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Accelerator-based Neutron Damage Facility using LEDA

By:

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TAMU ADS system - ADAMS

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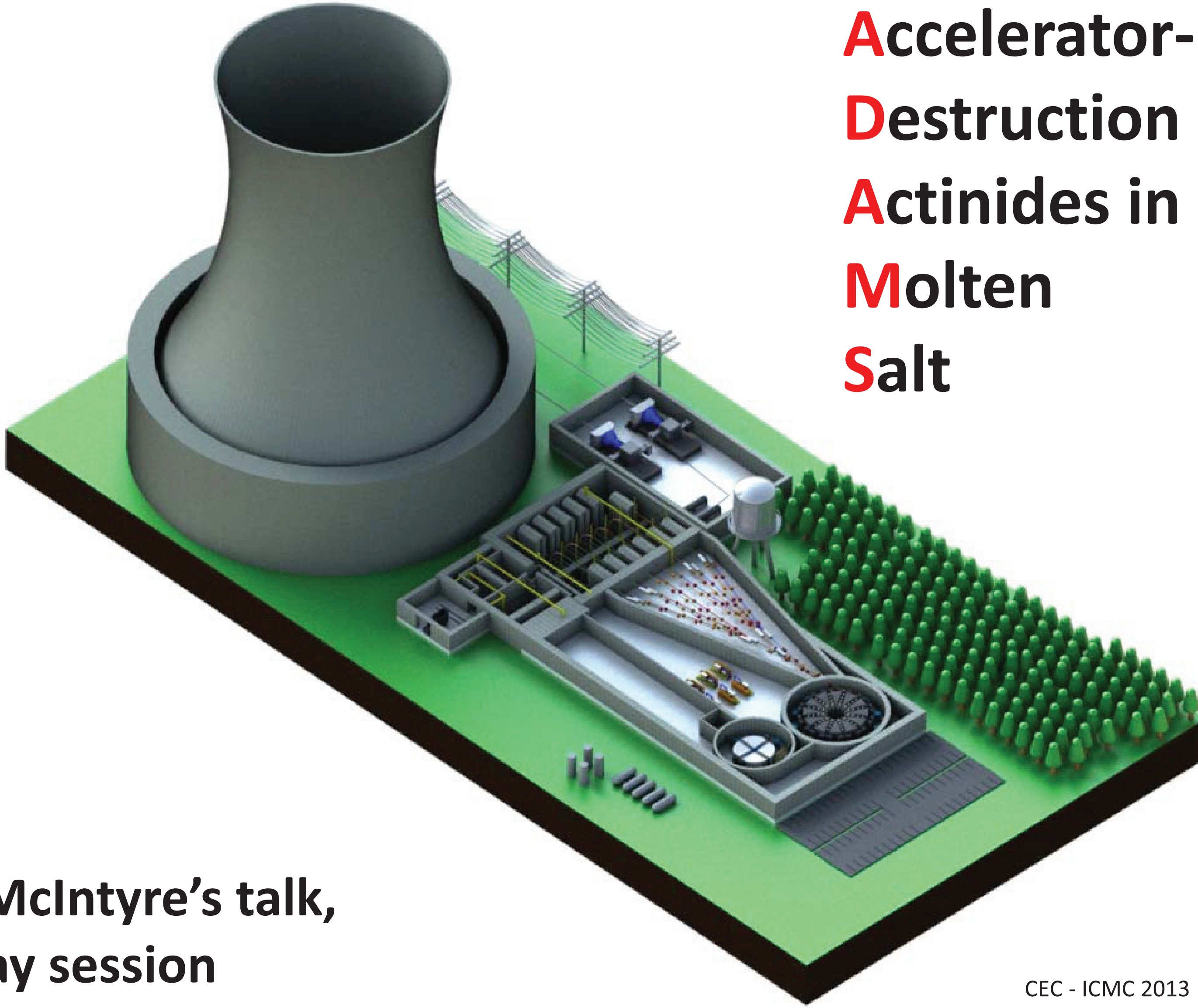

Accelerator-based
Destruction of
Actinides in
Molten
Salt

Peter McIntyre's talk, Monday session

TAMU ADS system - ADAMS

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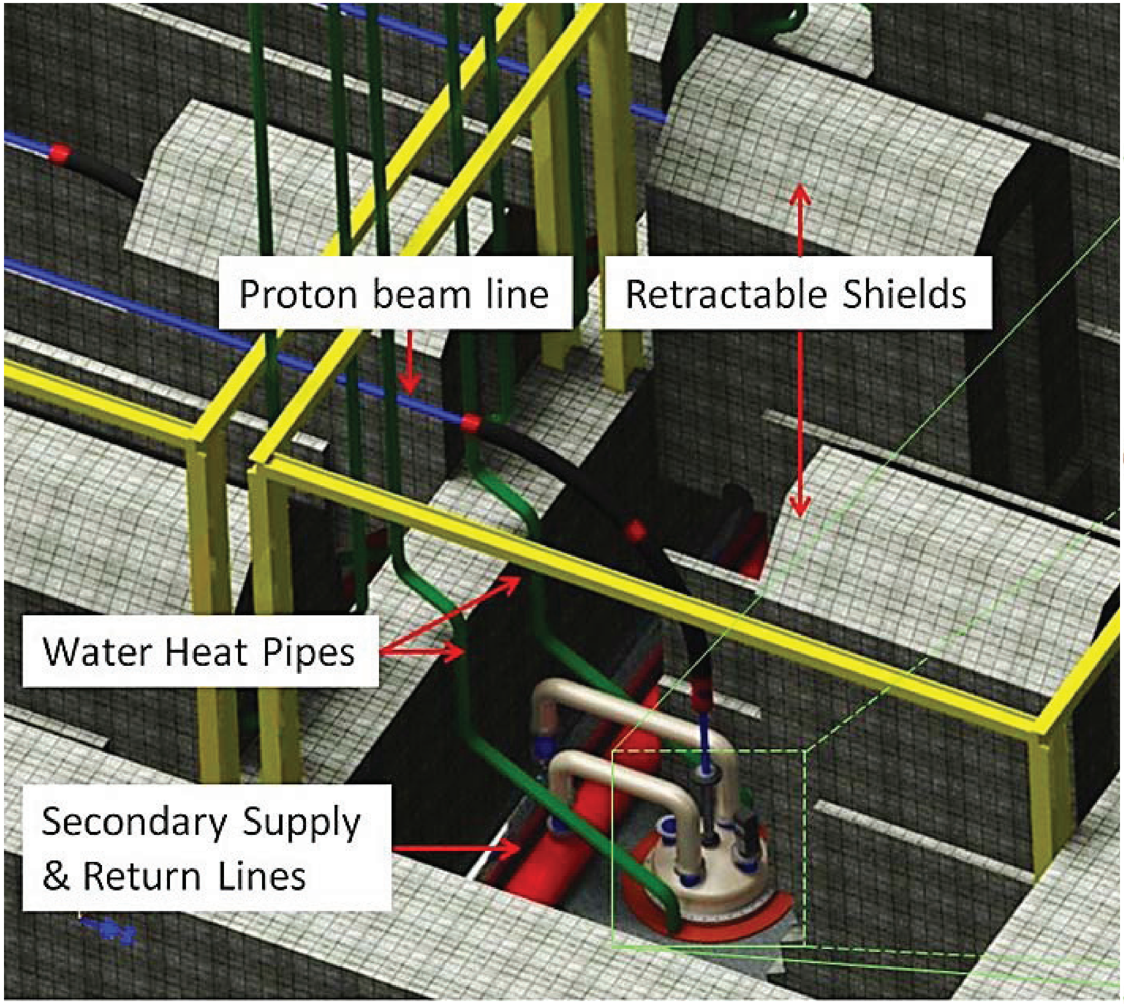
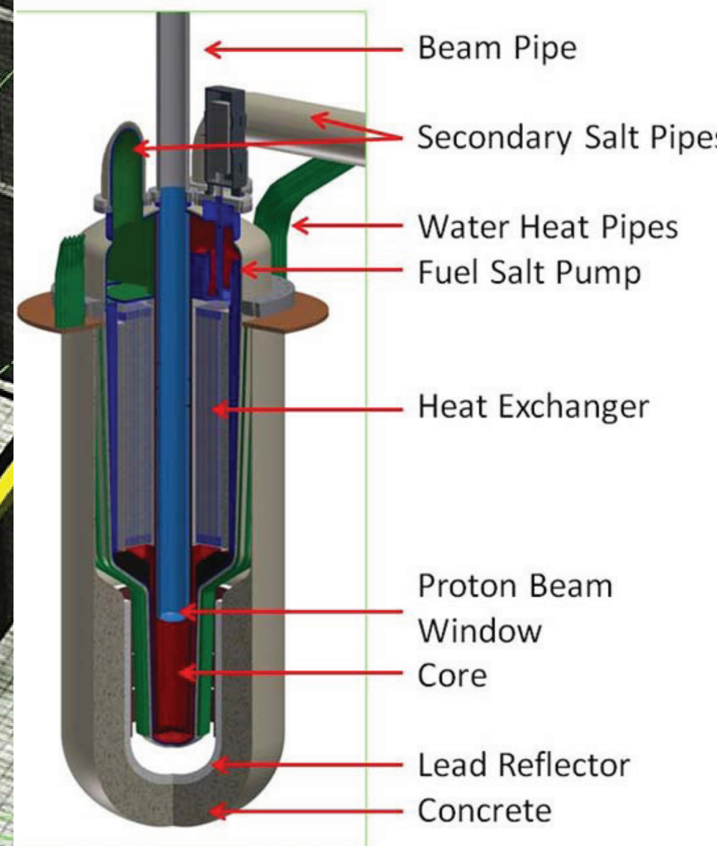
Accelerator-based Destruction of Actinides in Molten Salt





Peter McIntyre's talk, Monday session

Motivation

Qualify Materials for Nuclear Applications

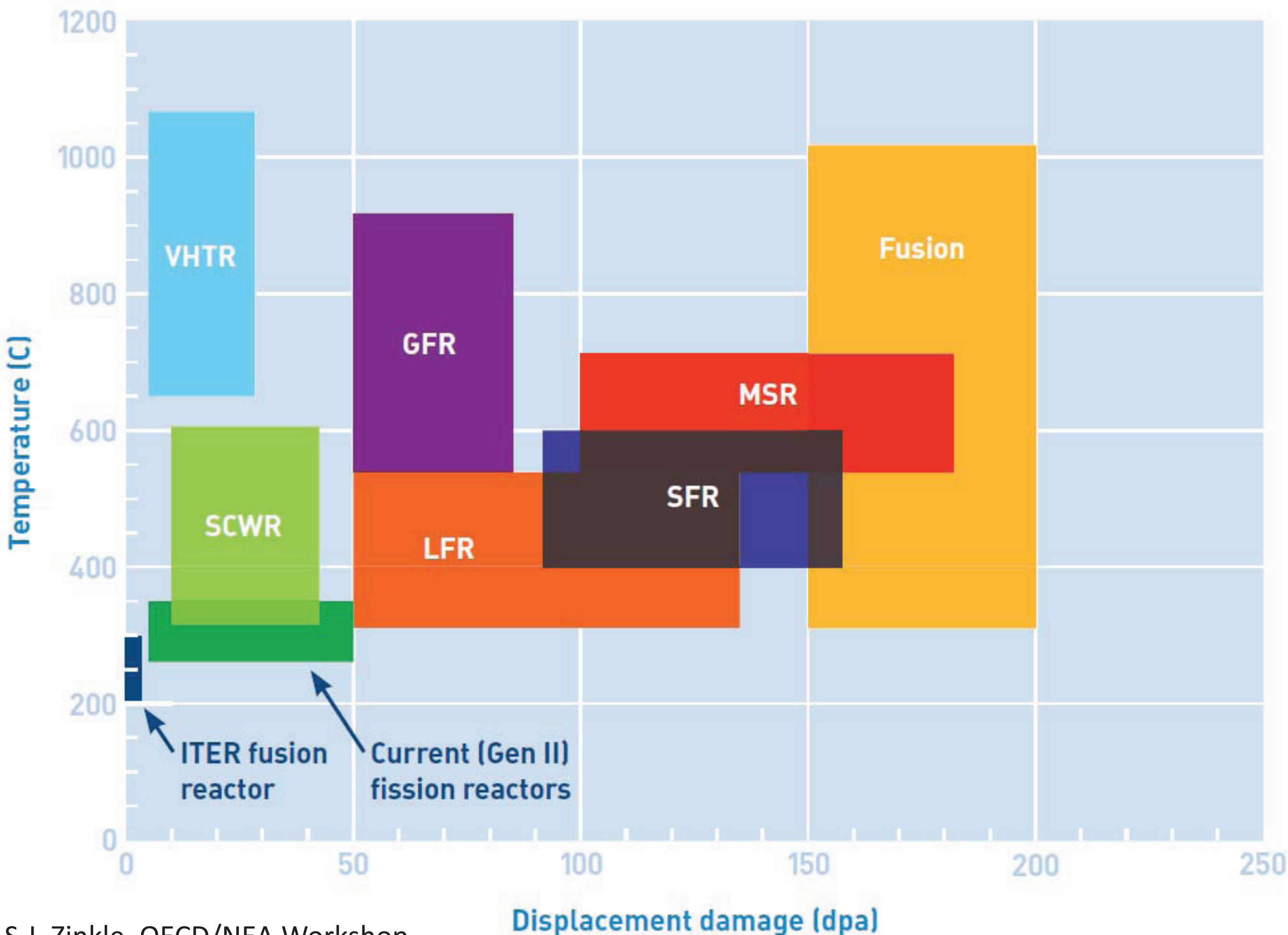


Image source: S.J. Zinkle, OECD/NEA Workshop on Structural Materials forInnovative Nuclear Energy Systems, Karlsruhe, Germany, June 2007

Motivation

Qualify Materials for Nuclear Applications

The domestic capability to test materials in high neutron fluence is required in order for nuclear power to continue, and grow, in the United States.

Candidate materials for Advanced Reactors (including our own ADS system, ADAMS)must be subjected to > 200 dpa (displacements per atom) in order to qualify the materials and quantify their lifetime performance.

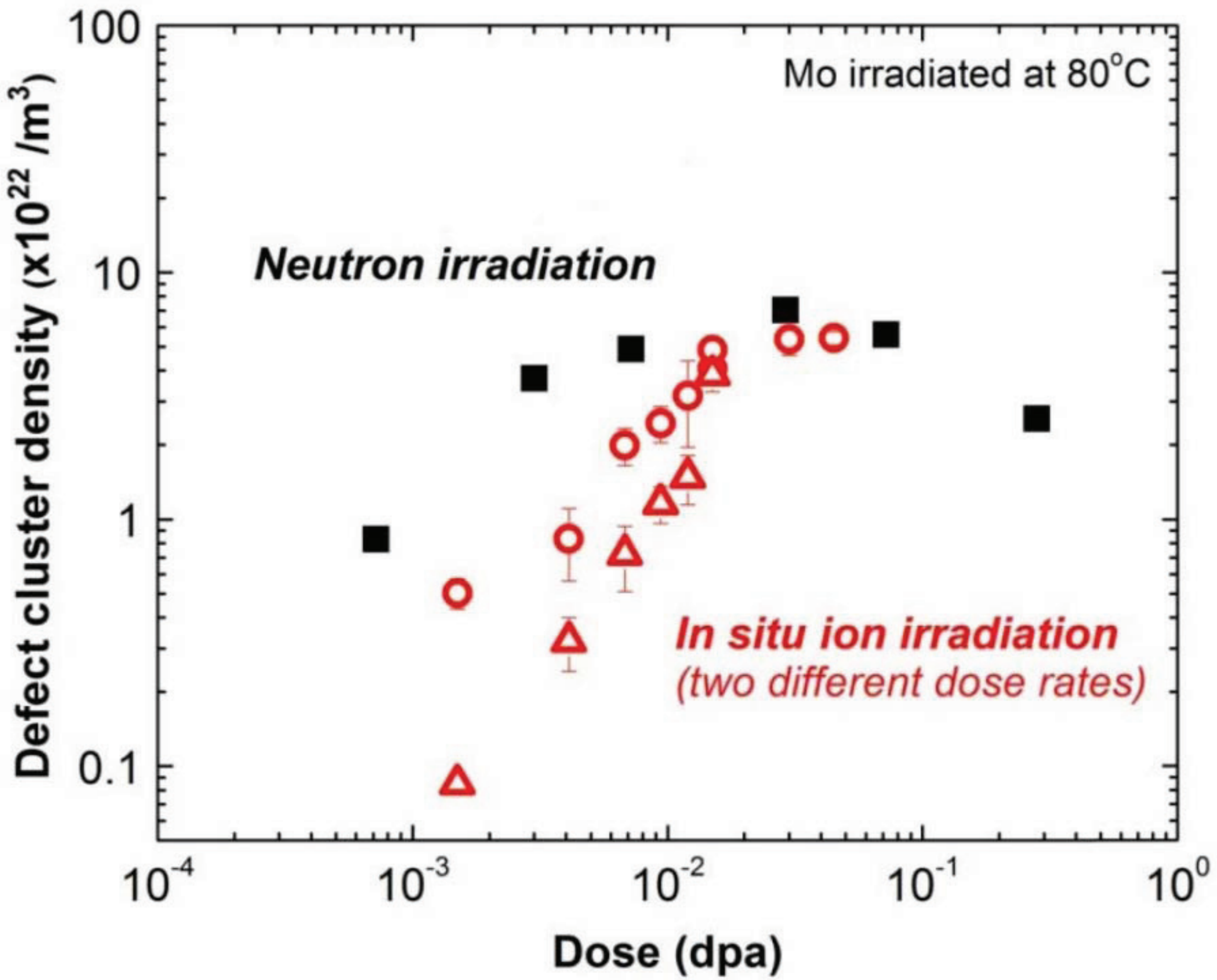
Currently takes over 15 years to test samples domestically, and 10 years to test internationally (Bor60, 18 dpa/year).

Motivation

Consequences –

- Lifetime of a reactor was initially set of 40 years – thus the 104 reactors in the US are surviving off extensions of lifetimes.
- 18 plants have submitted application for future construction.
- Thus far two permits have been issued – Vogtle 3 & 4. However concerns about the brittleness of the wall have been a key point about safety.
- This is the first agreement for **NEW** nuclear development in the United States since the Three Mile Island accident in 1979.
- Nuclear Engineers have turned to using Ion bombardment of materials and extrapolate the results to shorten the experiment duration.

Ions vs. Neutron Damage



Kr^{++} Ions used for irradiation of Mo

From Meimei Li, Argonne National Laboratory

http://puhep1.princeton.edu/mumu/target/RESMM12/li.pdf

Ions vs. Neutron Damage

In regards to ions much have been learned about the mechanism that cause damage, as they both flavors of particle use the same mechanisms. However they operate at dramatically different rates.

- Defect production, ions produce 10x more.
- Defect migration, ions produce 10x less.
- Defect annealing, ion produce 10x more.
- Different production of interstitial clusters and loops,
- and H and He production, as well as how damage induced is effected by their presence.

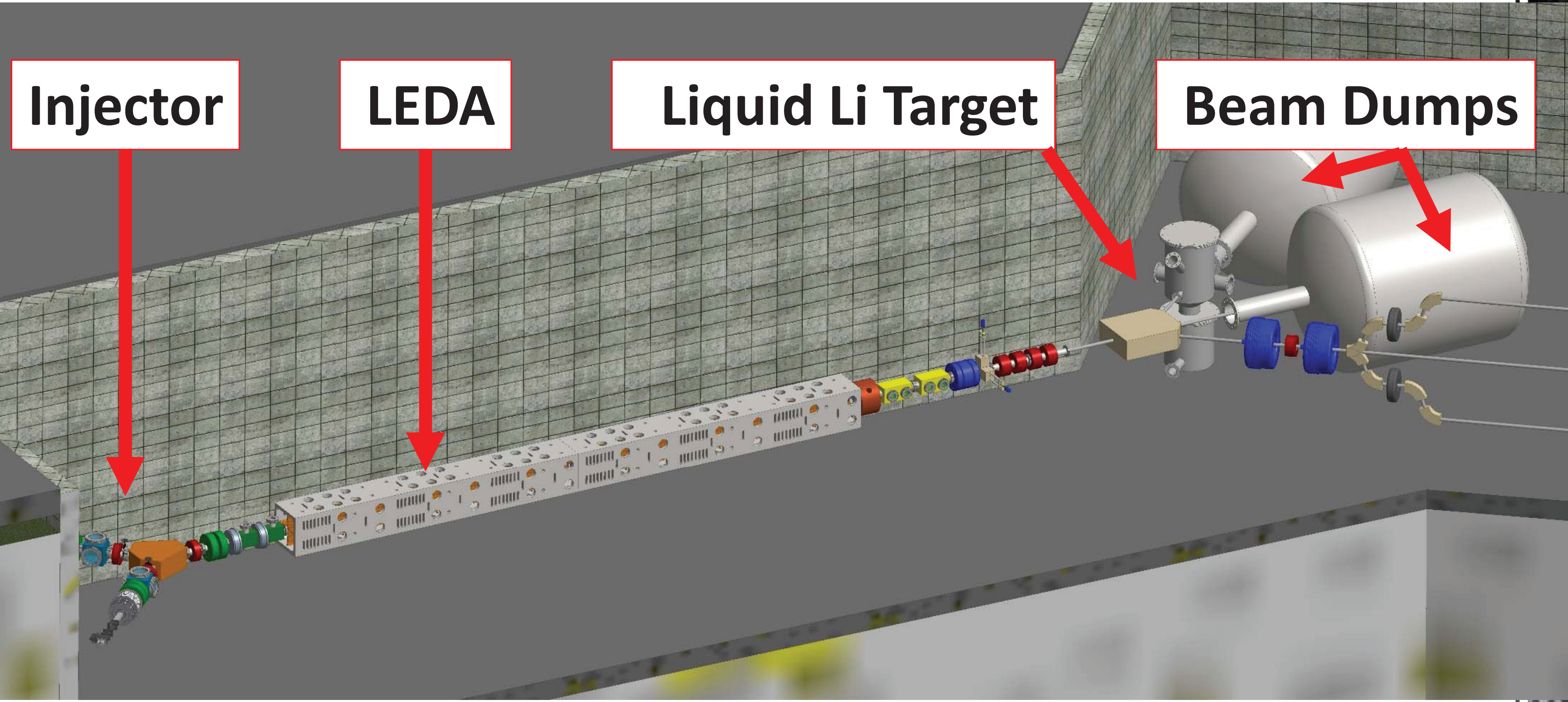
Though much has been learned about these mechanism,

You cannot predict fast neutron damage and its effects on materials using ions.

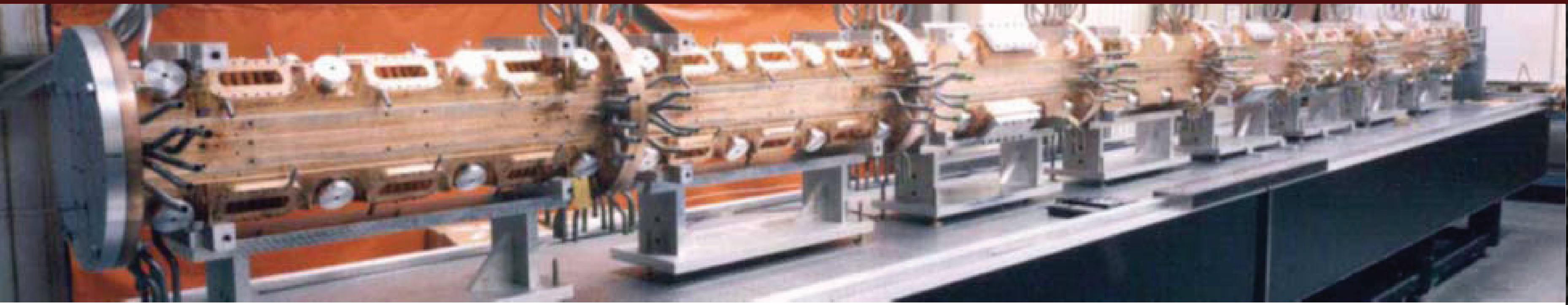
From Meimei Li, Argonne National Laboratory

AND – Phase 1

Why waste time and resources on Ions when you can use Neutrons, which is what is really needed.



LEDA



PARAMETER	VALUE
Frequency	**350 MHz**
Particle	$\mathbf{H^{+}}$
Input Energy	75 keV
Input Current	105 mA
Input Emittance, trans./norm.	0.020 π-cm-mrad rms
Output Energy	6.7 MeV
Output Current	**100 mA**
Output Emittance, trans./norm. longitudinal	**0.22 π-mm-mrad rms** 0.174 deg-MeV
Transmission	**95%**
Duty Factor	**100%**
Peak Surface Field	1.8 Kilpatrick
Average Structure Power	1.2 MW
Average Beam Power	0.7 MW
Average Total Power	1.9 MW
RF Feeds	12 Waveguide Irises

- **Built for Accelerator Production of Tritium (APT)**
- **Commissioned in 2003, operated at 98.7 mA at 6.7 MeV for a several hours.**

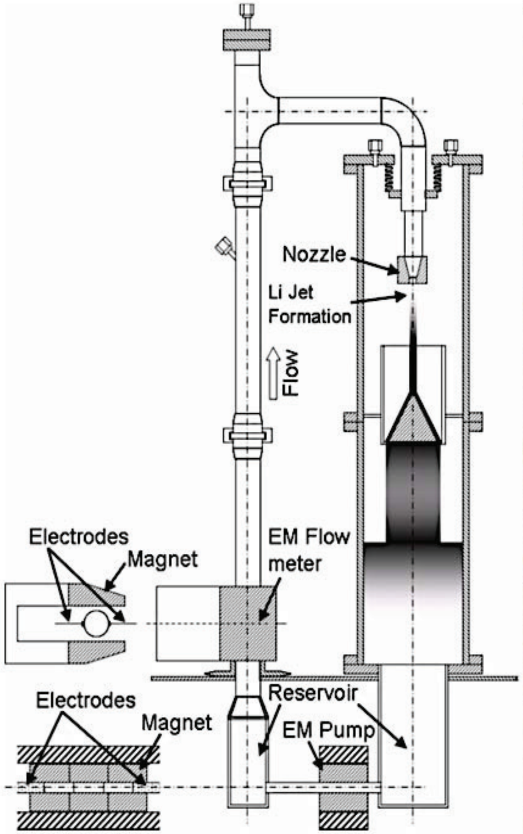
From: Young

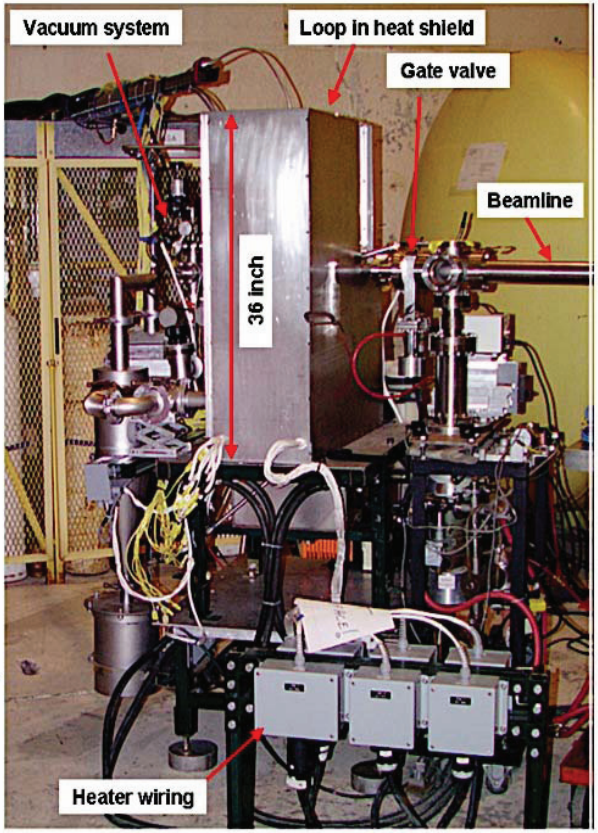
LEDA

- **Decommissioned in 2004 and placed in storage in a pristine state.**
- **LANL committed to a 10 year loan of LEDA, along with a RF power system (pulsed system) to TAMU for immediate commissioning.**

- **Commitment from CERN was obtained for a long term loan of two 1MW 350 MHz CW RF amplifiers for sustained operation during the LEDA loan. (note: needs some refurbishing)**

Lithium Target



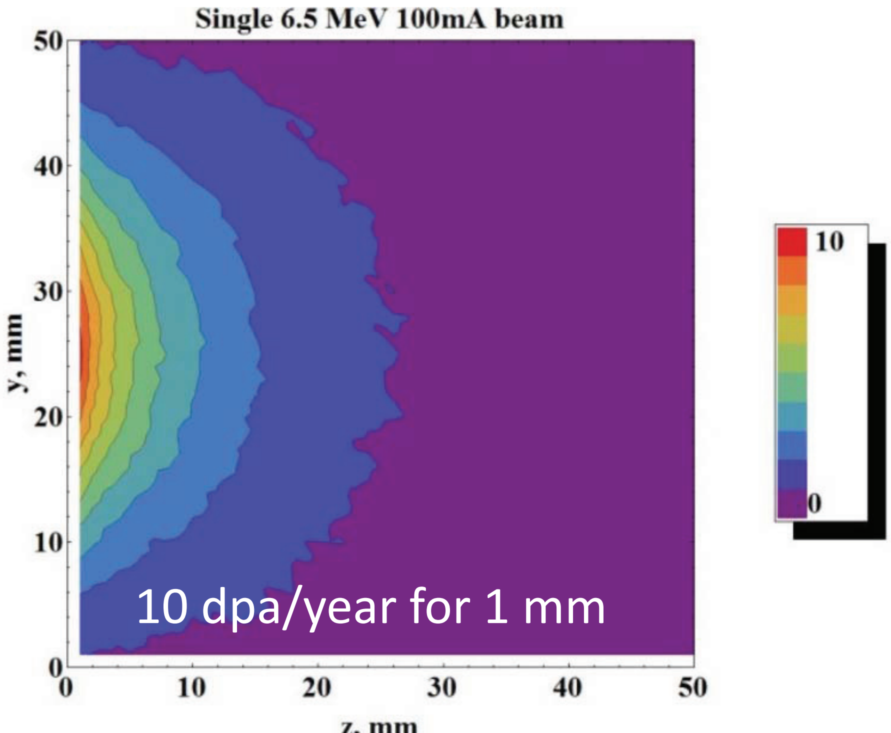


Schematic and Image of Lithium Target constructed at Argonne National Lab.
Slated to be used for stripping at KEK and FRIB
Lithium thickness is determined by Energy (confine the Bragg peak), so all protons remain in Li and only neutrons reach the sample

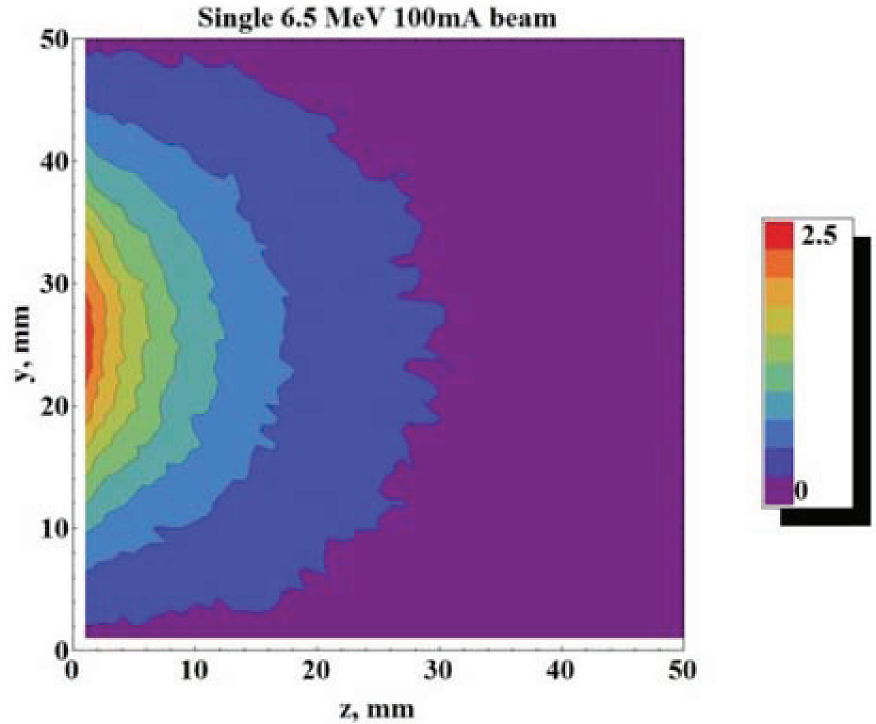
From: J. Nolen et al., "A High Power Beam-on-target Test of Liquid Lithium Target for RIA", August 22, 2005, ANL-05/22

AND 1 - Neutron Damage

Damage from AND 1 via neutrons



dpa/year



Heat (W/cc)

Bulk irradiation occurs vs. ion irradiation that penetrates only thin layers

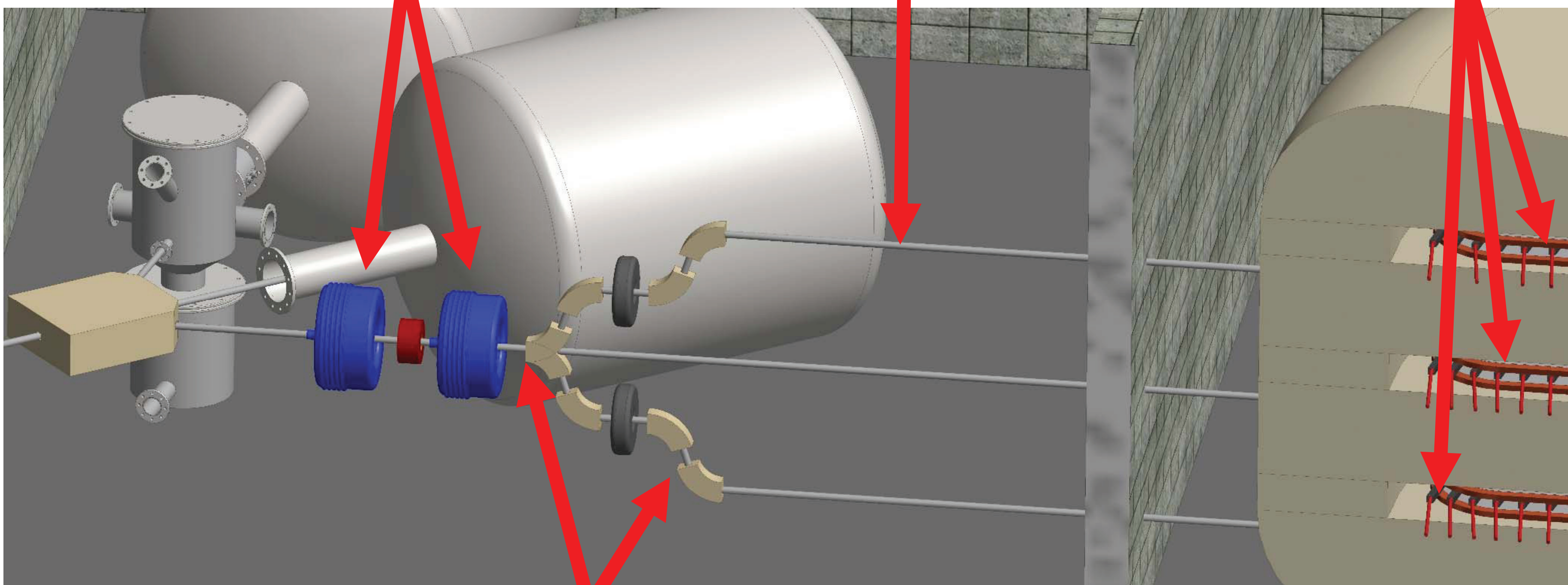
AND – Phase 2

350 MHz beam is split into 3 - 15 mA 116 MHz beams

Buncher Cavities

3 Beams

Cyclotrons



Beam Splitting Magnets

AND – 2 SFC

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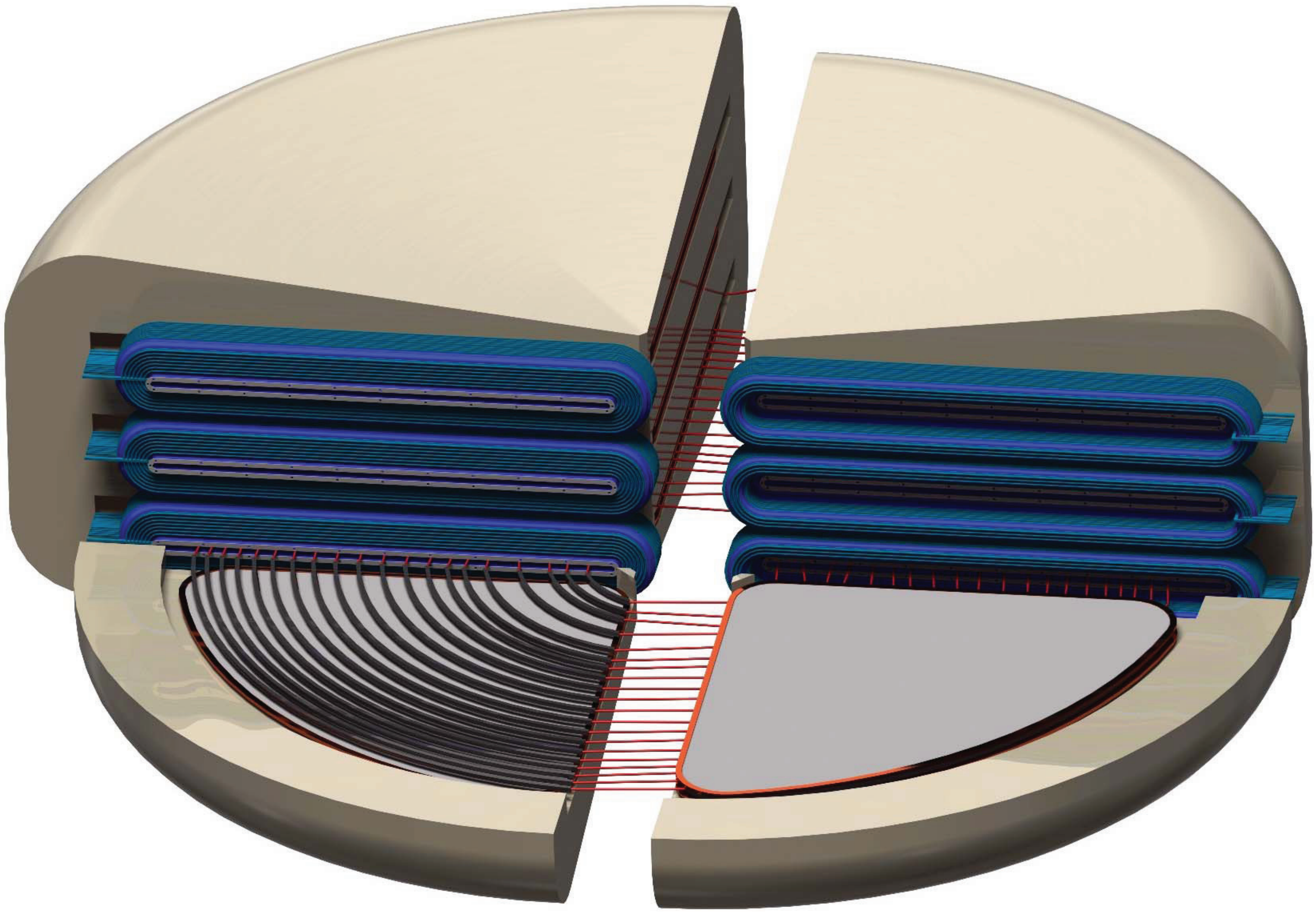
Strong Focusing Cyclotron (SFC)



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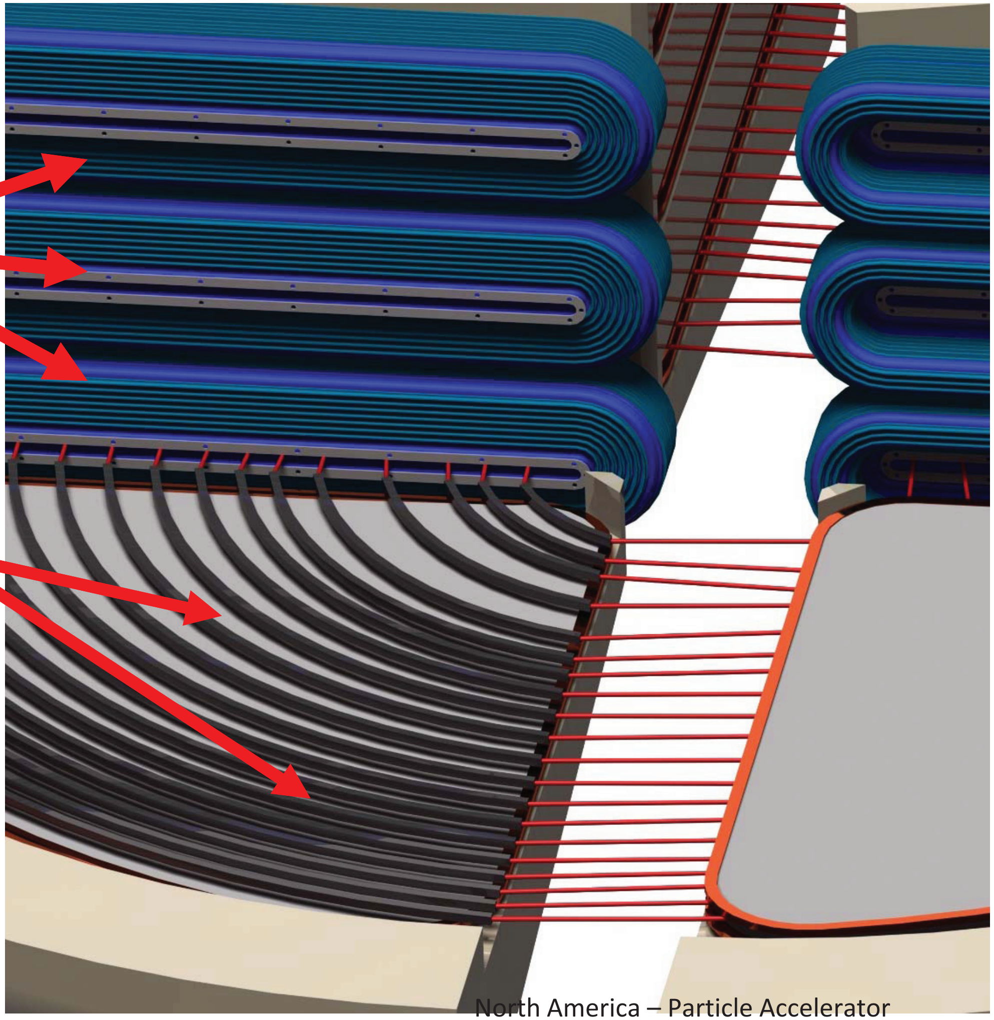
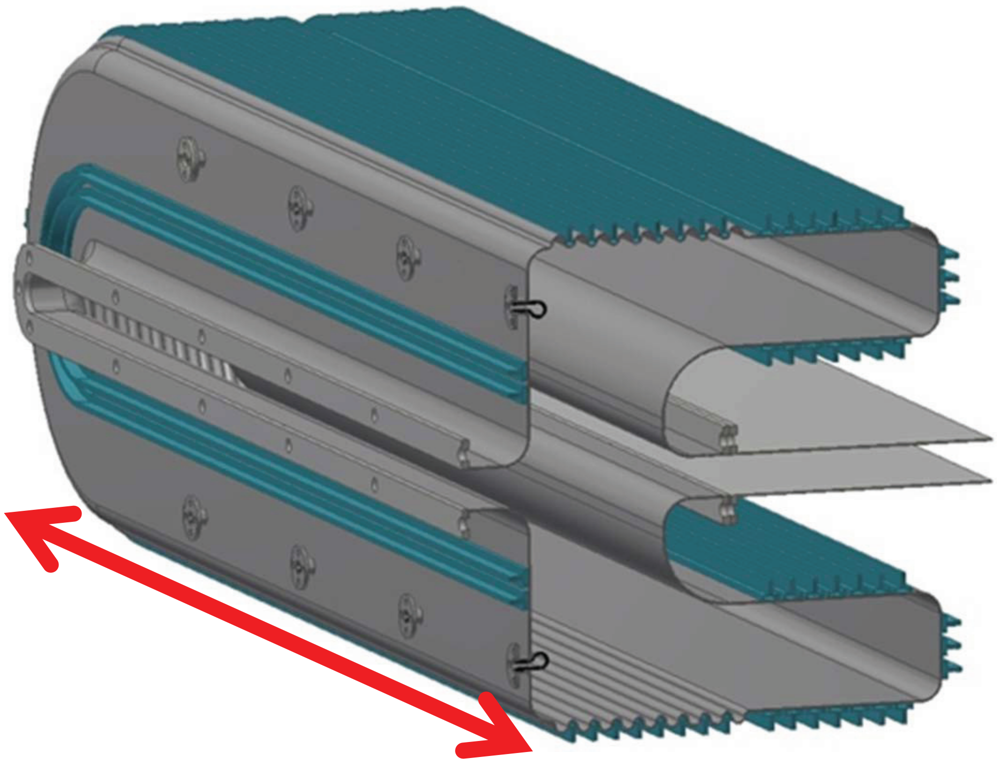
TAMU 100 – 3 flux-coupled cyclotrons

- **SRF Cavities**
- **Transport channels- quad and dipole windings**
- **116 MHz, *15 mA*, 100 MeV, 24 orbits**



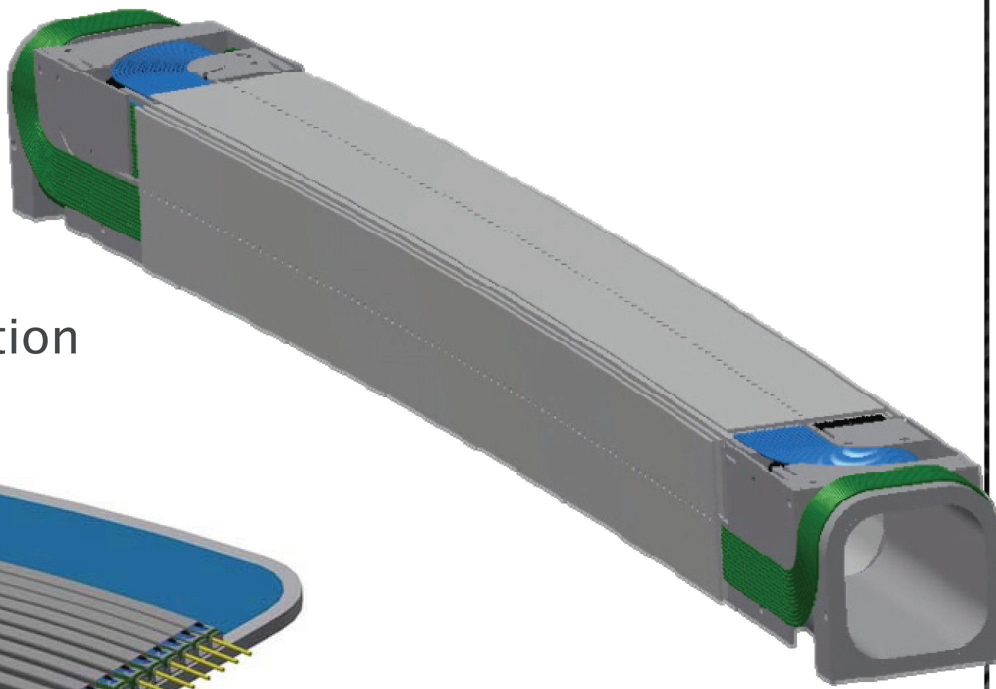
SRF Cavity

- 116 MHz
- Max E-field 21 MV/m
- Max B-field 54 mT
- ~2 MV gain per cavity
- 24 turns
- Provides minimum orbit separation of 5.6 cm

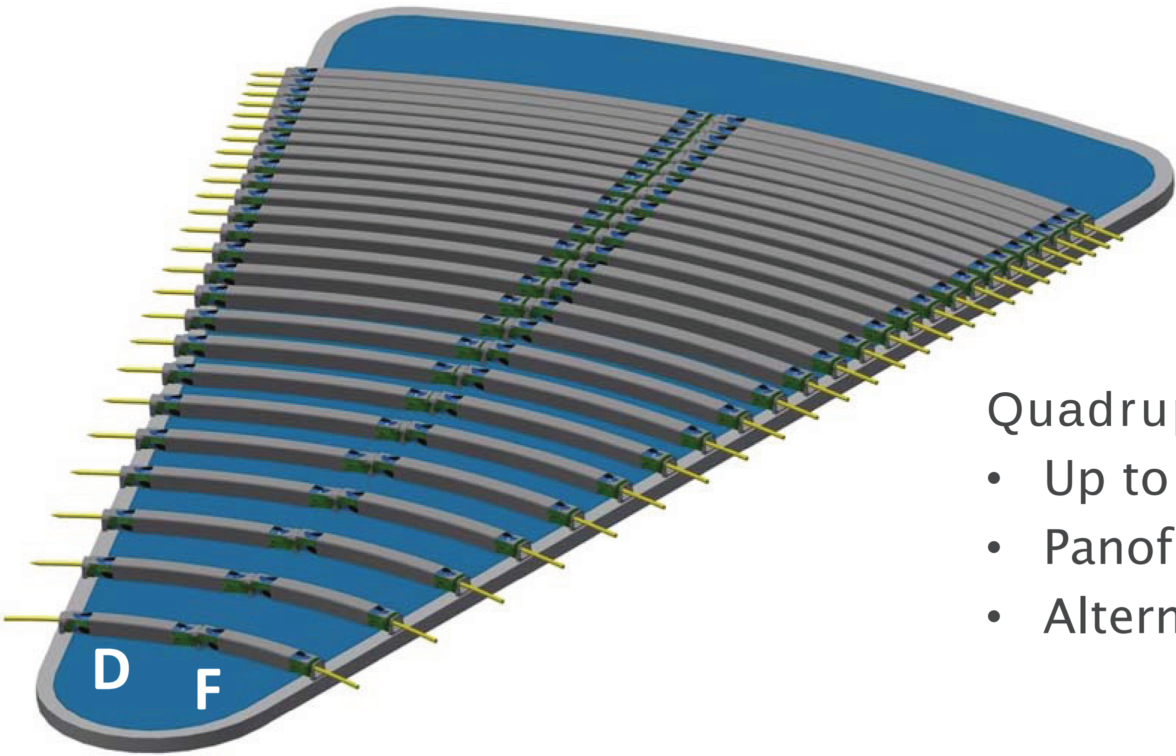


2.8 m, half length

Beam Transport Tubes



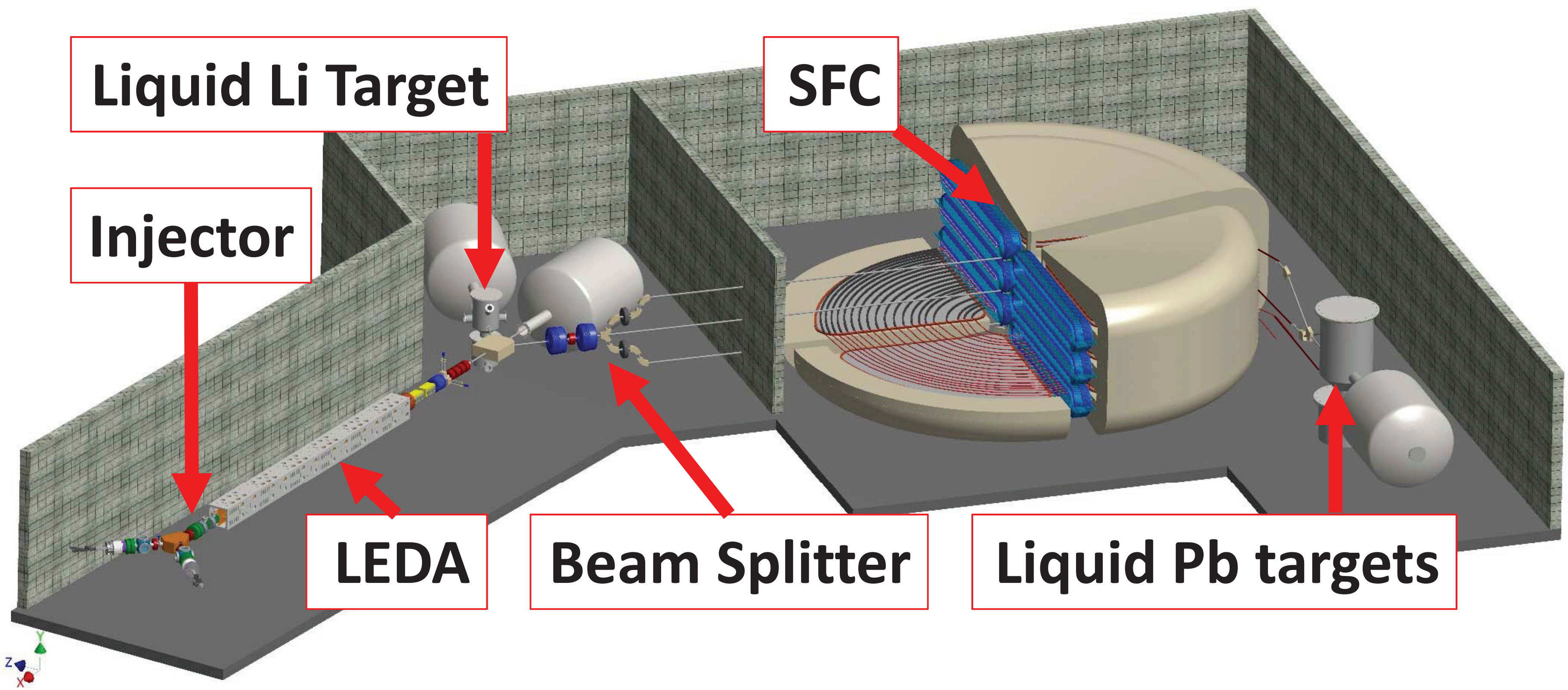
Dipole Windings
- Up to 20 mT
- Act as corrector for isochronicity,
- Septum for injection/extraction



Quadrupole Windings
- Up to 6 T/m
- Panofsky style
- Alternating-gradient focusing

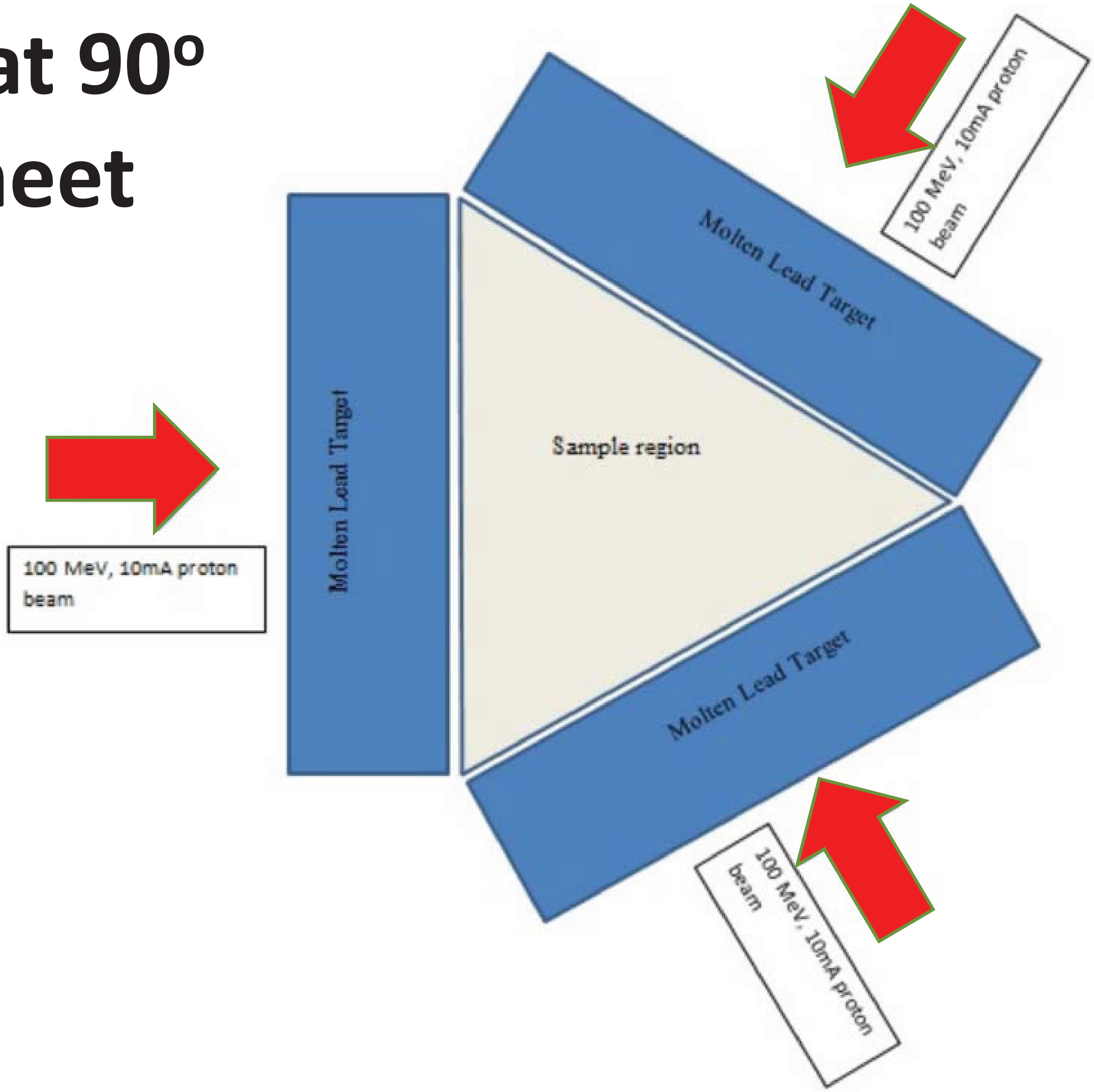
AND – Phase 2

3 beams are directed to 3 liquid Pb targets



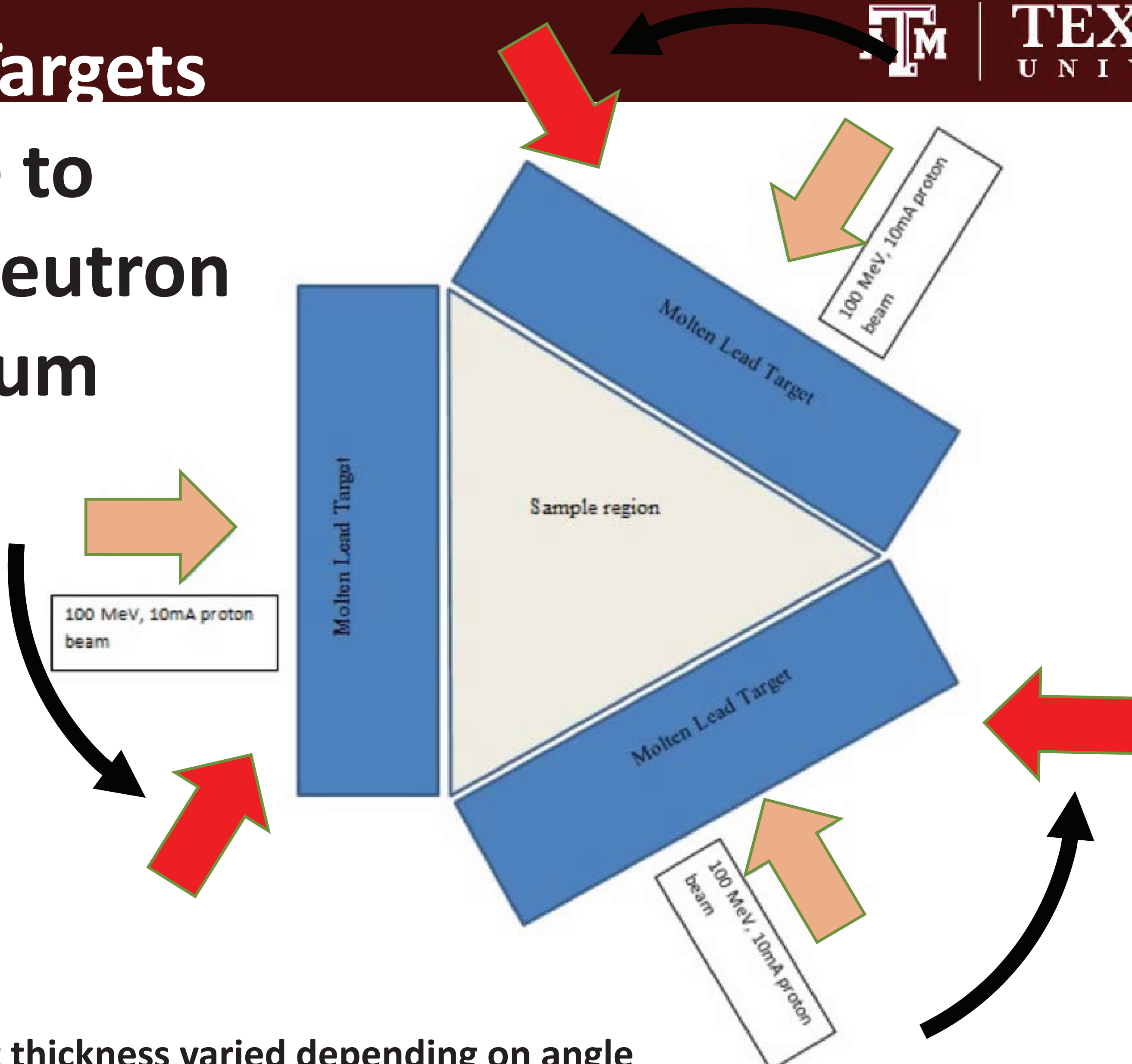
Lead Target for AND 2

Beams at 90º to Pb sheet



Pb Targets

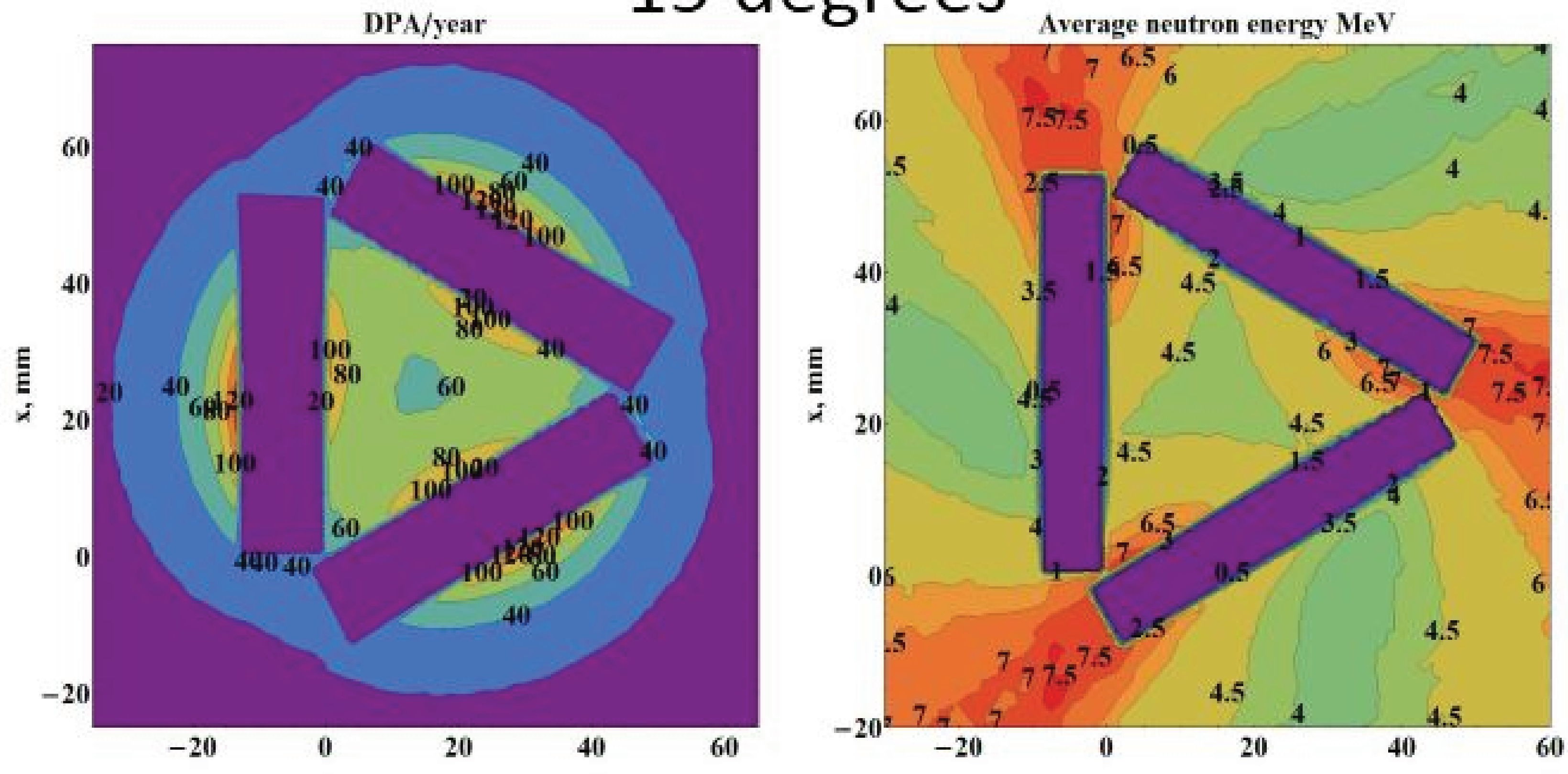
Rotate to tune neutron spectrum



Sheet thickness varied depending on angle

AND 2 Neutron Damage

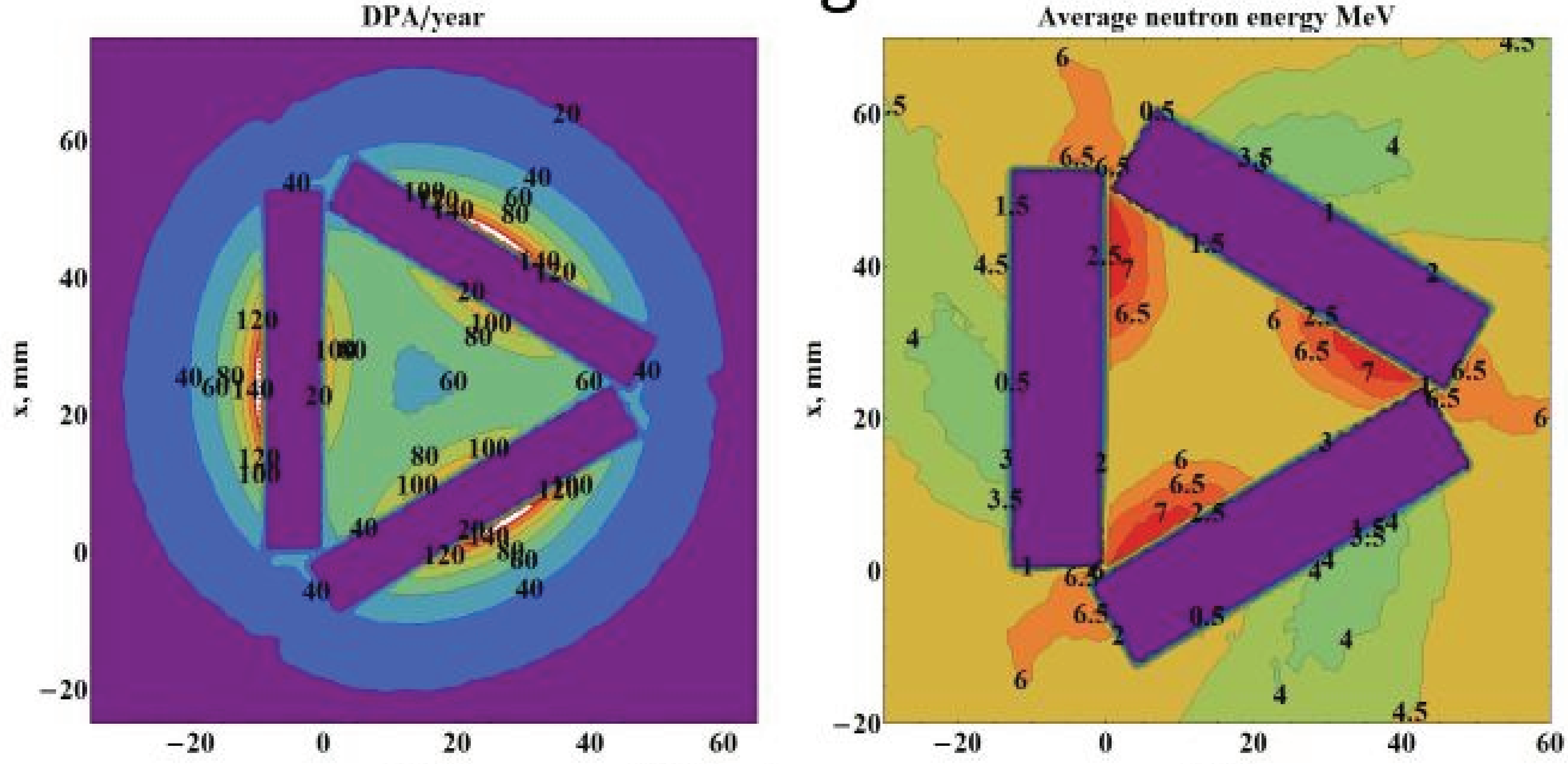
15 degrees



Average neutron energy of 4.5 MeV, minimum 50 dpa/year

AND 2 Neutron Damage

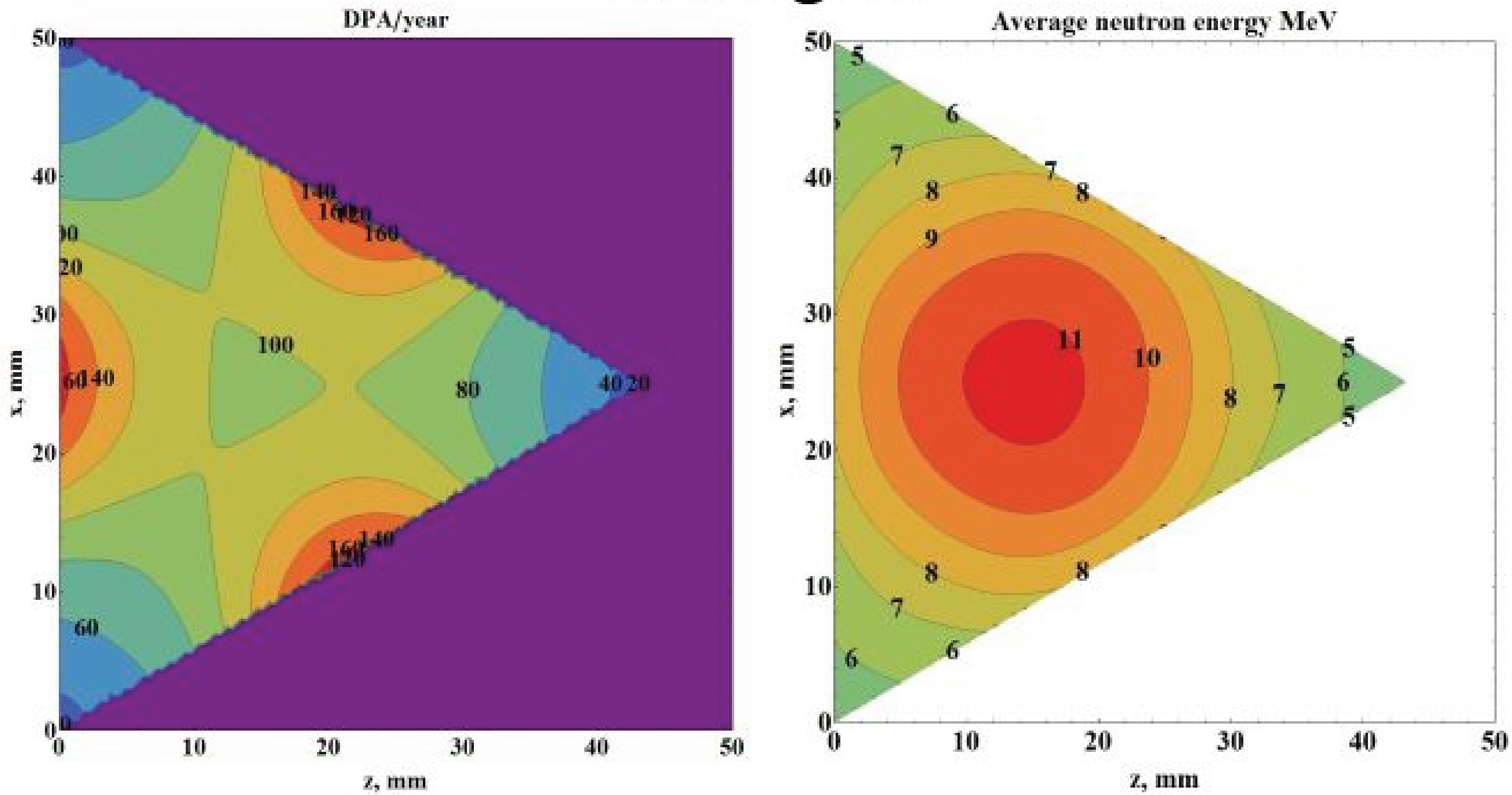
30 degrees



Average neutron energy of 5.5 MeV, minimum 60 dpa/year

AND 2 Neutron Damage

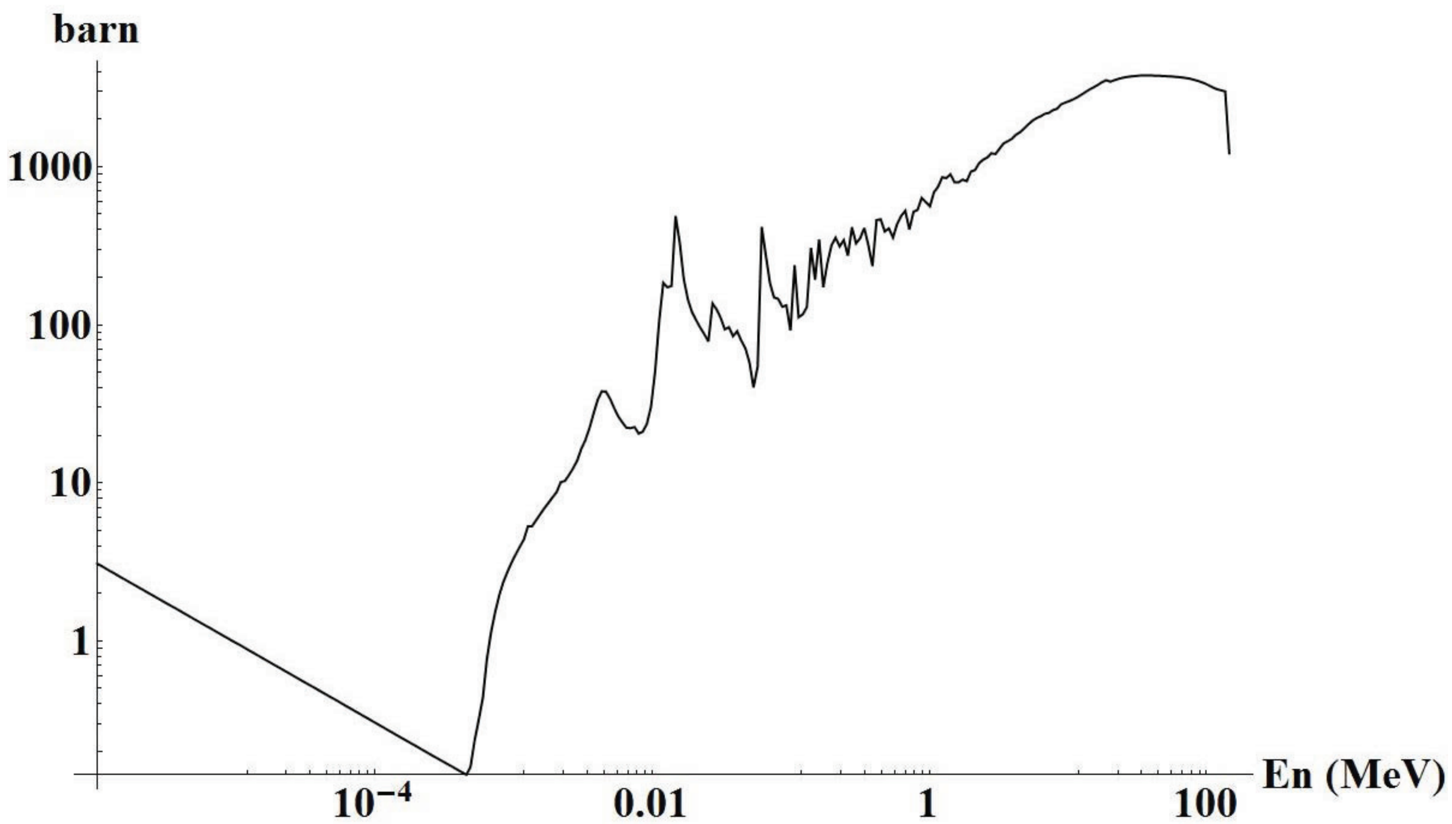
90 degrees



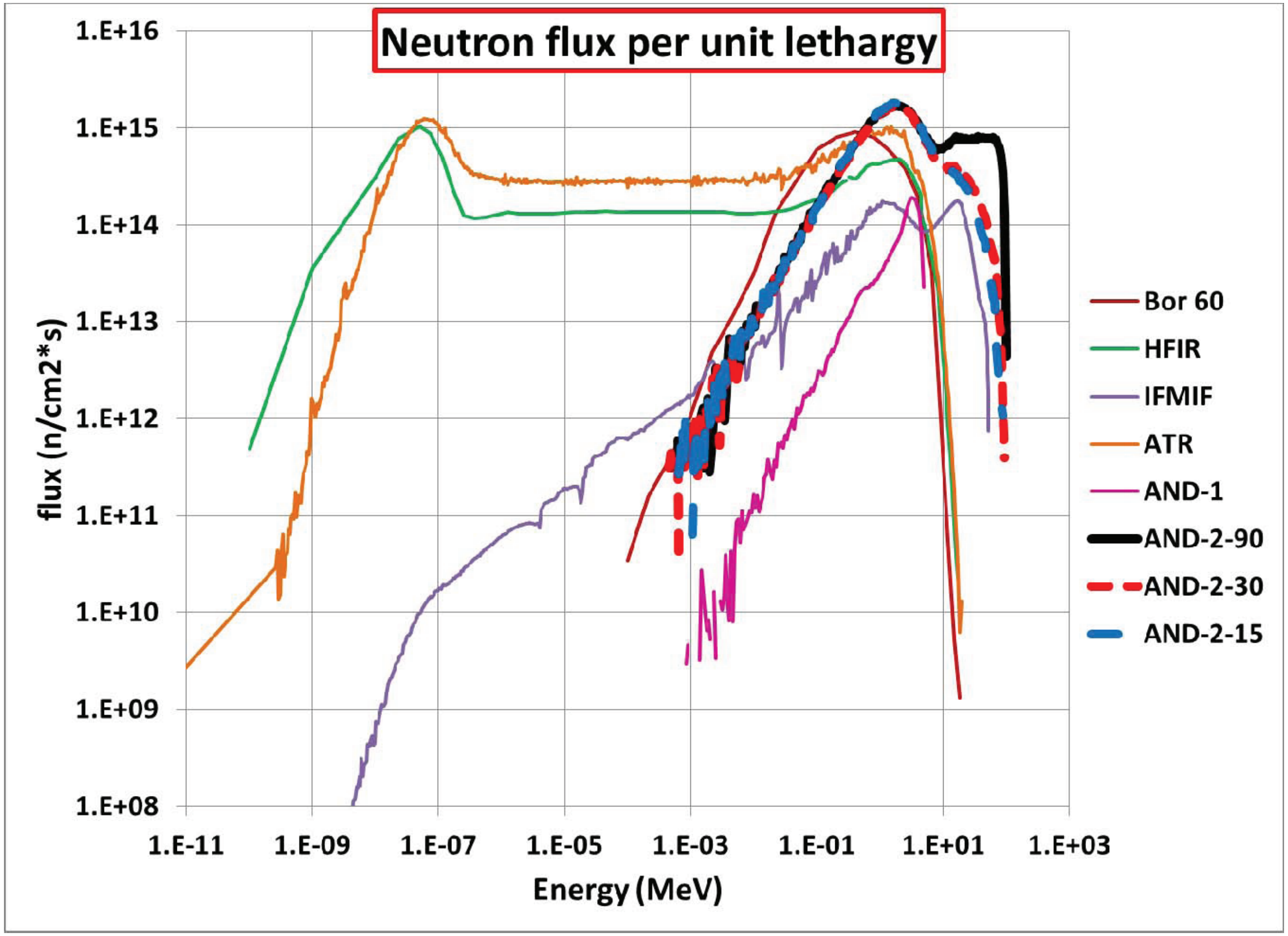
Average neutron energy of 8 MeV, maximum 160 dpa/year

Facility Comparison

dpa cross section as function of energy

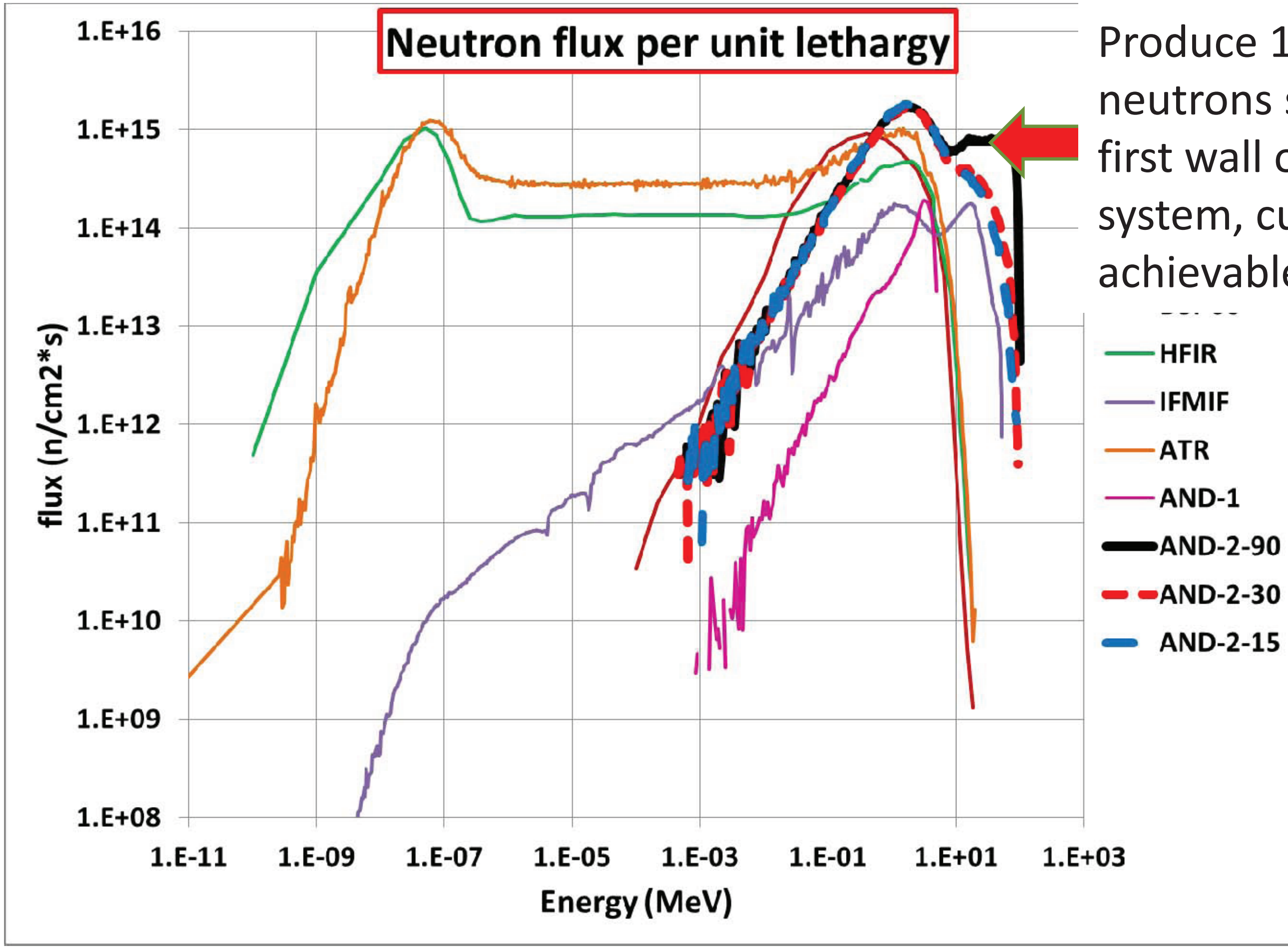


Facility Comparison



Various facilities' neutron flux and energy spectrum compared to AND 1 and AND 2 (at various angles). We can tailor to any average energy.

Facility Comparison



Produce 14 MeV neutrons seen by the first wall of a fusion system, currently not achievable.

Various facilities' neutron flux and energy spectrum compared to AND 1 and AND 2 (at various angles). We can tailor to any average energy.

Qualify Materials for Nuclear Applications

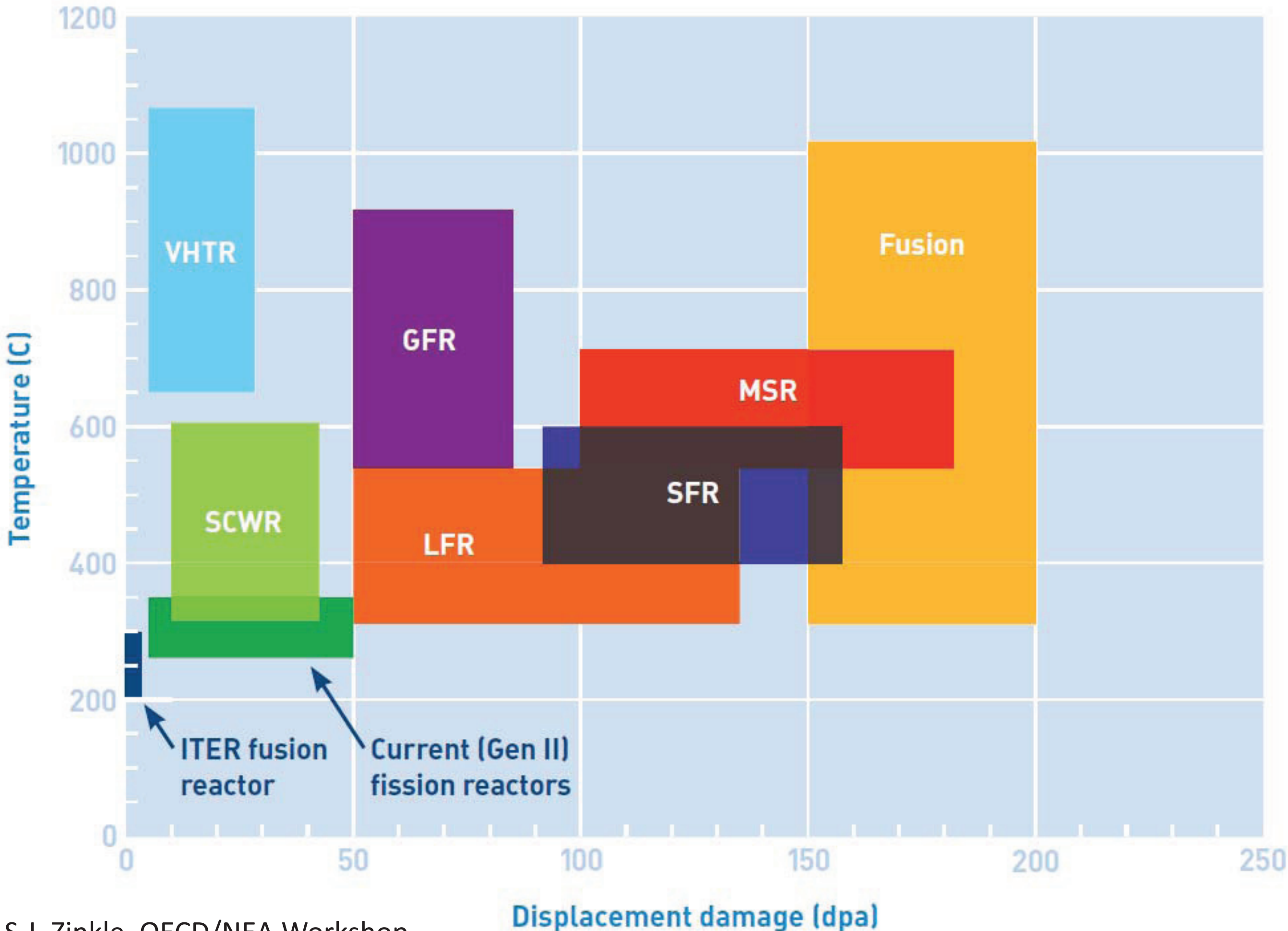
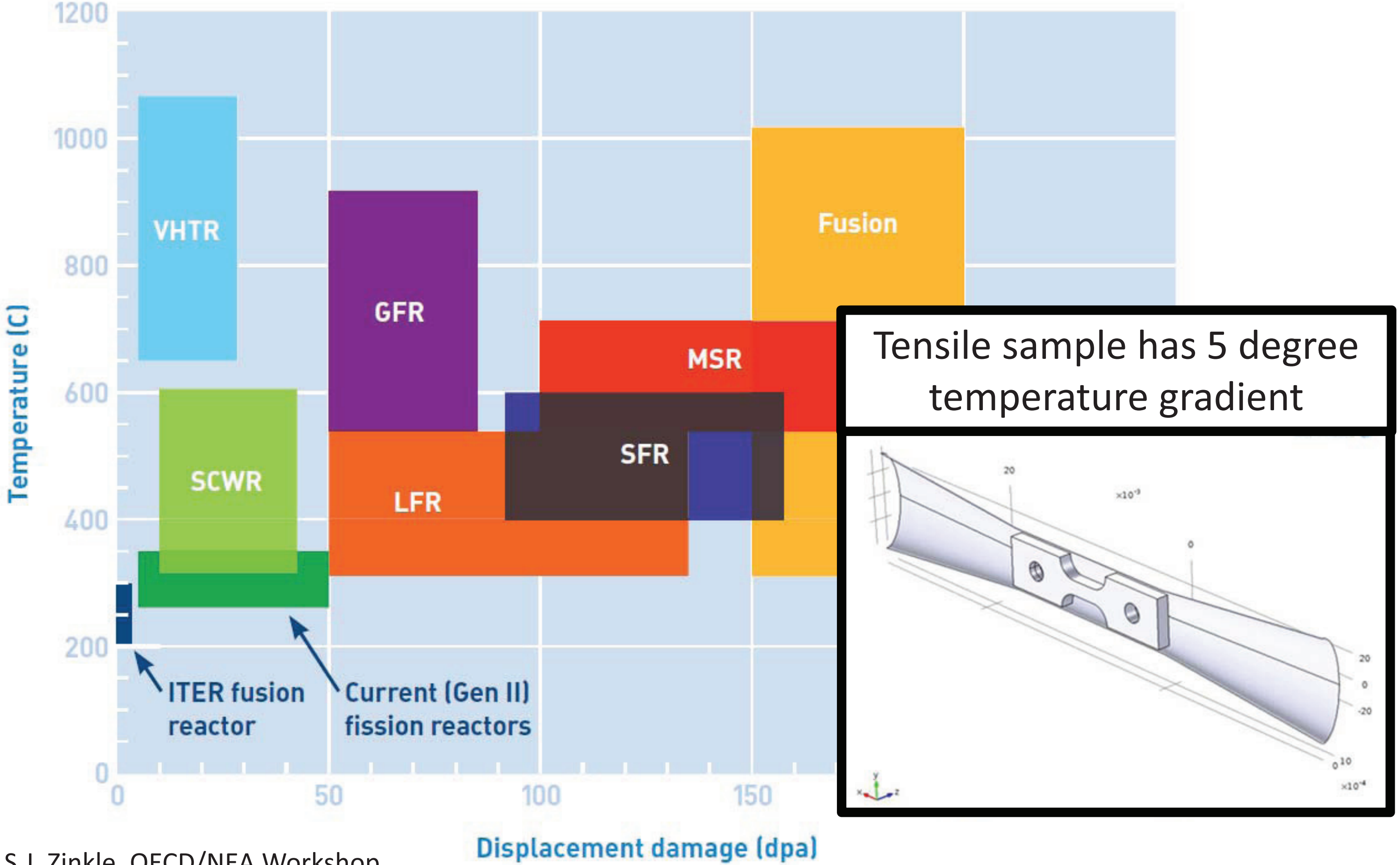


Image source: S.J. Zinkle, OECD/NEA Workshop on Structural Materials forInnovative Nuclear Energy Systems, Karlsruhe, Germany, June 2007

Qualify Materials for Nuclear Applications

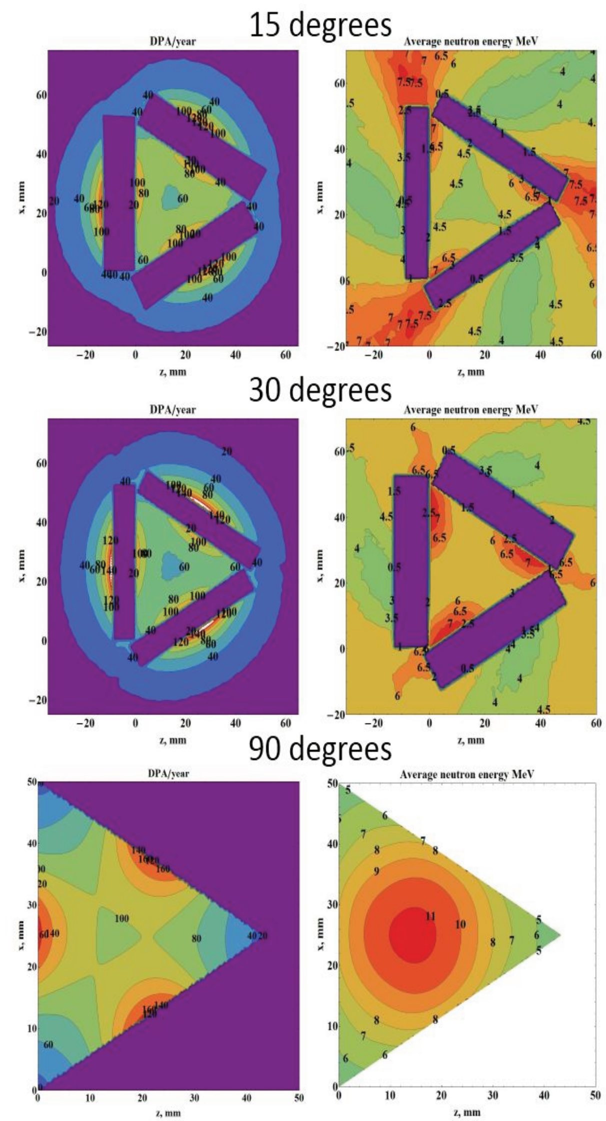


Tensile sample has 5 degree temperature gradient

Image source: S.J. Zinkle, OECD/NEA Workshop on Structural Materials forInnovative Nuclear Energy Systems, Karlsruhe, Germany, June 2007

Summary

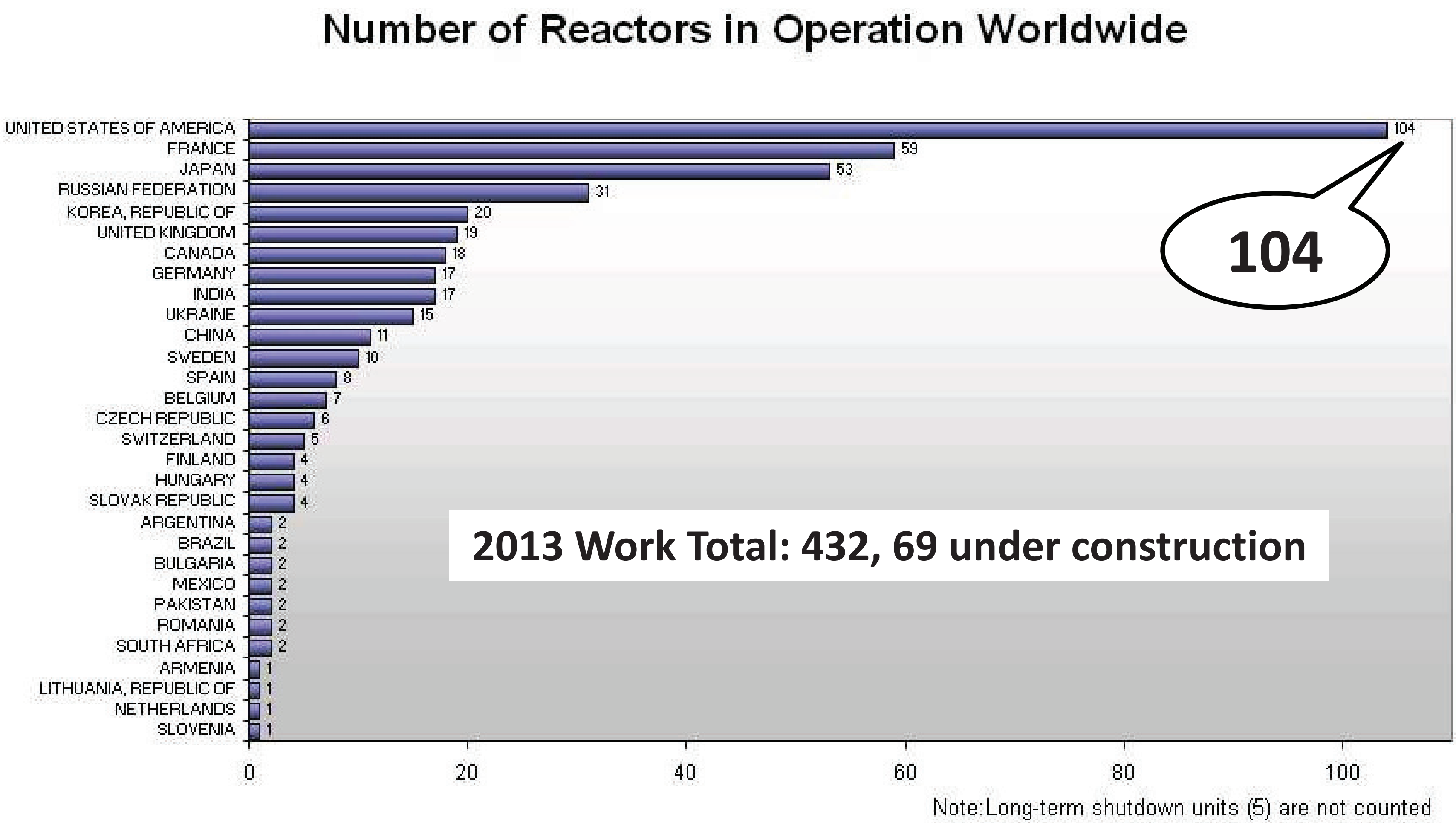
- AND 1 should provide proof of concept for Injector, LEDA, and Li Sheet flow
- SFC can provide high current (15 mA) at high energy (useful for ADS)
- Samples can be created to compare to with current user facilities
- Prediction of lifetime and properties cannot be performed with ions
  - must use neutrons
- AND 2 can produce >150 dpa/year of neutron damage through 21 bulk samples, in a controlled environment, simultaneously.



From Meimei Li, Argonne National Laboratory

Thank You for Listening

Qualify Materials for Nuclear Applications



2013 Work Total: 432, 69 under construction

Motivation

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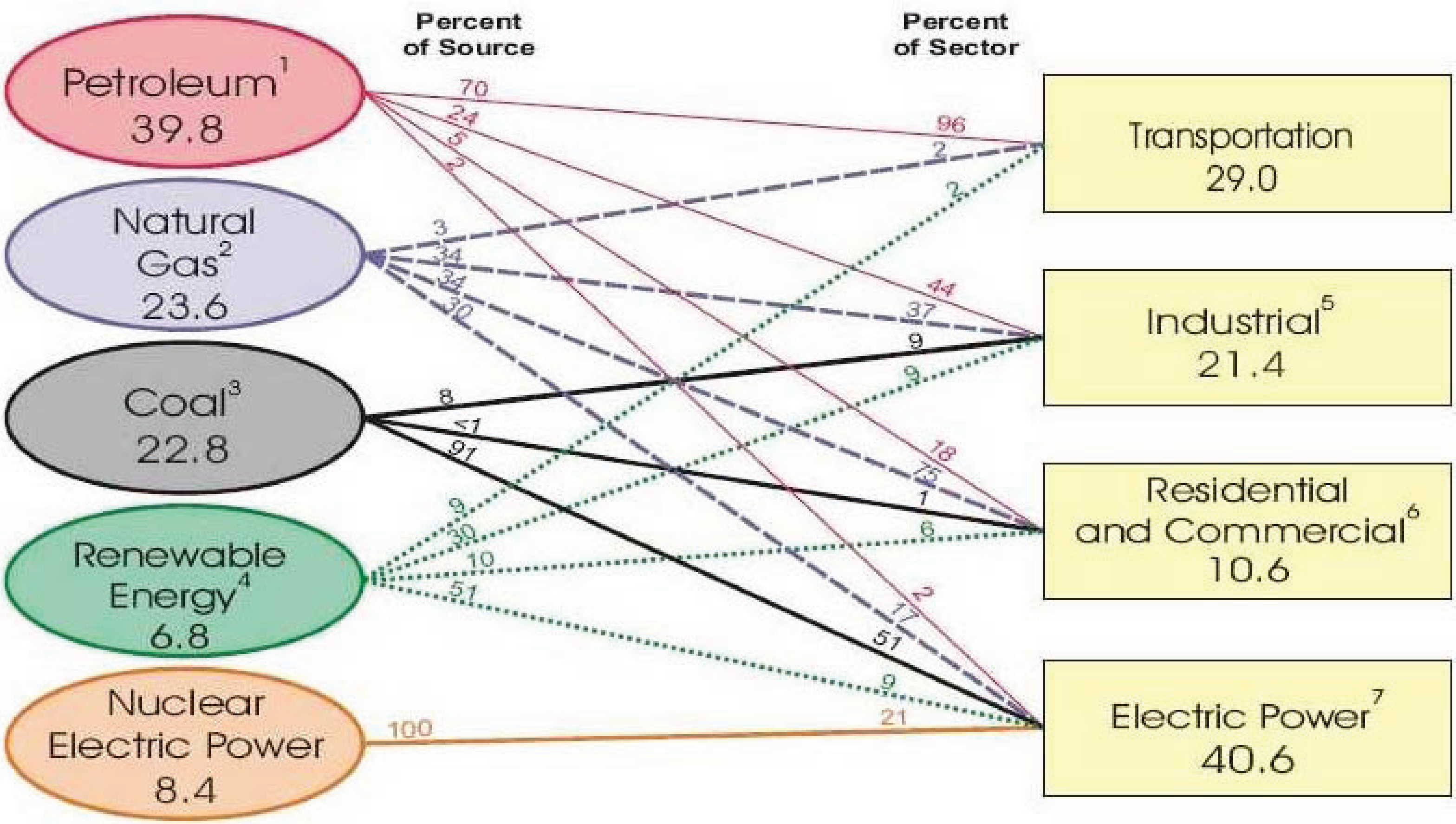
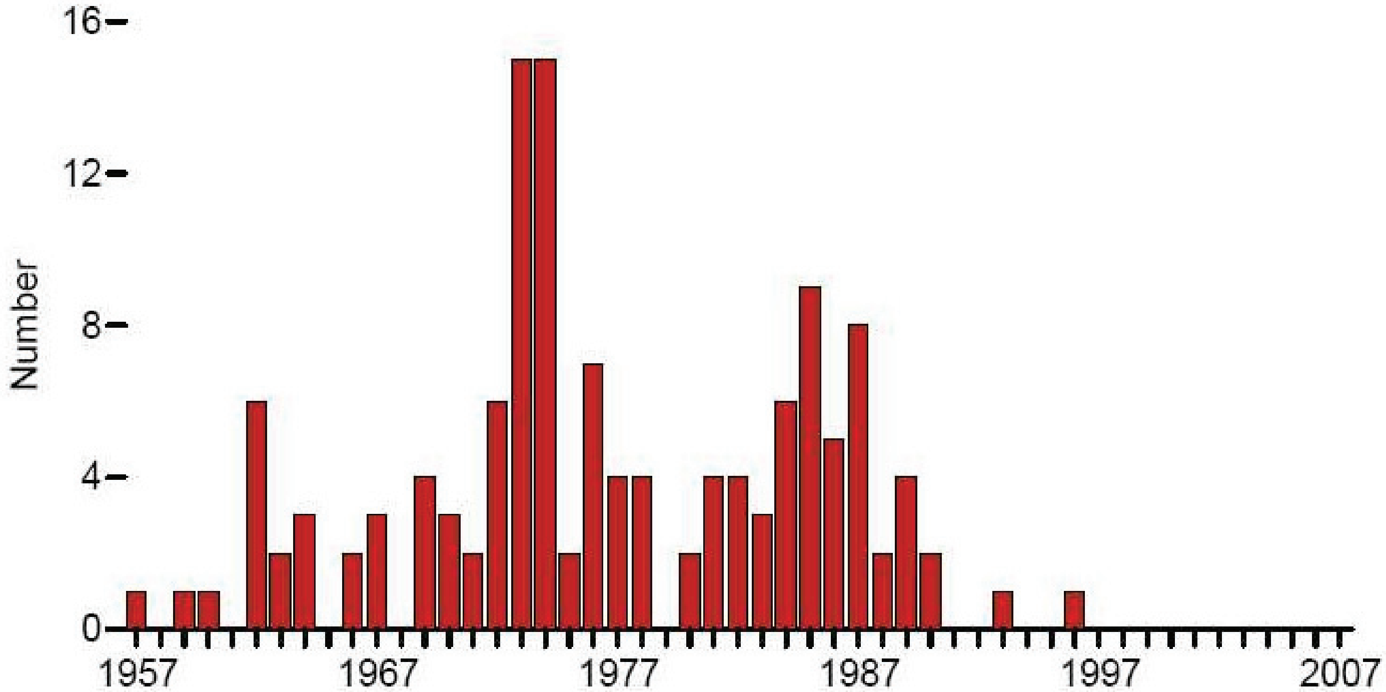
Qualify Materials for Nuclear Applications



8.4 % of total energy consumed, but 21 % of electrical power

Motivation

Figure 50. Full-Power Operating Licenses Issued



A total of 132 full-power operating licenses, or equivalent permission, were issued in the United States since the industry got its start in the 1950s. Most of the licenses were granted between 1962 and 1990. After 1990, one license was issued in 1993 and one in 1996.