Liquid Metal Technology for High Power Targets

FAIR Community meeting

26th January 2006

Mike Fitton
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Introduction

- Design outline of liquid lithium production target for Super-FRS at FAIR
- Design considerations
- Current projects exploring liquid metal technology
- Properties of liquid metals
- Proposed future work

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Design outline for Super-FRS production Liquid Metal Target

Beam parameters

- Up to 10^{12} - ^{238}U ions per pulse at 1GeV/u
- Pulse length = 50ns

Problem

- High Instantaneous power deposited in fast extracted beams (equivalent to 200 GW)
- Target could be destroyed by single pulse

Possible Solution

- Windowless
- Liquid lithium target

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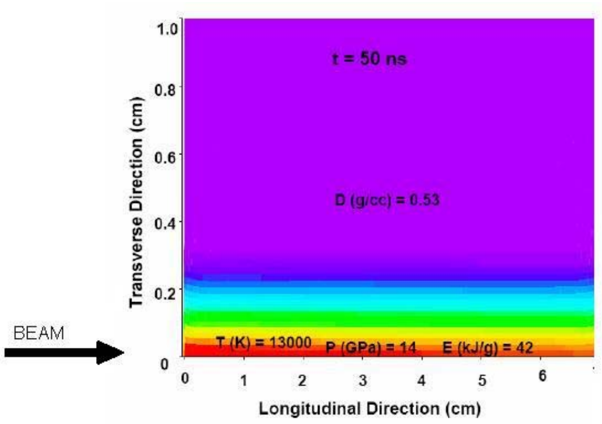
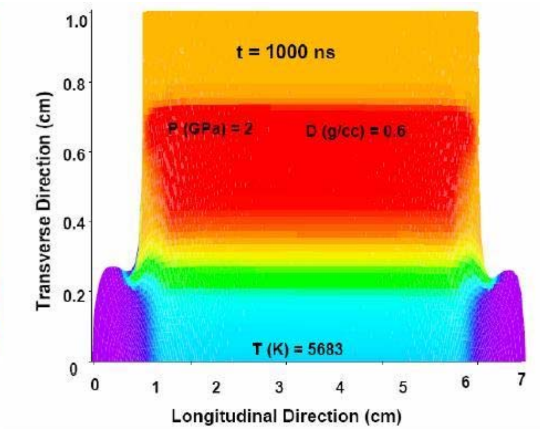
Initial Calculations for fast extraction

Using BIG-2 (2D hydrodynamics code)

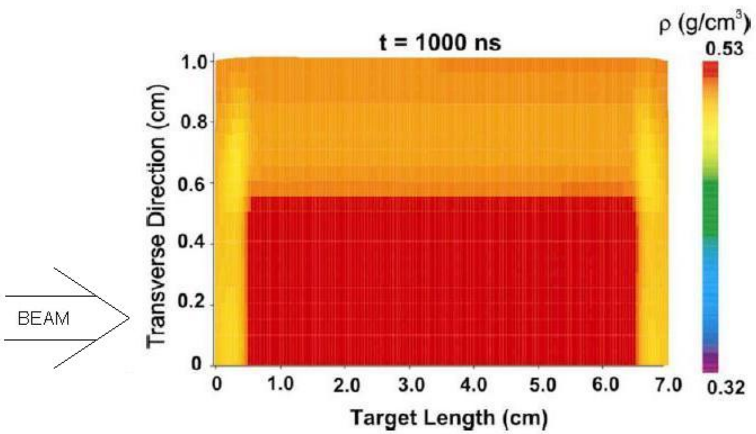
Beam spot size $\sigma_x = \sigma_y$ =1mm (highest power density case)





- Max Temp = 13,000K
- Max Pressure = 14GPa
- Velocity = 10km/s !!
- Explosive dispersal

Enlarged beam spot – 48mm^2



- Only small change to density
- Flow should not be destroyed
- Surface may splash but cannot confirm with this model

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Why Liquid lithium

- **Low atomic mass → Target/nuclear considerations**
- **Low density and viscosity → Easy to pump**
- **Good working Temperature range – 1161°**
  Melting point (181°C)
  Boiling point (1342°C)
- **Low vapour pressure (10^{-7}Pa at 200°C)**
- **Low Prandtl Number → good heat transfer**
- **High heat capacity (4.4 kJ/kg K)**

$$\Pr = \frac{C_p \cdot \mu}{k}$$

Considerations for liquid metal targets

- Shock waves and dispersal of jet
- Obtaining reliable material properties and equation of state (EOS)
- Corrosion and erosion caused by liquid metals
- Purification and Chemical control
- Safety (Radiological & Chemical)

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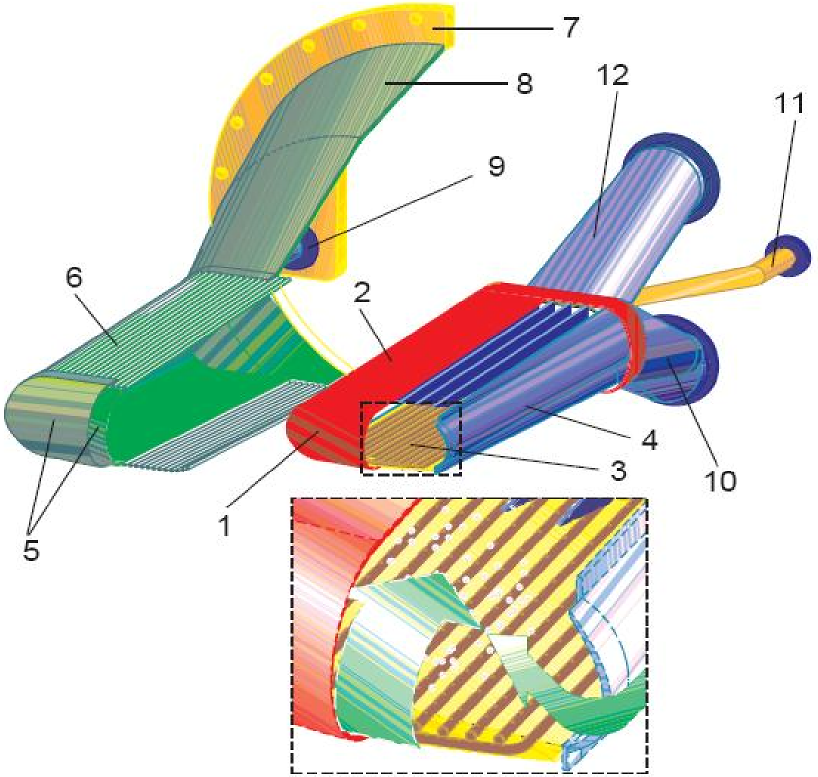
Parameters of Target utilising Liquid Metals

	Target Material	Beam	Peak power density (J/cc/pulse) Average power deposited	Pulse length
GSI/Fair	Li	Heavy ions	30,000 (0.012 MW)	5×10^{-9} s
Nufact target	Hg	8 -50 GeV Protons	300 (0.4 MW)	Few $\times 10^{-9}$ s
ESS	Hg	1.3 GeV Protons	20 (2.8 MW)	1.4×10^{-6} s
SNS	Hg	1 GeV Protons	13 ? (1.4 MW)	0.7×10^{-6} s
RIA	Li	400 MeV Uranium ions	4 MW/cm^3 (0.12 MW)	CW
IFMIF	Li	40 MeV D^+	0.1 MW/cm^3 (10 MW)	CW

ESS – European Spallation Source



1: target beam window
2: *target shell*
3: *lower flow guide with He-injector system*
4: *side baffle plate*
5: *return hull beam window, double shell*
6: *return hull shell with cooling system*
7: *target unit main flange*
8: *return hull connector part*
9: *return hull coolant supply*
10: *Hg-inlet transition manifold*
11: *He-supply*
12: *Hg-He-mixture outlet*

ESS Technical report – Volume III, chapter 4

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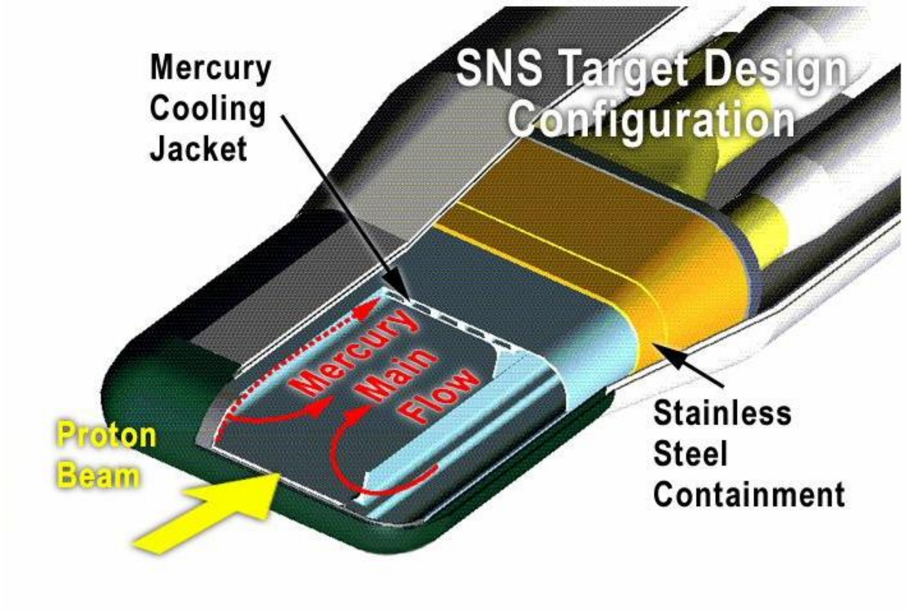
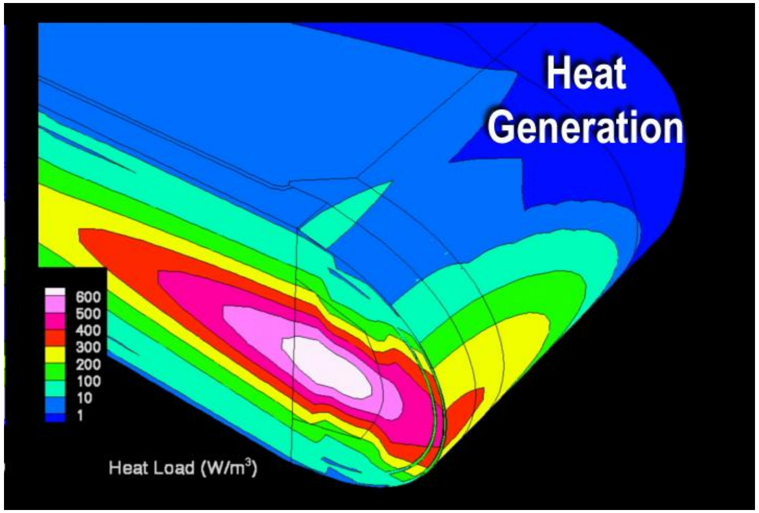
SNS – Spallation Neutron Source





www.sns.gov -Oak Ridge, Tennessee

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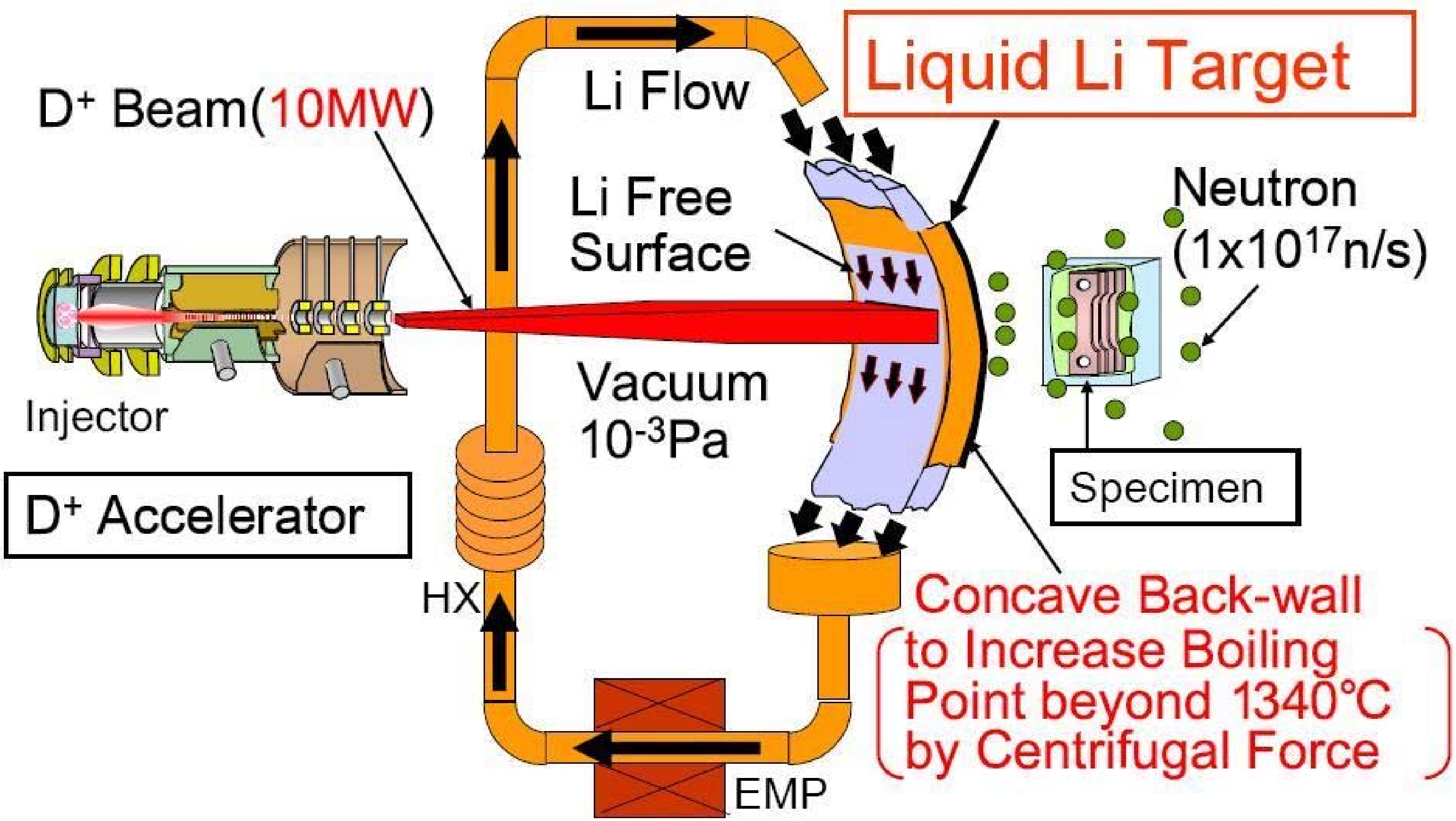
IFMIF – International Fusion Materials Irradiation Facility



Japan Atomic Energy Research Institute

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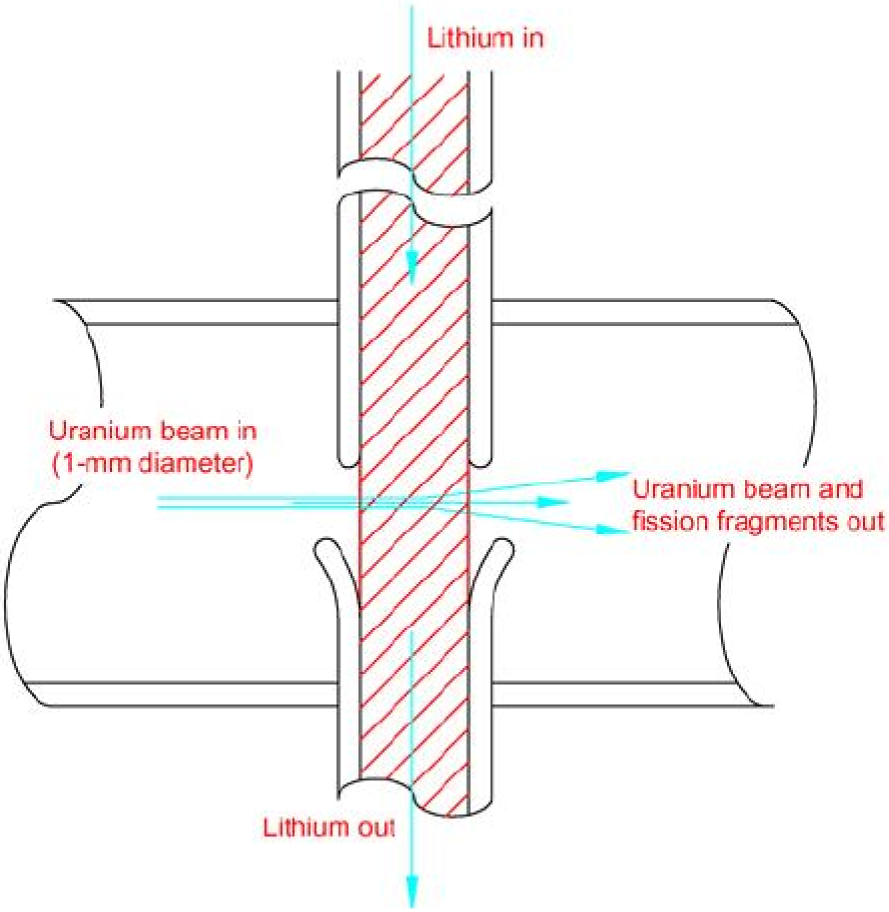
RIA – Rare Isotope Accelerator



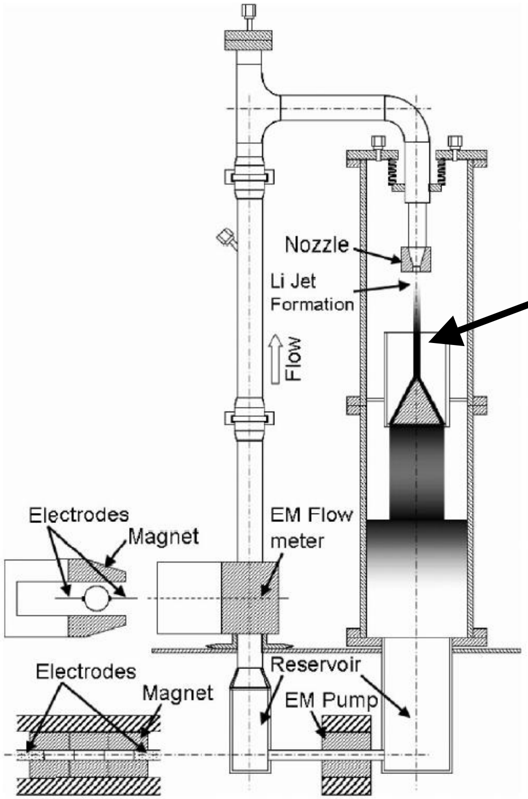
Proposed Design

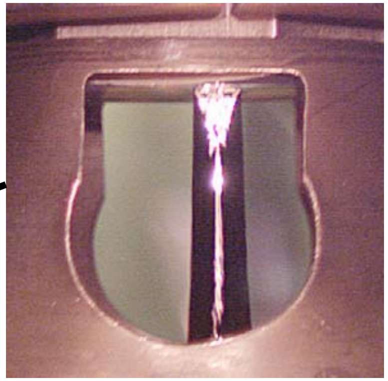
- Windowless Lithium Target
- Lithium flow up to 20m/s
- Target thickness 20-30mm
- Uranium ion beam

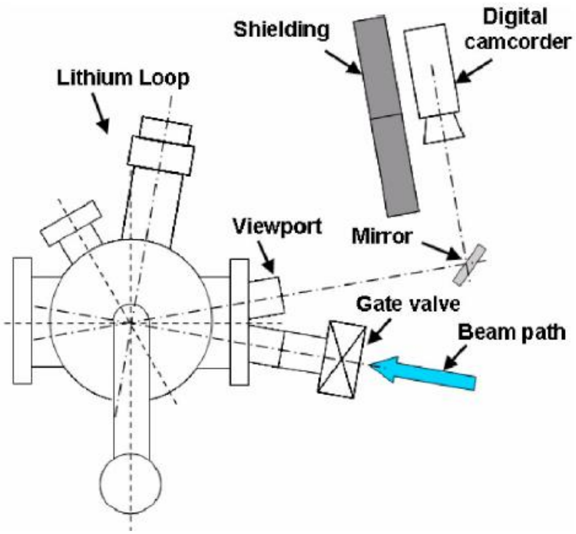
However

- Beam is NOT pulsed
- Power density much lower than proposed at GSI/FAIR

RIA – Prototype experiments



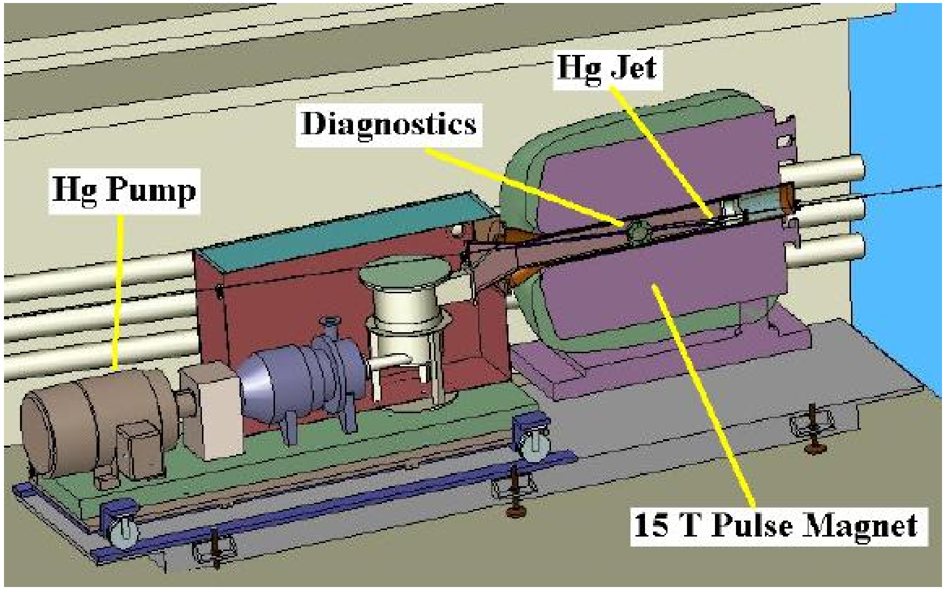




- Test done with 1MeV electron beam – 20kW
- Max power density was equivalent to a 200kW 400MeV uranium beam
- Operated stably and without excess vaporisation with flow rates as low as 1.8m/s

Argonne National Laboratory

Muon Collider/Neutrino Factory



- Liquid Mercury jet target within solenoid magnet
  - Magnet is for particle capture but also has hydrodynamic effects

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CCLRC
Rutherford Appleton Laboratory

Magnetohydrodynamic (MHD) simulation of a Mercury jet

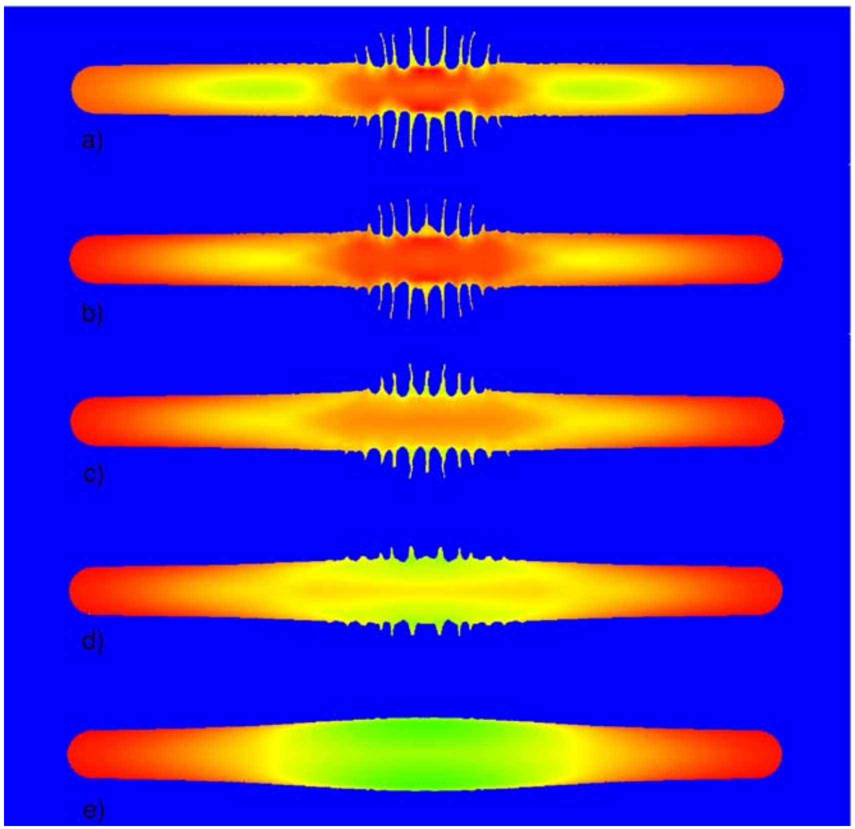
B = 0

B = 2T

B = 4T

B = 6T

B = 10T



- MHD effects reduce velocity of shock
- Magnetic field results in compressive forces on free surface of jet

Roman Samulyak - BNL

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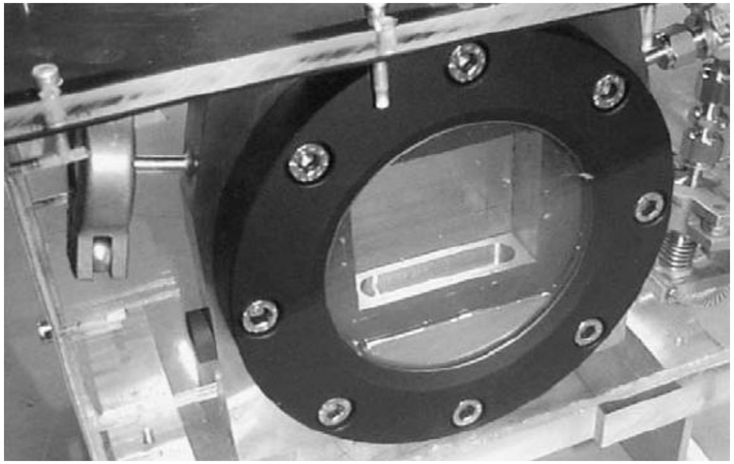
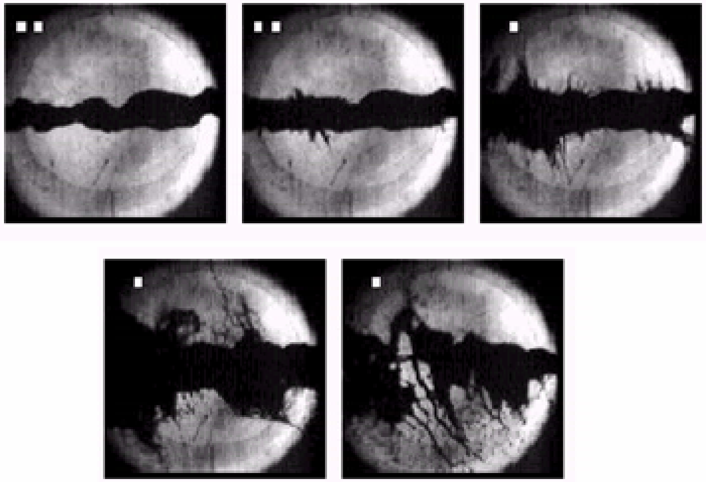
Pulsed Proton Beam Experiments

MERIT – ISOLDE, CERN



- Splash velocities of up to 50m/s were recorded
- Splash velocity scales with power density
  - Proton Intensity
  - Spot size
- Larger dispersal if pulses separated by less than 3μs.

E951 - AGS, BNL



- Splash velocities of 5 - 50m/s recorded
- Single pulse equivalent to 1MW
- Dispersal scales with proton intensity
- Dispersal is not explosive

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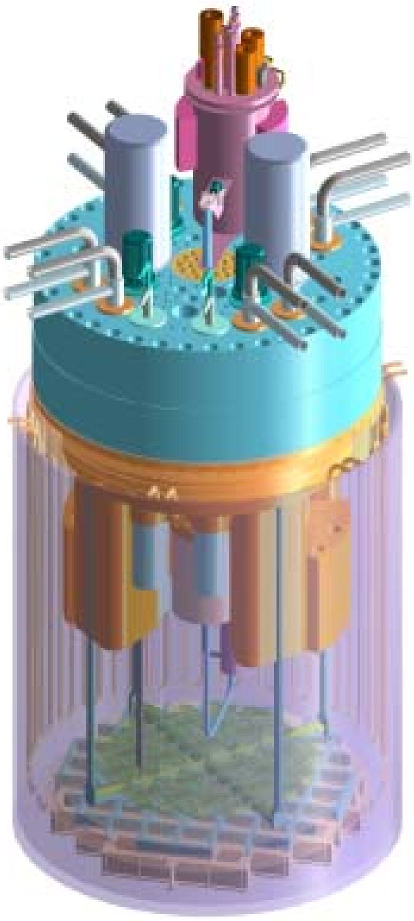
MYRRHA – ADS Research Reactor



SCK CEN – BELGIUM

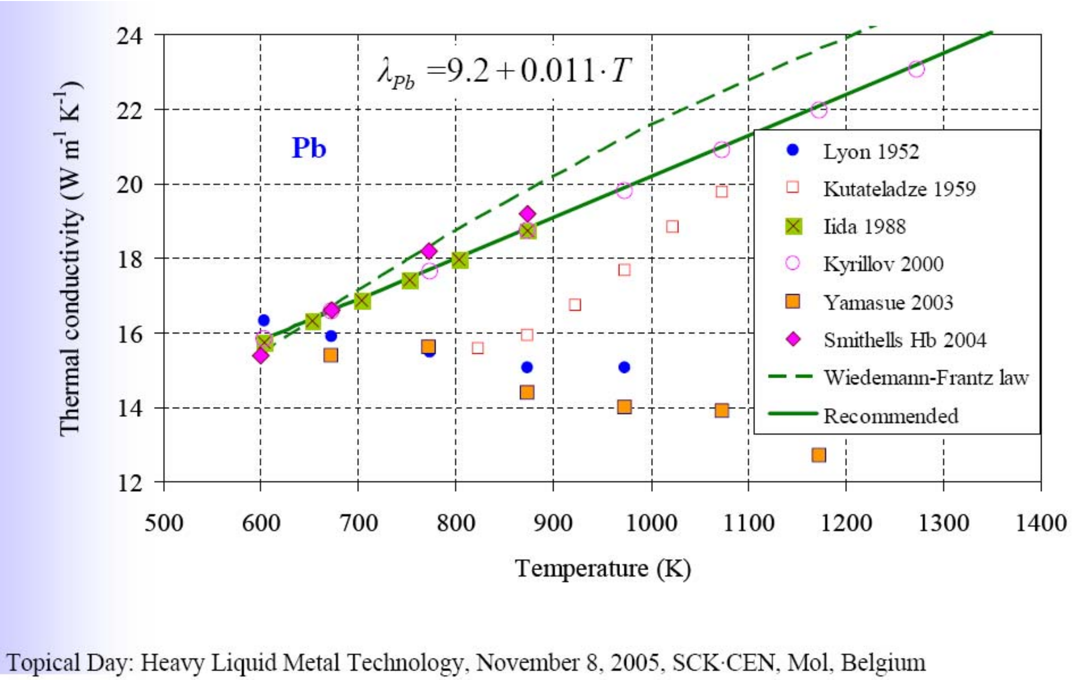
ADS – Accelerator Driven System

- Non critical fission core
- Neutrons created by spallation at centre of core
- Neutrons then amplified by reactor
- Liquid metal used as coolant

Neutron Spallation Source

- 350MeV, 5mA, CW Proton Beam
- Windowless LBE spallation target

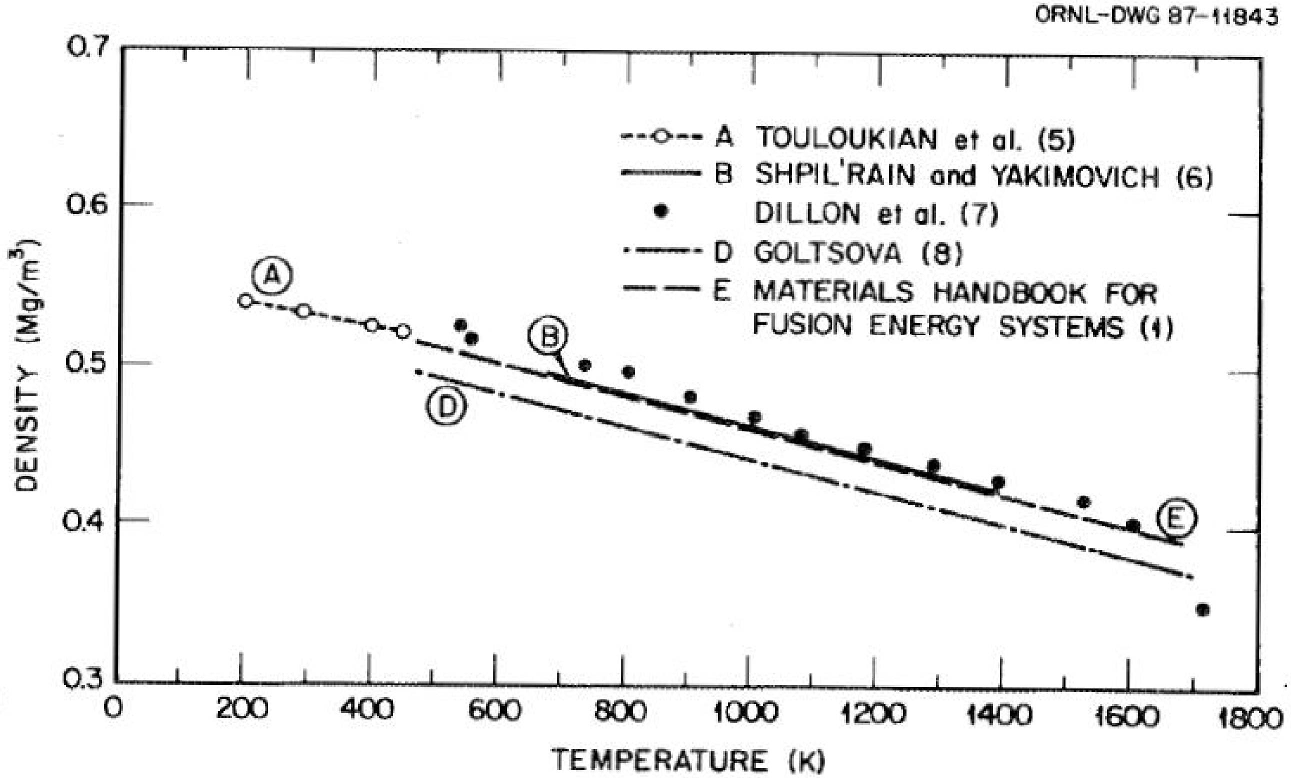
Properties of liquid metals



Thermal conductivity of liquid lead

- Not all liquid metals are well characterised
- Large discrepancies exist for some materials
- Care must be taken with material properties used for analysis

Material Properties of Liquid Lithium



Comparison of experimental studies on the effect of temperature on the density – Oak Ridge National Laboratory 1988

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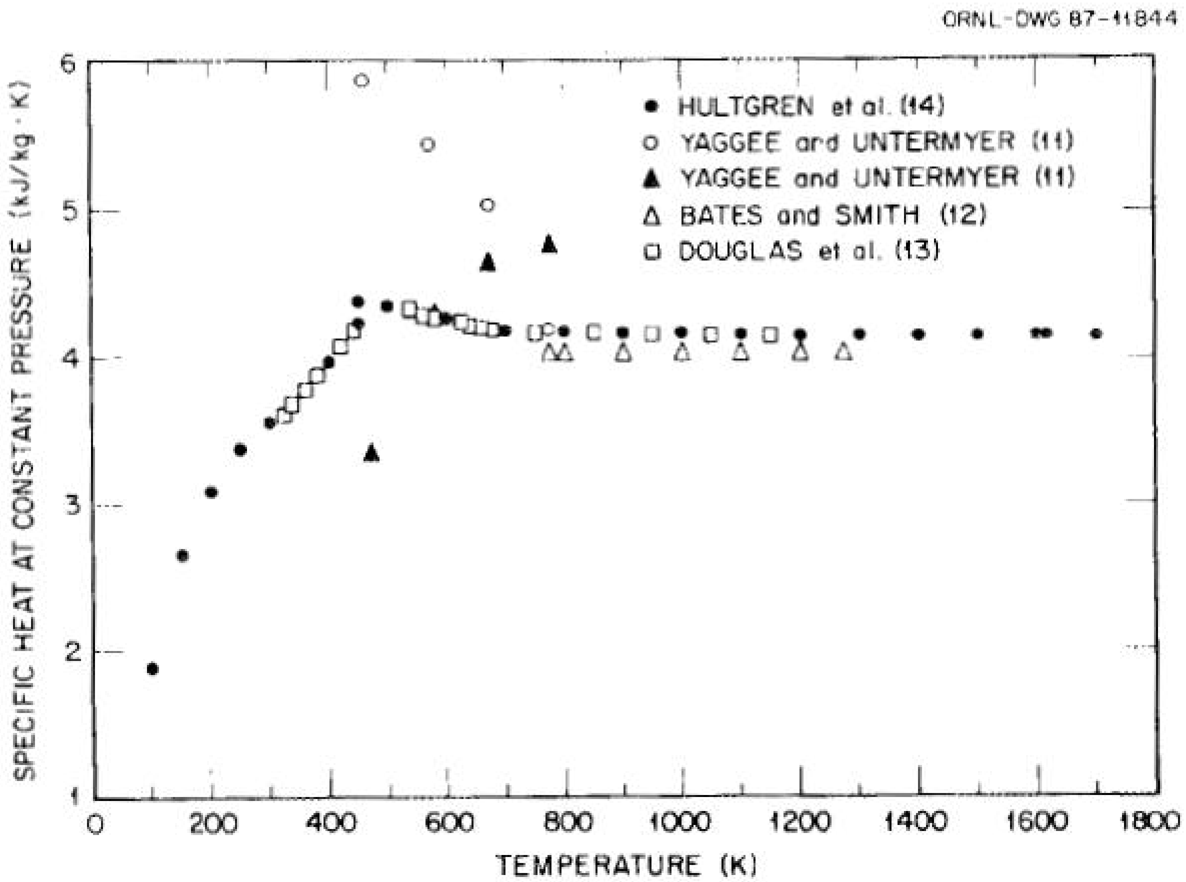

Comparison of experimental studies on the effect of temperature on the specific heat of lithium – Oak Ridge National Laboratory 1988

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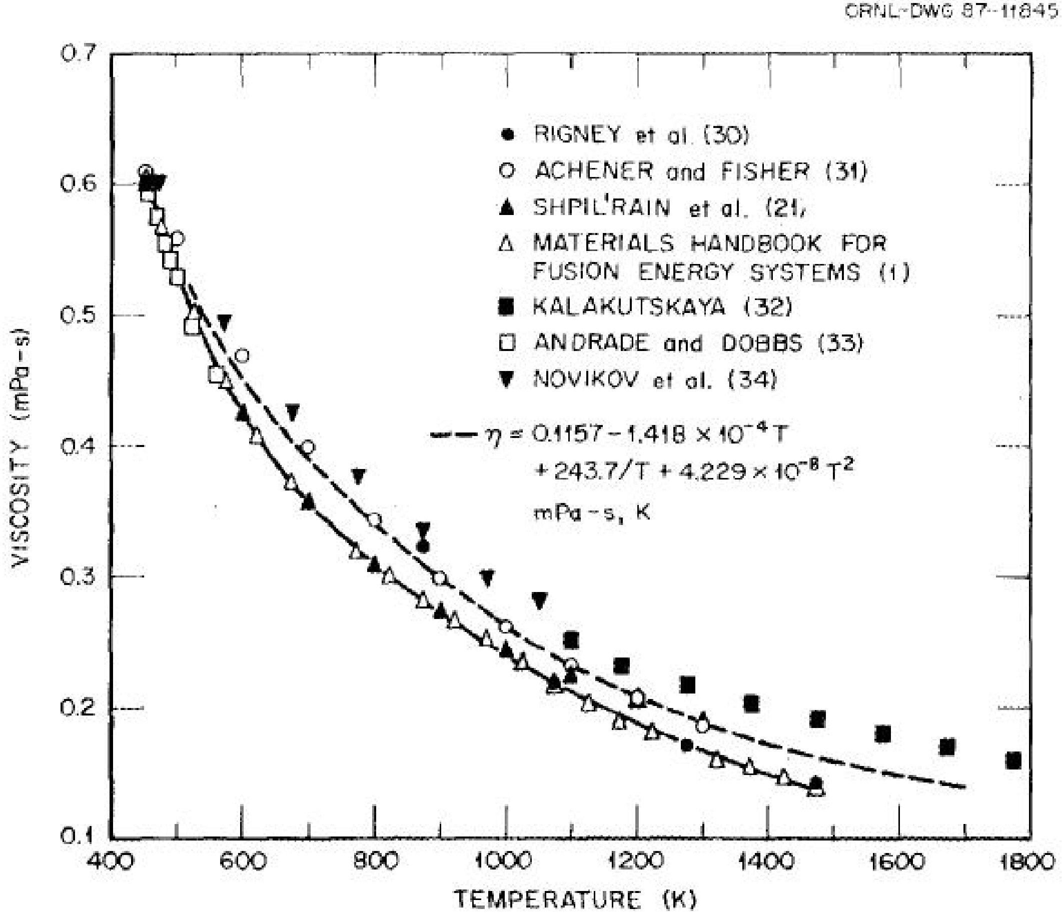

Comparison of experimental studies on the effect of temperature on the viscosity of lithium – Oak Ridge National Laboratory 1988

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Proposed future work

- Simulation of liquid lithium target to determine limiting factors of design is required.
  - Simulations should include
    - Free surfaces (predict ejection of Lithium)
    - Shock waves
    - 3D
    - An appropriate EOS model

- Experiments similar to RIA, but with pulsed beam could be useful for validation.

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