Solid Targets for Neutron Spallation Sources

Eric Pitcher
Los Alamos National Laboratory

Presented to:
AHIPA Workshop
October 20, 2009

Solid spallation targets produce higher neutron fluxes than liquid metal targets

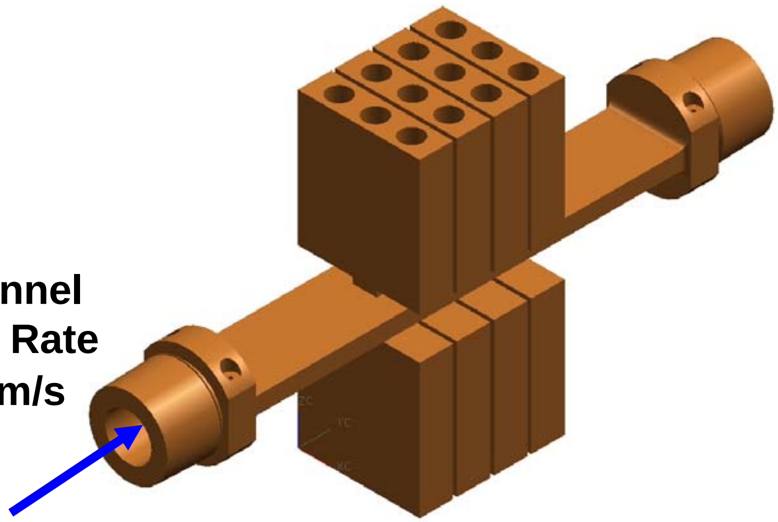
- Neutron flux ~ neutron production density
- Neutron production density ~ mass density
- Mass densities (g/cc):
  - Tungsten: 19.3
  - Liquid Hg: 13.6
  - Liquid Pb-Bi: 10.5
- So long as solid target coolant volume fraction in a tungsten target is less than 30%, solid tungsten targets will generate equal or greater neutron flux than liquid metal targets

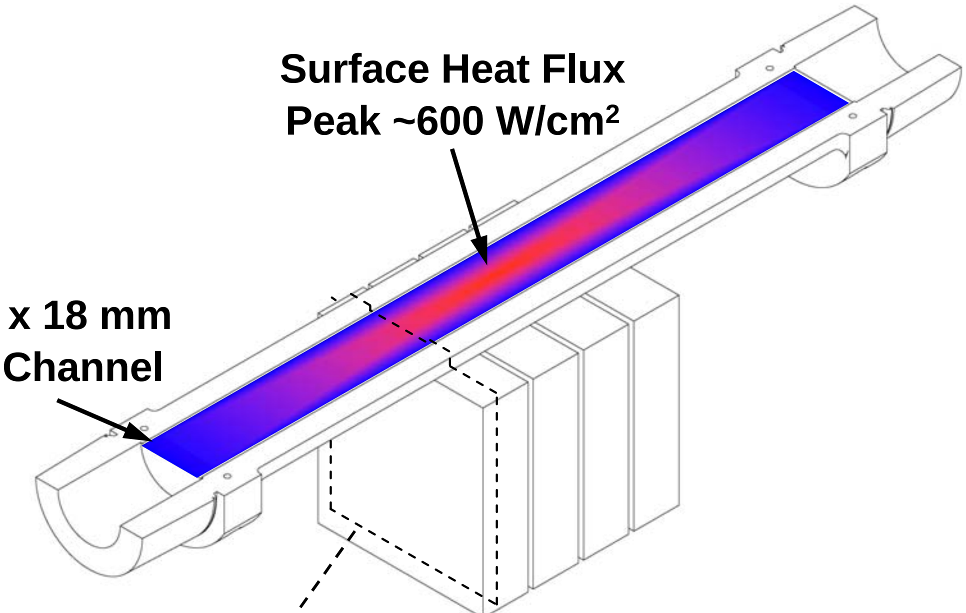
A tungsten target with heat flux up to 600 W/cm^2 can be cooled by water

- For single-phase D_2O:
  - 10 m/s bulk velocity in 1mm gap
  - 70 $\mu A/cm^2$ beam current density on 4.4-mm-thick W plate produces 600 W/cm^2 at each cooled face
  - A 1-mm gap cooling each 4.4-mm tungsten plate gives a coolant volume fraction of 19% and an average mass density of 15.9 g/cc
  - Neutron production density of this high-power target is
    - 15.9 / 13.6 = 17% greater than Hg
    - 15.9 / 10.5 = 51% greater than Pb-Bi

An experiment was conducted to validate the target thermal-hydraulic performance

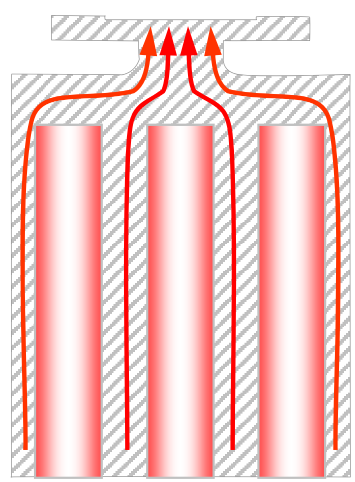
Copper Test Section

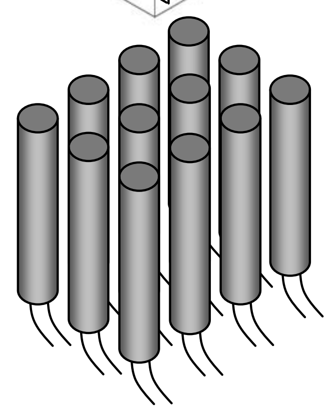




Test Goals:

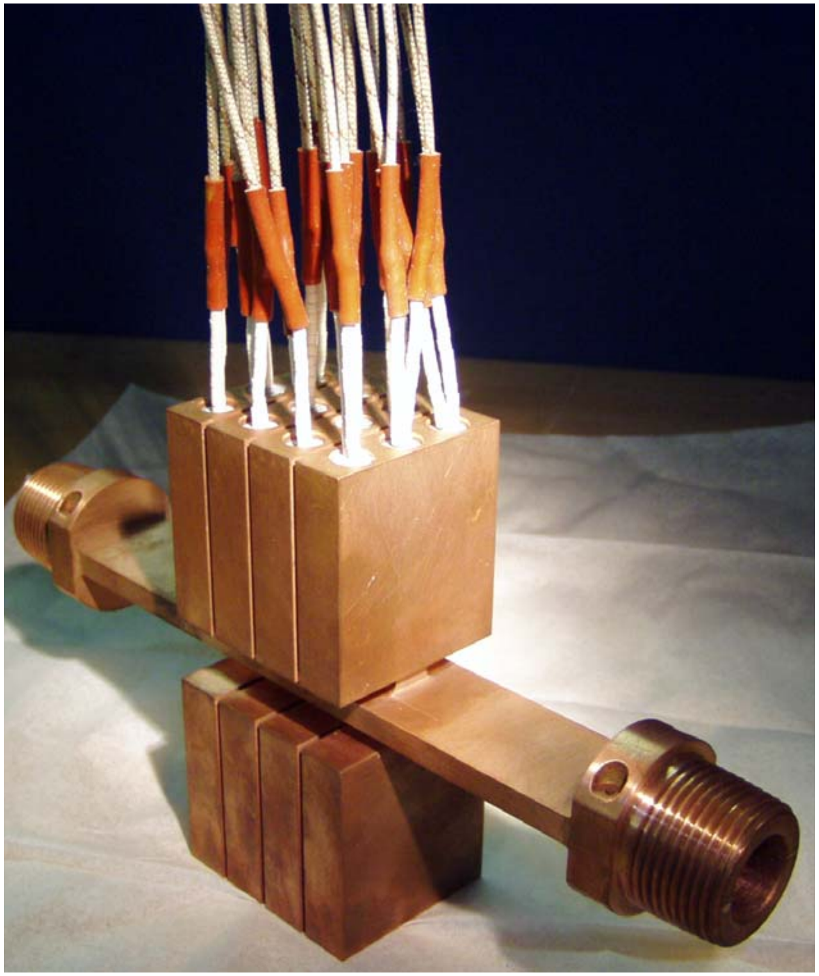
- Determine single-phase HTC
- Identify plate surface temperature @ 600 W/cm^2
- Measure subcooled flow boiling pressure drop
- Investigate effect of plate surface roughness



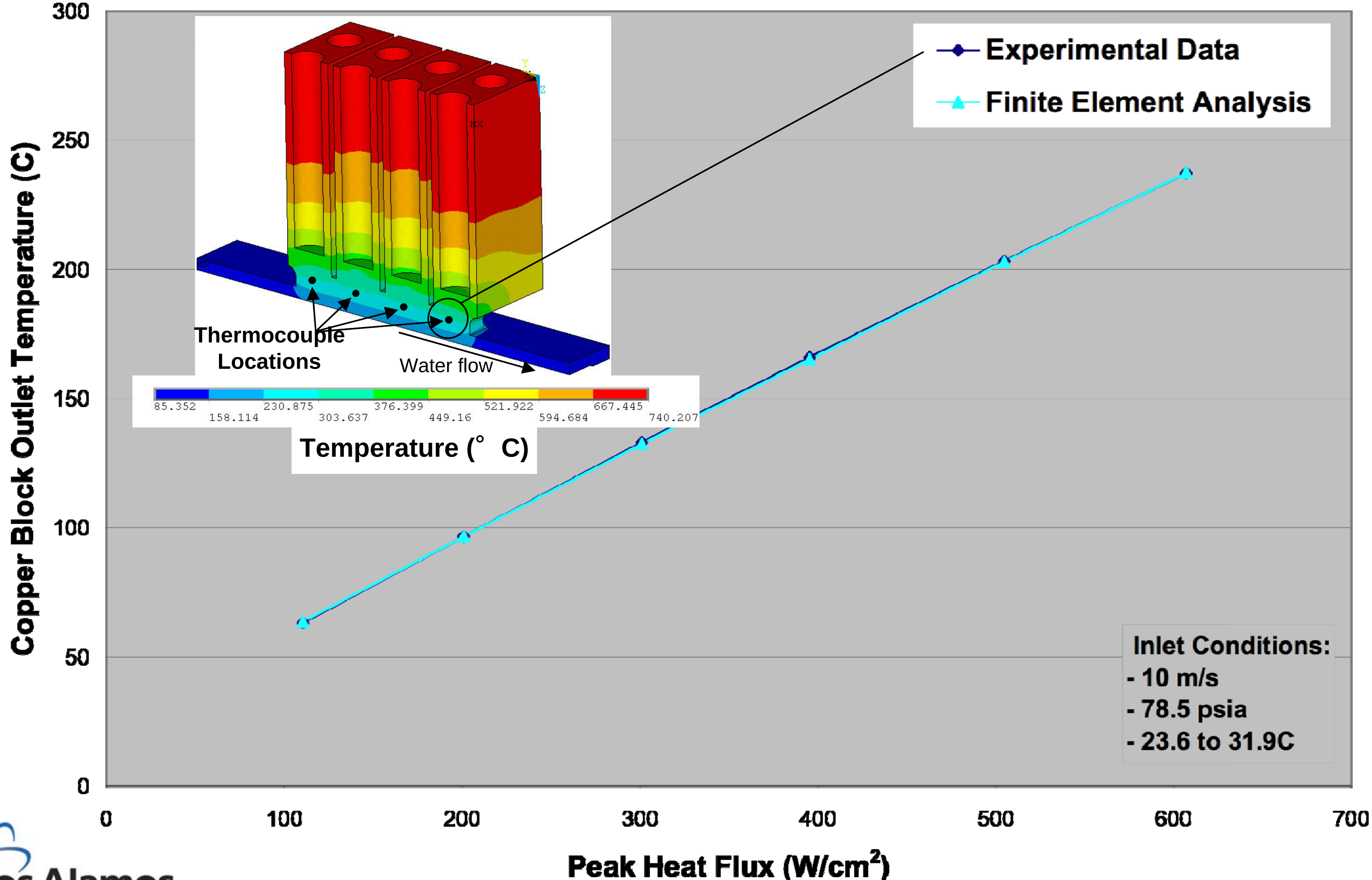


Cartridge heaters in tapered copper block will simulate beam spot heat flux

Thermal-hydraulic experiments using water coolant confirm heat-transfer correlations



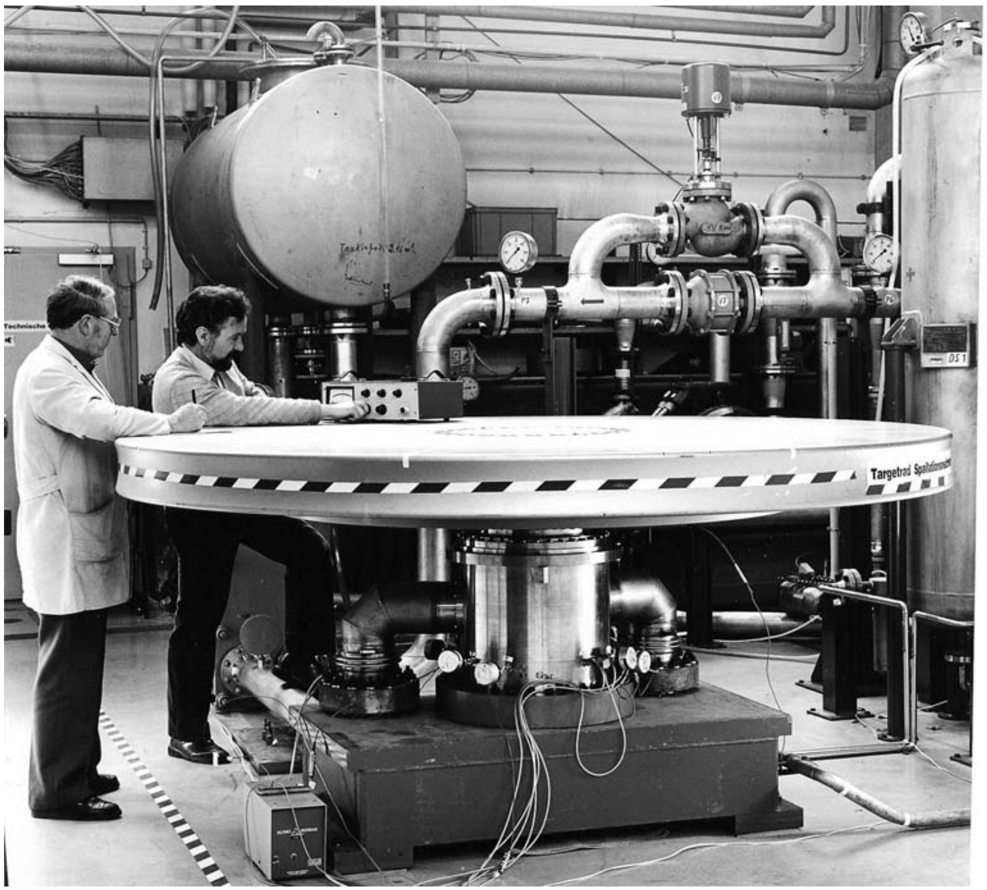
Experimental results match test data using Handbook heat transfer coefficient



For both liquid & solid targets, the target lifetime is limited by damage to the target front face

- Experience base:
  ISIS (SS316 front face): 3.2×10^{21} p/cm^2 = 10 dpa
  SINQ (Pb-filled SS316 tubes): 6.8×10^{21} p/cm^2 = 22 dpa
  MEGAPIE (T91 LBE container): 1.9×10^{21} p/cm^2 = 6.8 dpa
  LANSCE A6 degrader (Inconel 718): 12 dpa
  SNS first target container (SS316L): 7.5 dpa
- MTS design, annual dose (70 μA/cm^2 for 4400 hours):
  (T91-clad tantalum front face): 6.9×10^{21} p/cm^2 = 23 dpa

Rotating solid targets:
What goes around comes around



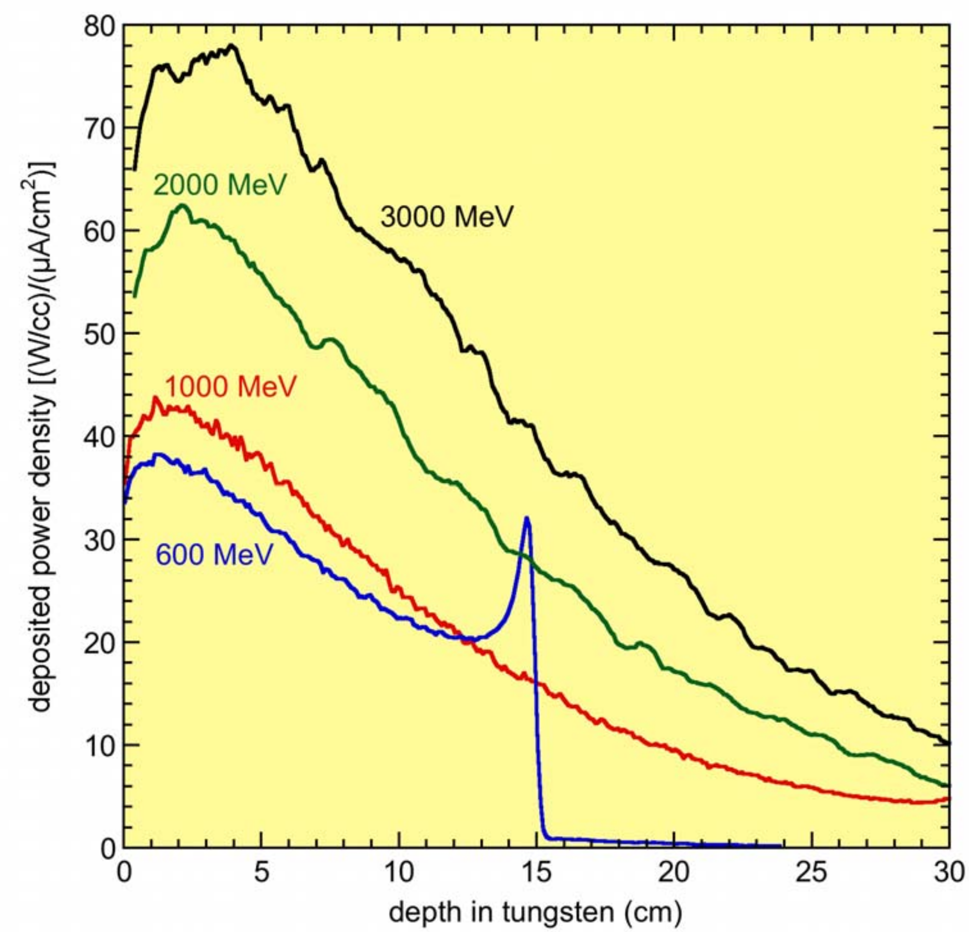
German SNQ Project rotating target prototype (circa 1985)

- Rotating target distributes:
  - radiation damage to the target front face over larger area
    ➔ longer service life
  - Energy deposition over a larger volume, which reduces coolant volume fraction
    ➔ higher n prod density
  - Decay heat over a larger volume
    ➔ possibility to passively cool under design basis accidents

Environment and safety issues: solid vs. liquid

- Decay heat ~ beam power
- Liquid metal targets distribute the decay heat within the total liquid metal volume, typically ~100x larger than solid target volume
  ➔liquid metal targets have ~2 orders of magnitude lower decay heat than solid (stationary) targets
- Over the life of the facility, the waste volume is roughly the same for all targets, liquid metal and solid (both stationary and rotating)
- For most countries, the disposal of activated Hg is more challenging than W or Pb

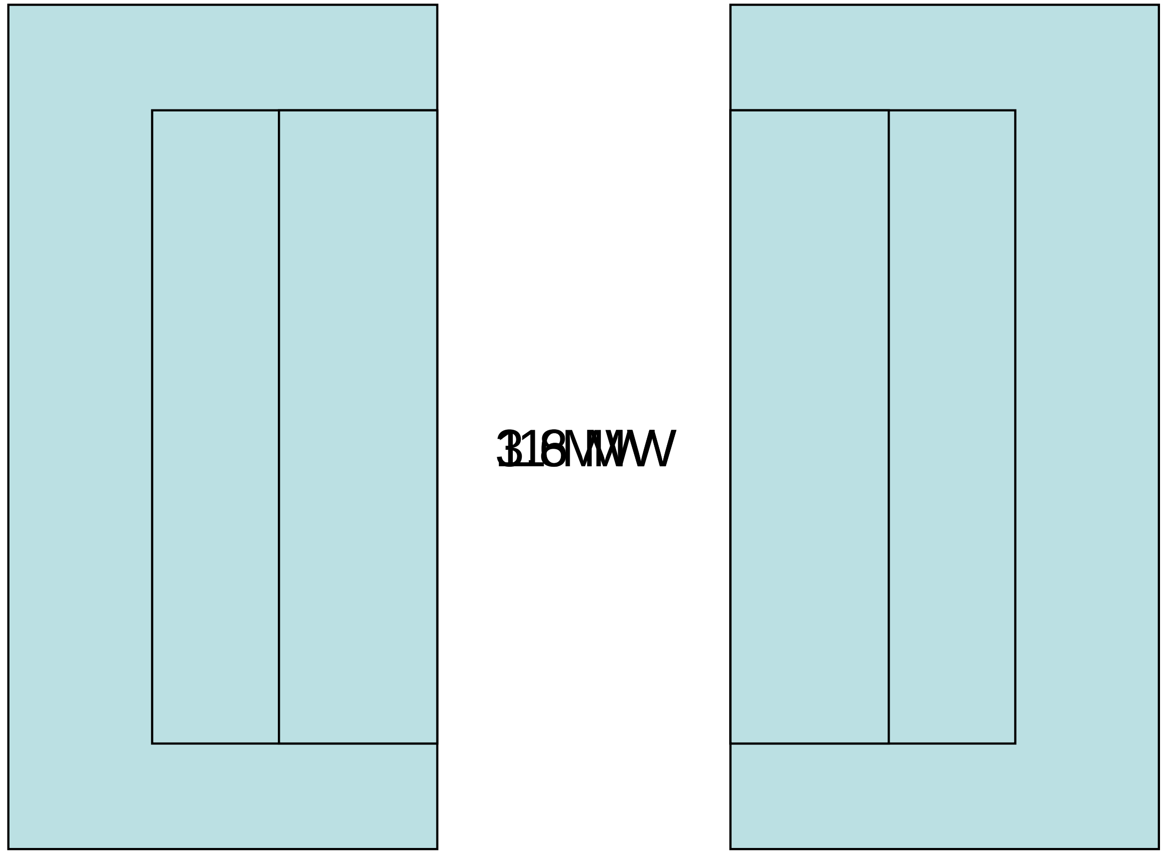
Towards higher beam power:
Which is better—more energy or more current?



- Above ~800 MeV, target peak power density increases with beam energy
- Addressed by:
  - Higher coolant volume fraction for solid targets
  - Higher flow rate for liquid metal targets
  - Bigger beam spot

Towards higher beam power: Which is better—more energy or more current?

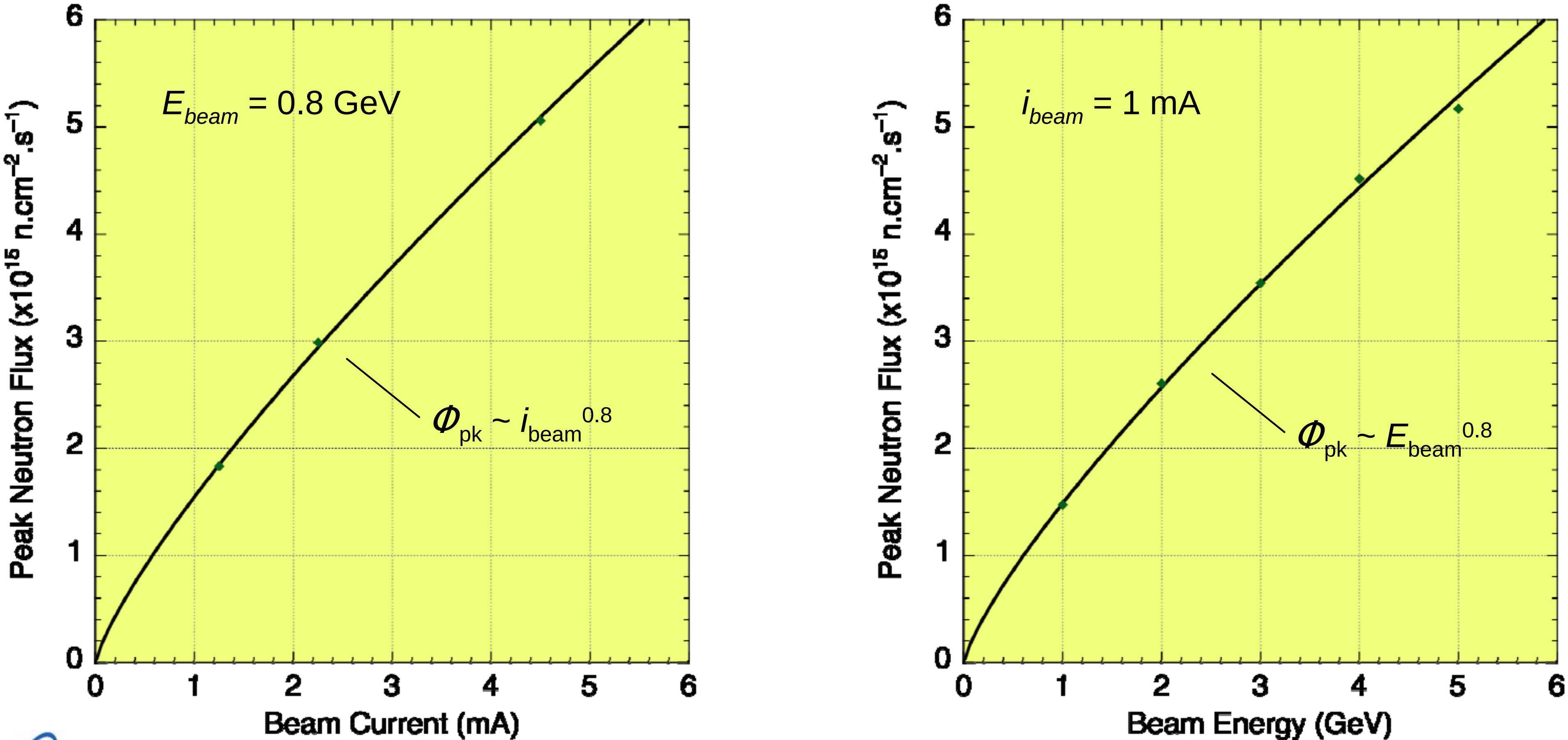
- If target lifetime and coolant volume fraction is preserved, higher beam current requires larger beam spot



MTS Beam Footprint on Target

Peak neutron flux goes as $P_{beam}^{0.8}$

$$\Phi_{pk} \sim E_{beam}^{0.8} i_{beam}^{0.8}$$



Summary

- A water- or metal-cooled stationary solid target is viable beyond 1 MW
  - Solid targets have higher neutron production density than liquid metal targets
  - Replacement frequency is determined by target front face radiation damage, and is therefore the same as for a liquid metal target container if the beam current density is the same
  - A rotating solid target will have much longer lifetime than stationary targets
- Target “performance” ~ (beam power)$^{0.8}$
  - Does not depend strongly on whether the power increase comes from higher current or higher energy