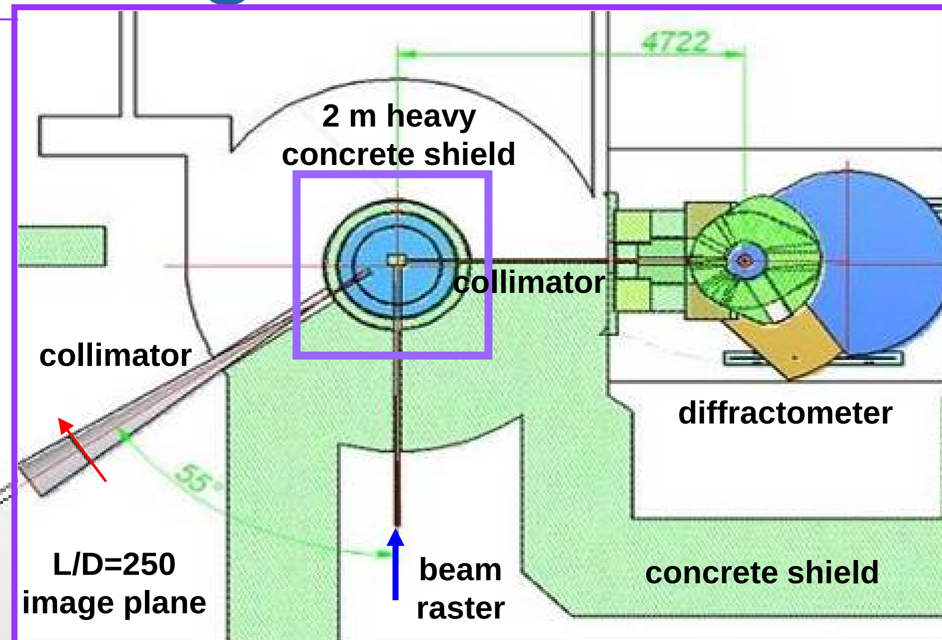


IRR-1 radiography facility capabilities

#	Capability	Requirement for SARAF TNS
1	Neutron flux on image plane $6x10^5$ n/(s*cm^2)	High intensity neutron generator
2	Resolution – L/D > 250	System geometry
3	Cadmium ratio > 15	Effective neutron thermalization
4	Neutron flux homogeneity, better than 3% cm^2	Small neutron opening from source to radiography system, high neutron density in thermalization system
5	Gamma dose < 300 mR/hr	Effective gamma shielding

Preliminary system design





Available technologies for neutron converter design

Target design	Carbon	Beryllium	Lithium
Static	SPIRAL-I	LENS, SPES	Birmingham BNCT, BINP
Rotating	FRIB, SPIRAL-II	ESS-BILBAO	?
Liquid	X	X	IFMIF, LiLiT

Target design	Advantages	Drawbacks
Static	Simple	High heat flux, Radiation damage, Large neutron source
Rotating	Low thermal stress, Low radiation damage density	Complex mechanism, Reduced neutron conversion efficiency
Liquid	Low thermal stress, Low radiation damage Small neutron source	Complex system, Only for lithium

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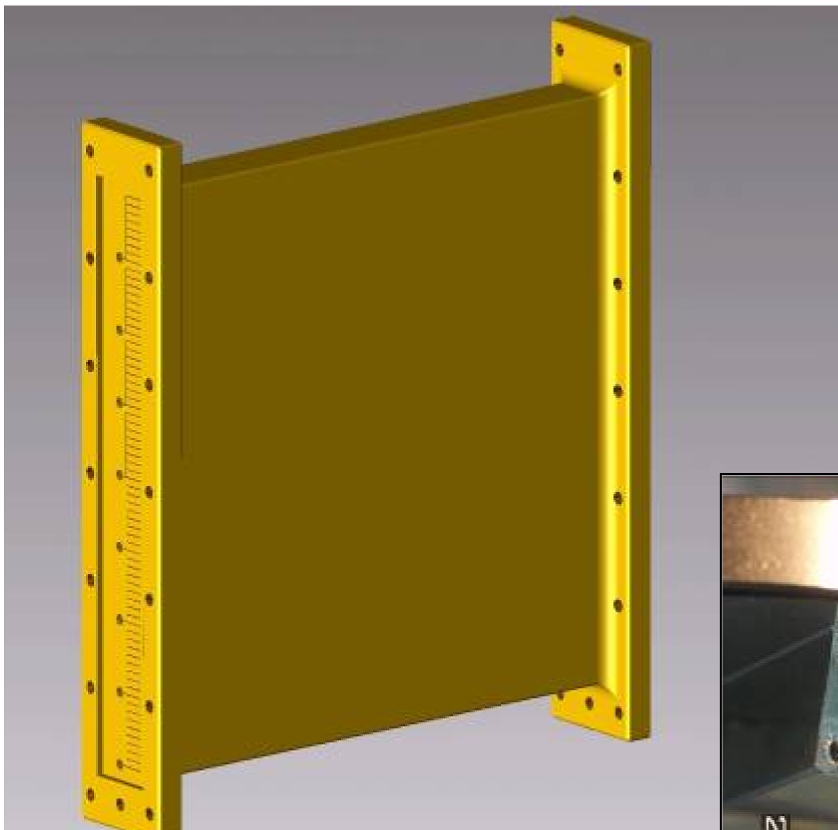
2005 DESIGN CHOICE

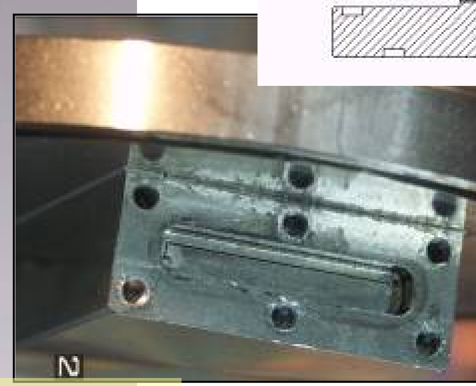
Target fail modes review – R&D risks

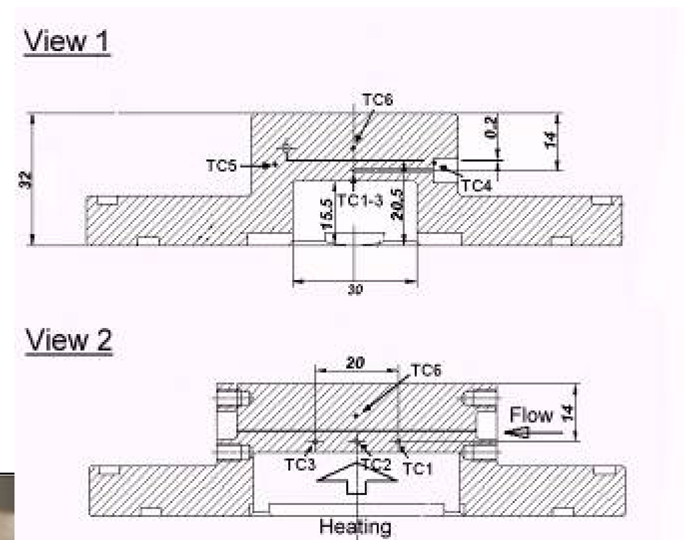
- Short term fail modes
  - Target cooling
  - Mechanical loads
- Medium\ Long term fail modes
  - Radiation damage – limited knowledge, difficult to evaluate
  - Mechanical reliability
  - Radiation safety

Micro-channels cooling of a solid target

Proposed 80 kW micro-channels cooled neutron source (size 100x100 mm^2) and prototype test section (channel width 0.2 mm, made of Aluminum)

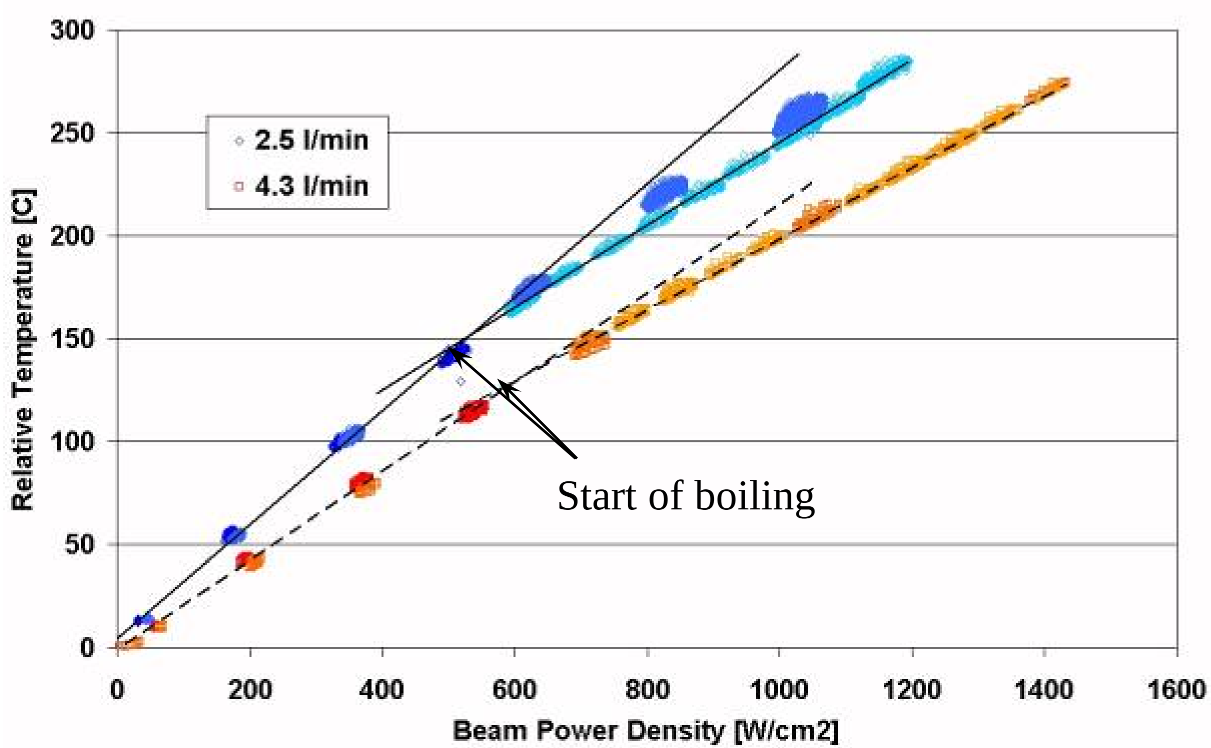






H. Hirshfeld *et al.*, NIM A 562(2006)903-905

Micro-channels cooling – experimental results



Measured wall temperature above coolant temperature as function of heating power flux for two flow rate. Distinctive change in heat transfer capability can be noticed at power flux of about 600 W/cm^2. Stable operation has been achieved for heating power of up to 1400 W/cm^2

Radiation damage from high current low energy proton beam

- Irradiation of solid targets cause fast accumulation of hydrogen gas at traps close to the targets surface (depth < 100 μm)
- Unless released or chemically locked, the gas bubbles may fracture the target

SARAF phase-I Tungsten beam dump after irradiation by ~10 mA*hr protons at 2-3 MeV

Radiation damage in Be thick targets

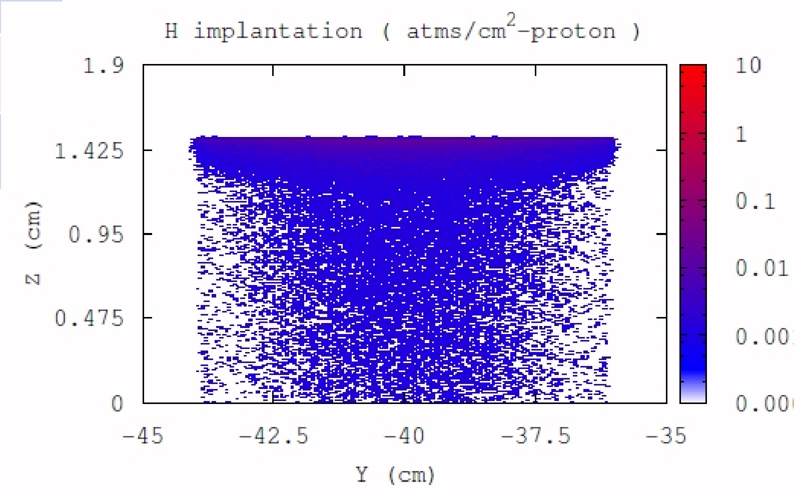
Design studies for ESS-BILBAO neutronic applications laboratory

ESS-BILBAO Target Group

Life time estimation regarding gas implantation

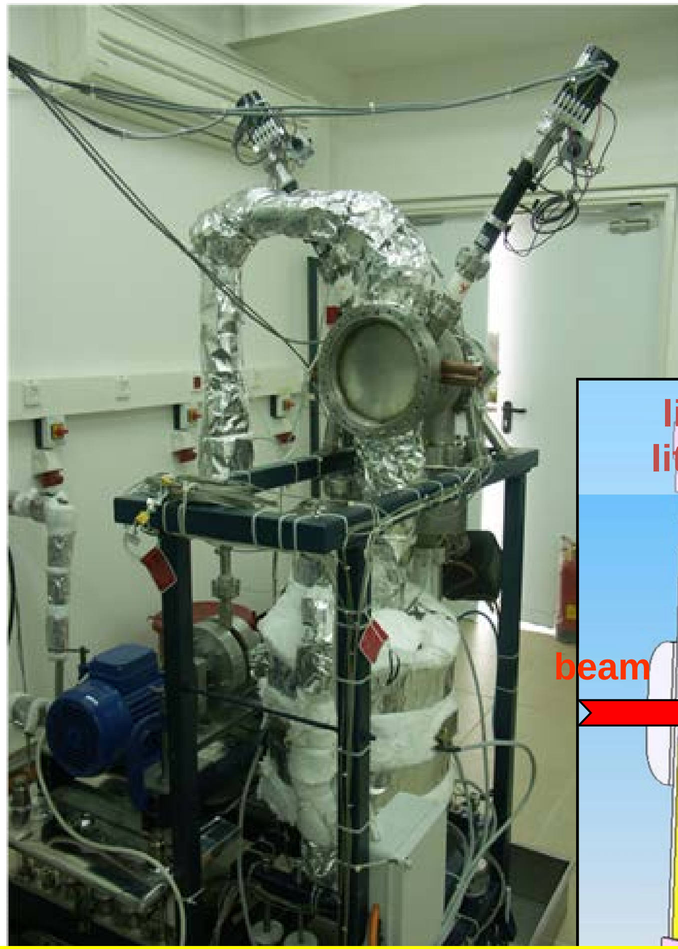
	LENS	ESS-B	ESS-B rot
Avg. Intensity [mA]	0.62	2.25	
Operation time [hr]	156	171	3420
Implantation [a/cm^3]	18	4.5	

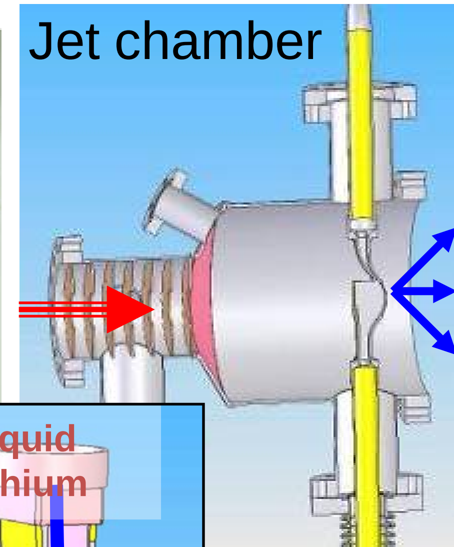
50 MeV p beam

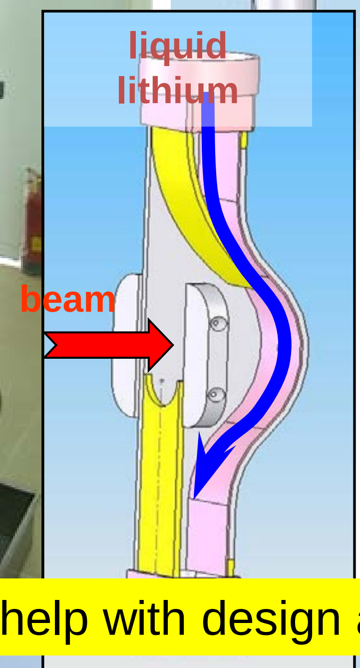


Liquid Lithium Target - LiLiT

- Proton energy: ~2 MeV
- Proton current: <3.5 mA
- $T \approx 220^{0}C$
- $T_{max} \approx 350^{0}C$
  - Jet: 18 mm x 1.5 mm
  - Lithium velocity: 20 m/s
  - Wall assisted lithium jet
- Operating at SARAF since 10/2013



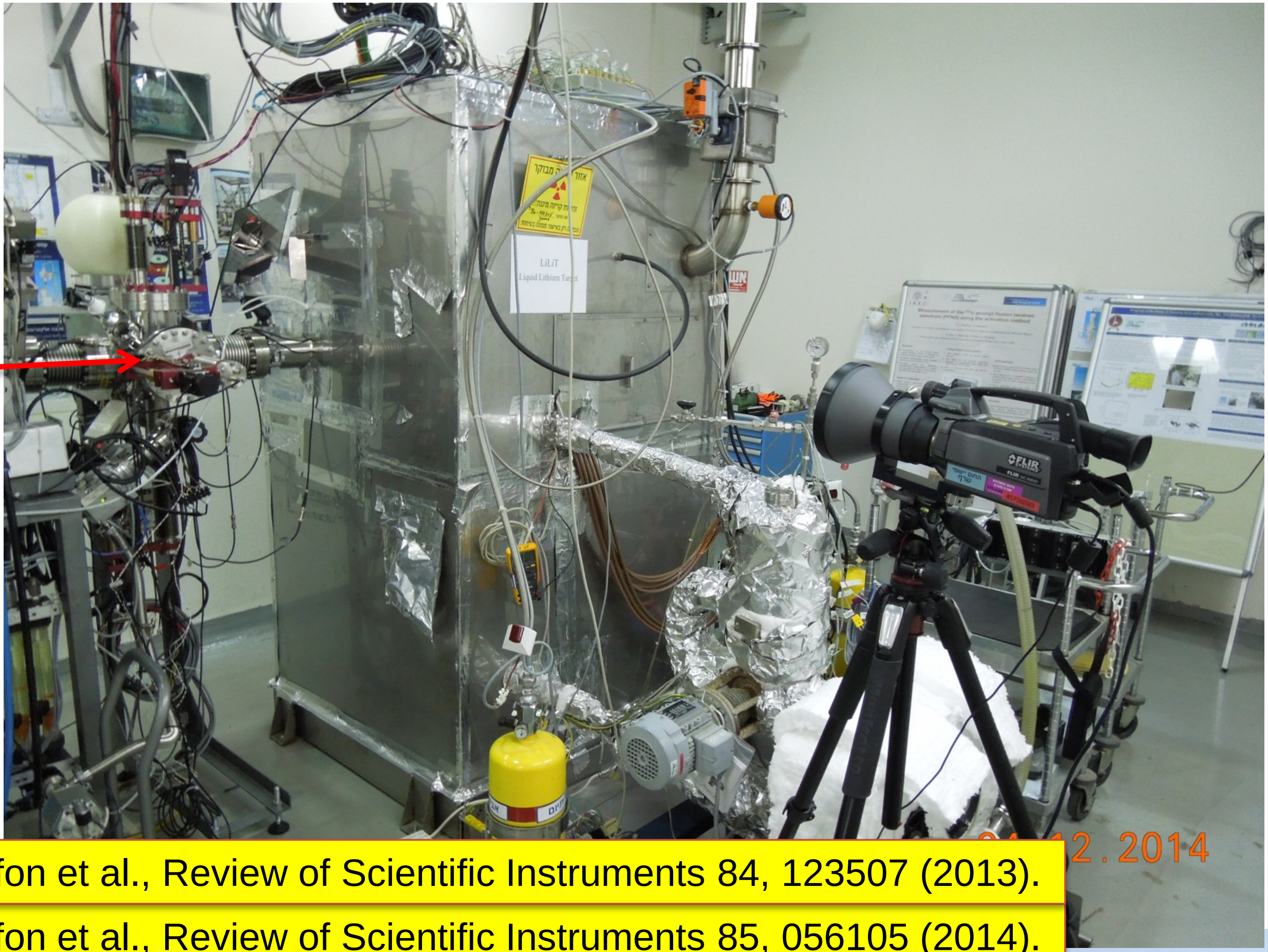




Thanks for J. Nolen, C. Reed & Y. Momozaki for the help with design and training

LiLiT installation at SARAF

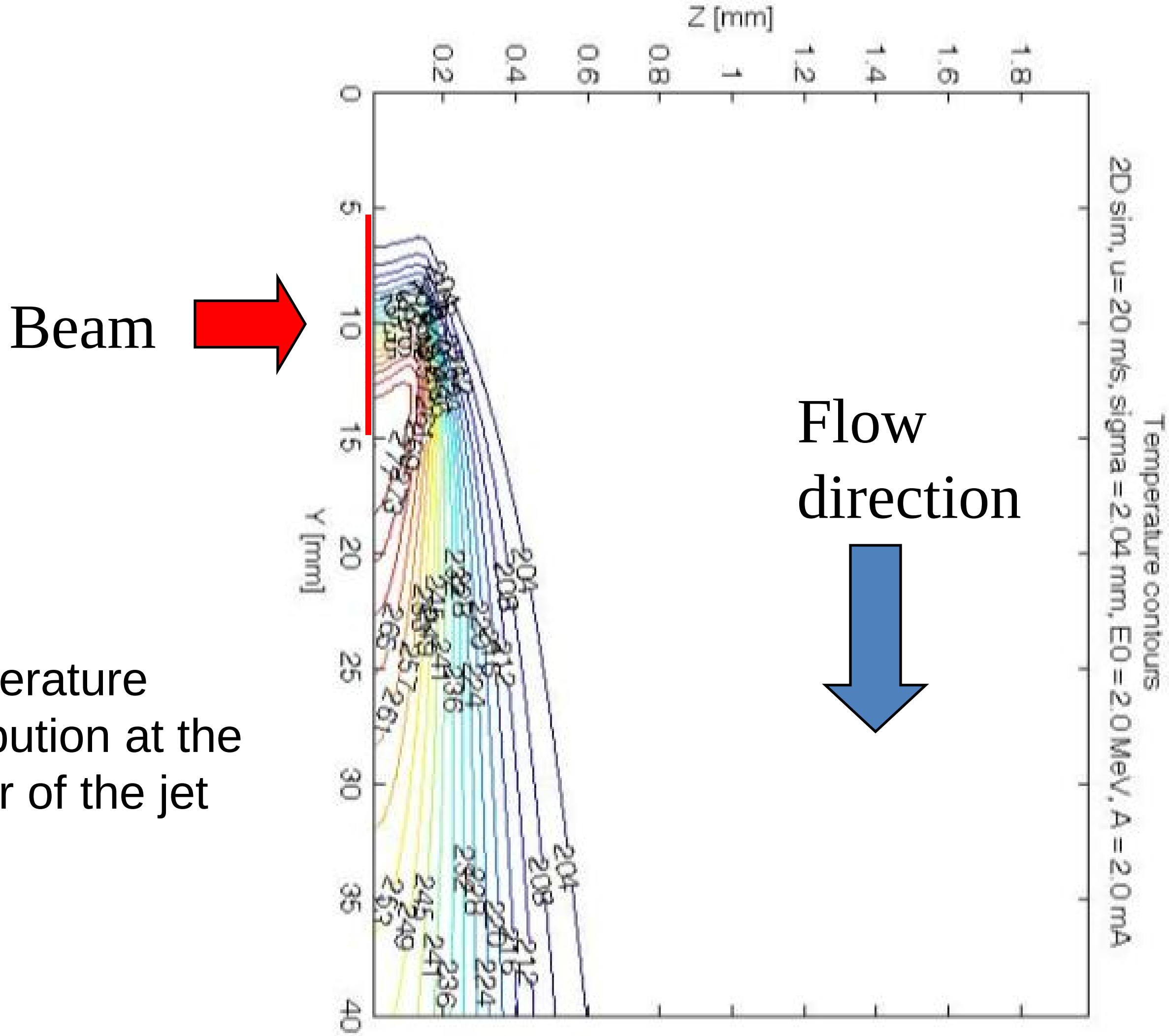
Beam



S. Halfon et al., Review of Scientific Instruments 84, 123507 (2013).

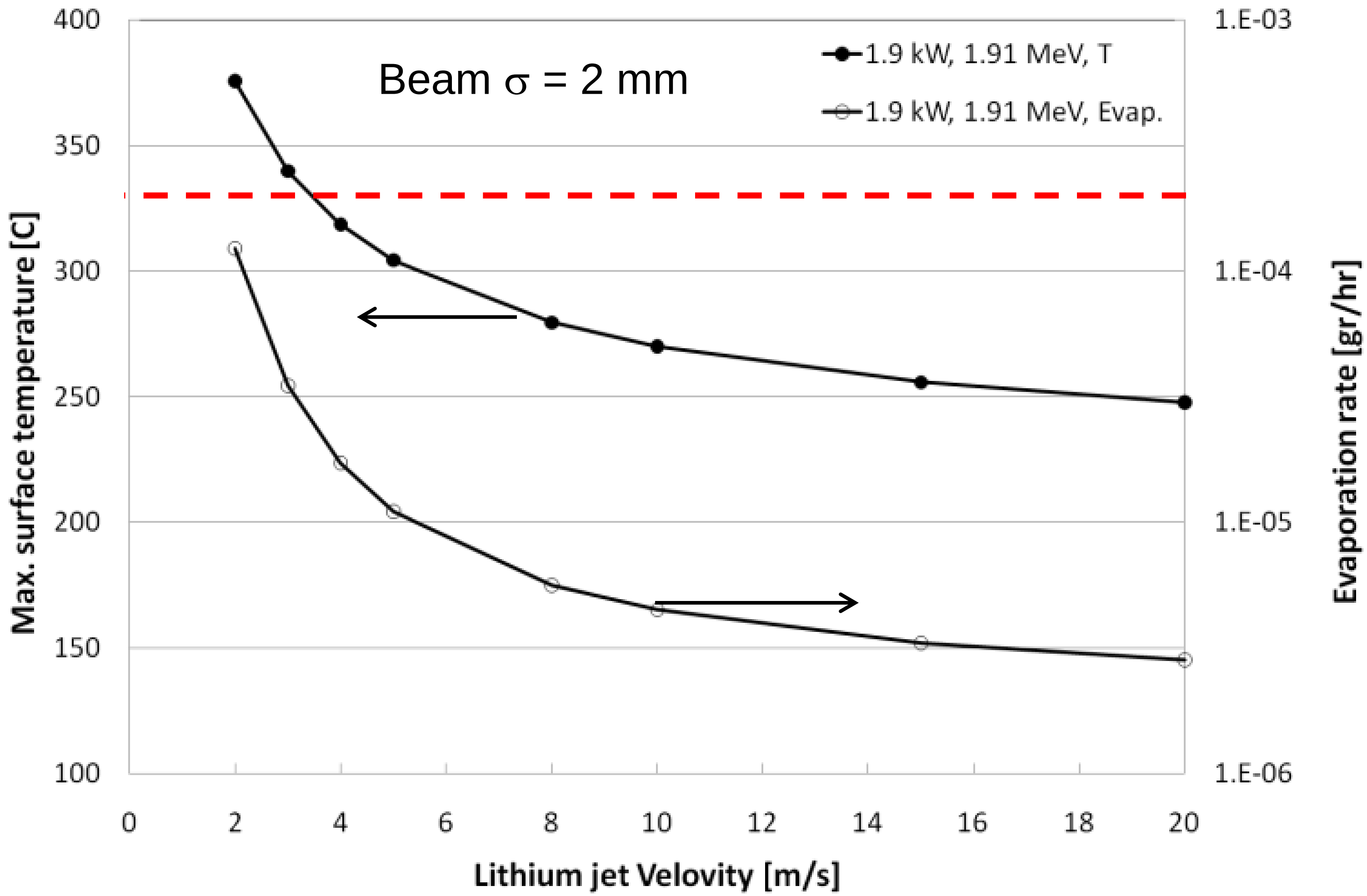
S. Halfon et al., Review of Scientific Instruments 85, 056105 (2014).

LiLiT thermal model



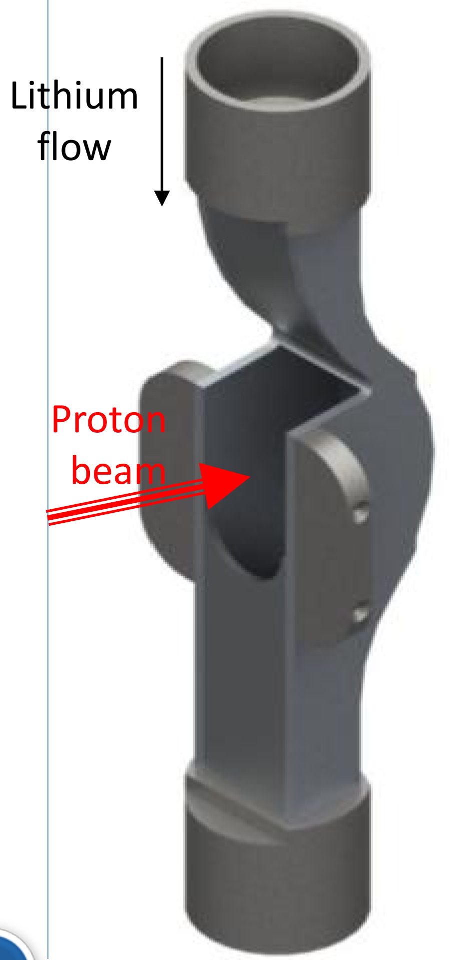
Temperature distribution at the center of the jet

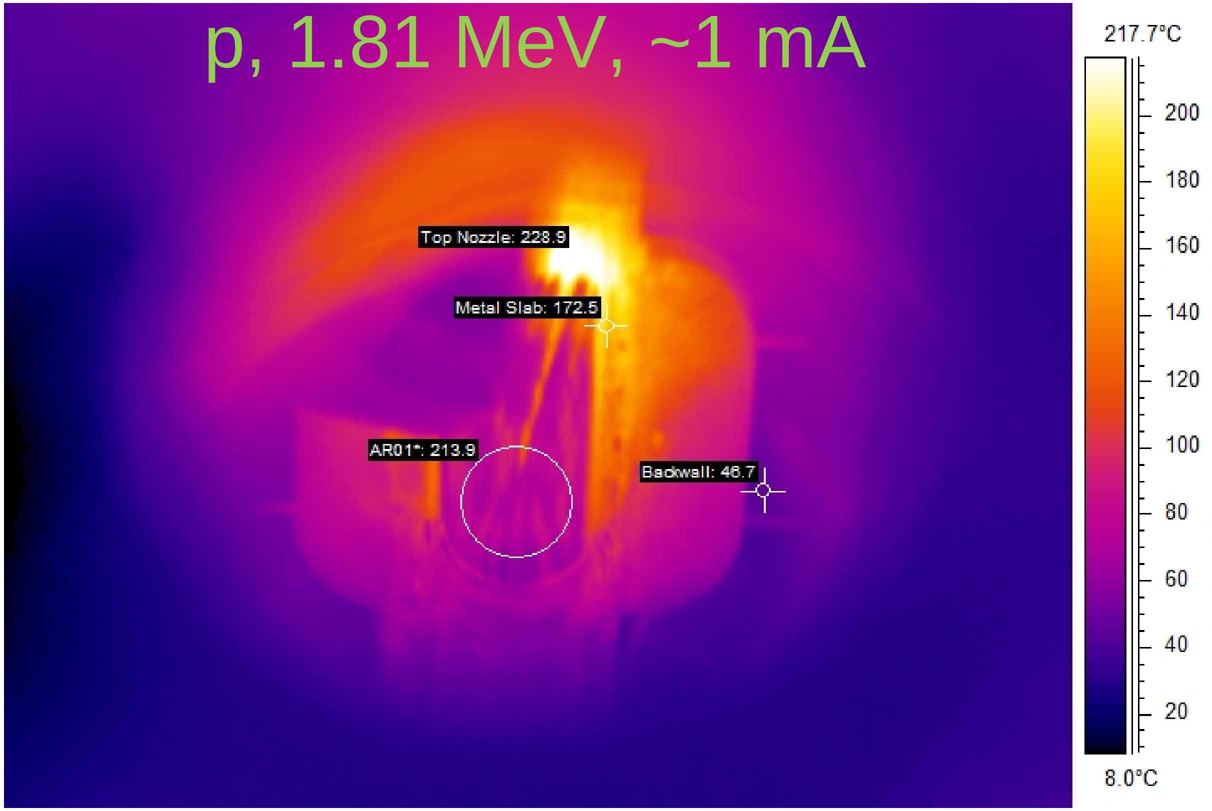
Jet velocity effect



S. Halfon et al., AIP Conference Proceedings 1525, 511-515 (2014).

Liquid Lithium free surface proton irradiation

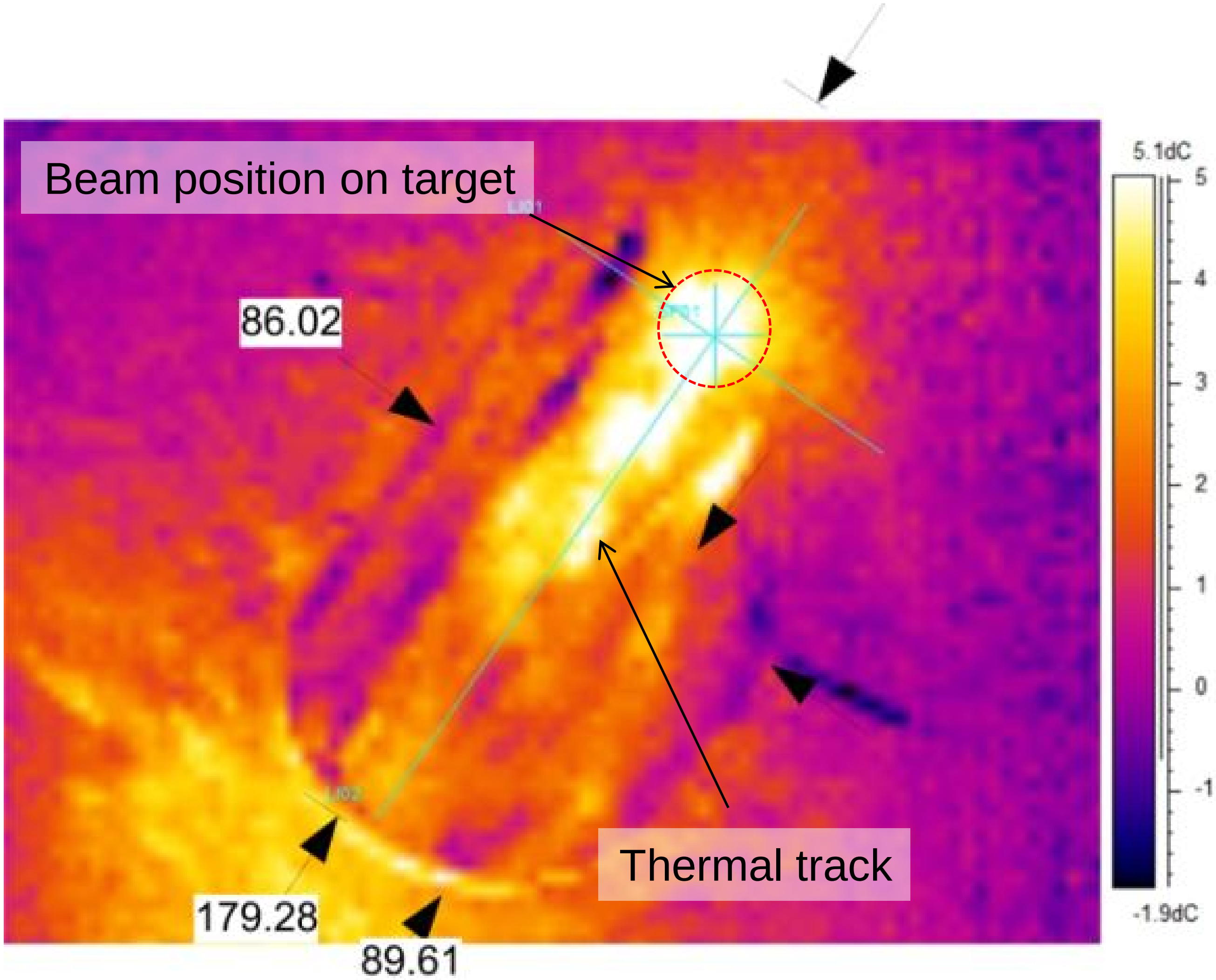




Emissivity - $\varepsilon_{Li} = 0.05$

$\varepsilon_{SS} = 0.4\text{-}0.6$

Measured lithium temperature



1.5 mA Protons beam at 1.92 MeV Beam power ~3 kW
Beam size, σ=2.5 mm

Calculated heat-up 200^{o}C

Measured ~ 50^{o}C

Summary

- Design choices for TNS has been reviewed based on:
  - Short and long term failure modes
  - System requirements
  - R&D risk analysis
- SARAF TNS design is considering changing from a static beryllium target to a liquid lithium target