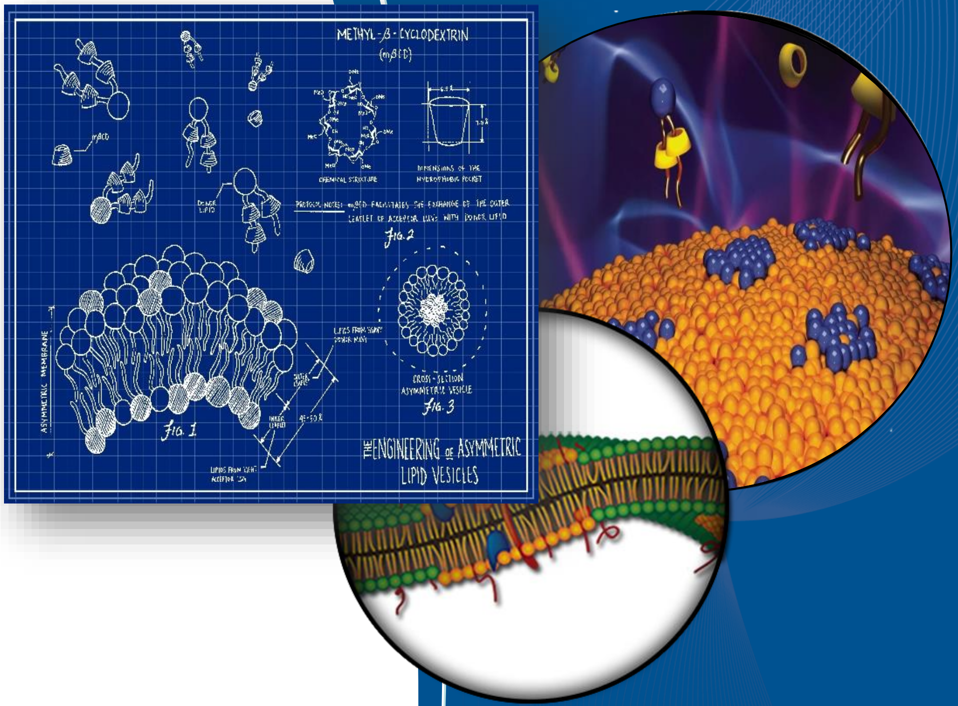
A CANS for Canada: A future neutron source for Canada



Drew Marquardt

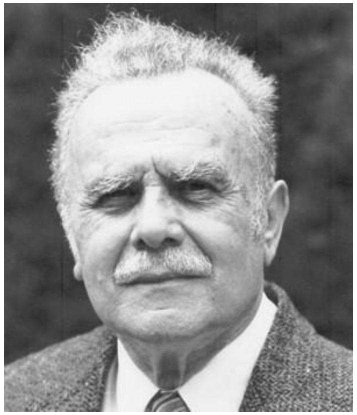
Department of Chemistry and Biochemistry

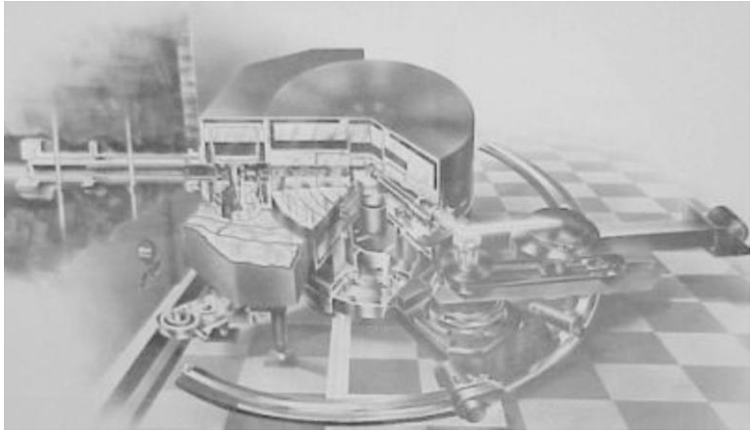
University of Windsor

Beam-based Probes of Condensed Matter Physics, Chemistry and Related Fields in Canada Virtual Meeting
June 3, 2021

Rich History of Neutron Scattering

- **1994 Nobel Prize in Physic – Bertram Brockhouse**
  - For the development of neutron scattering techniques for studies of condensed matter.
- Confirmed the existence of topological materials
  - Prediction of such materials was the subject of the 2016 Nobel Prize in Physics





Neutron’s Impact in Canada

- Clean environment
  - Improved the reliability of turbines in hydroelectric dams.

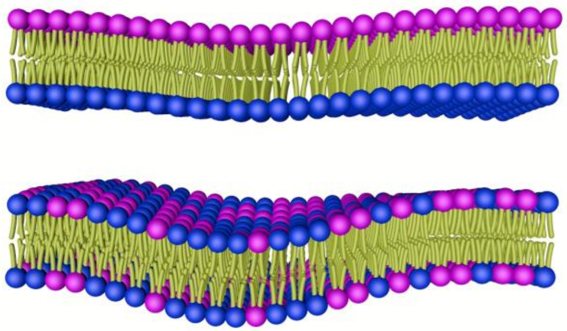
- Economic competitiveness
  - Developed methods of reducing scrap waste during manufacturing.

Neutron's Impact in Canada

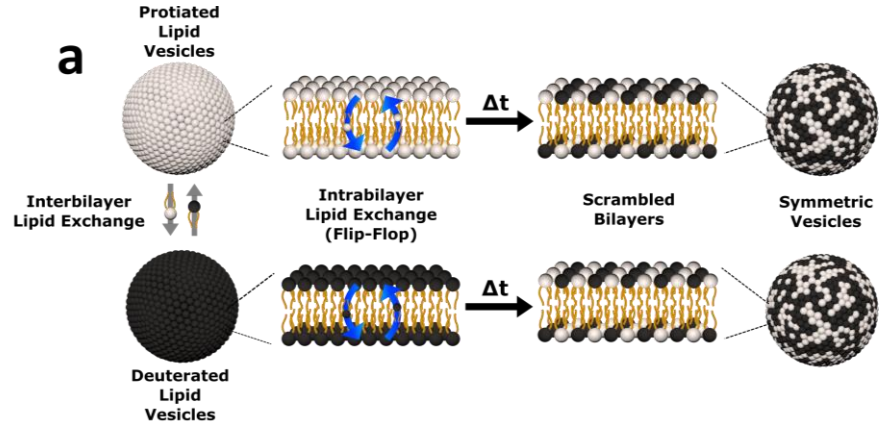
- Safety and security
  - Extended the lives of Canada's fleets of ships.

- Health and food security
  - Accelerate the development of drought resistant crops.

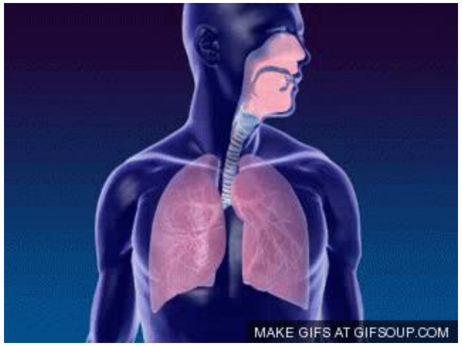
Biological connection



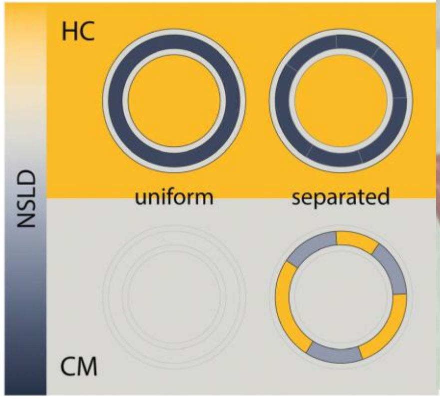
Nanoscale, 2020,12, 1438-1447

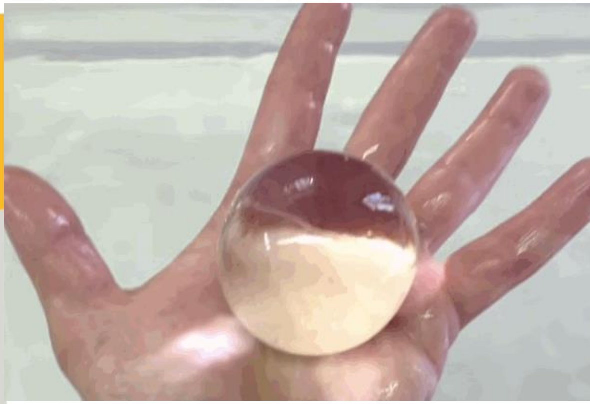


New J. Chem., 2021, 45, 447-456
Biophys. J., 2019, 116, 5, 755-759



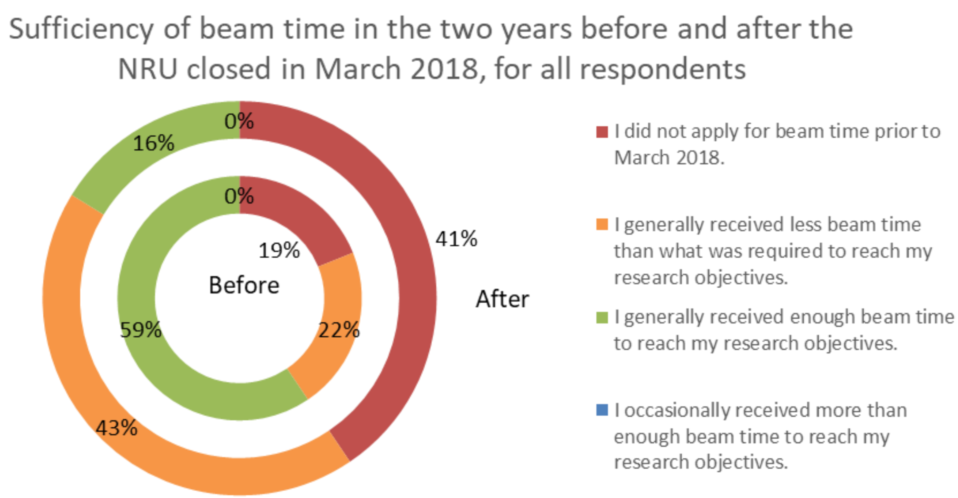
Chem. Res. Toxicol., 2020, 33, 9, 2432–2440
BBA-Biomembr., 2020, 1862, 9, 183189

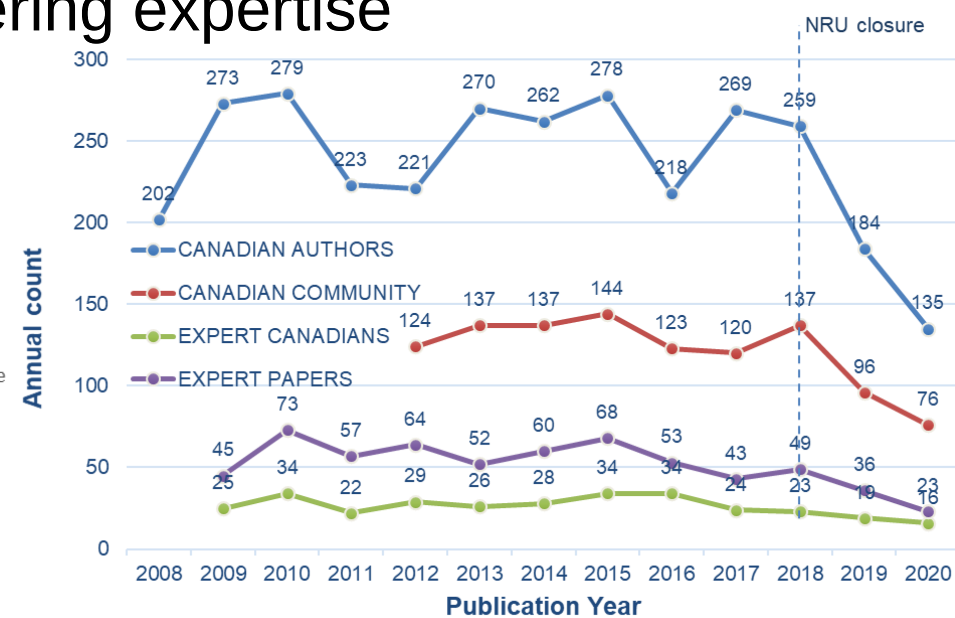




Neutron Scattering Challenges

- 40% of users have not conducted an experiment since the NRU closed (March 2018)
- Exploratory experiments
- Expand the user base without a domestic source
- Retention of neutron scattering expertise





CANADIAN INSTITUTE FOR NEUTRON SCATTERING

* The neutron **user community** is defined as those with 2 publications in a 5 year period using neutron beams.
The **expert community** is defined as those with 4 publications in a 2 year period using neutron beams

Short-term and Long-term Efforts

https://wegotthiscovered.com/tv/pinky-brain-returning-animaniacs-revival/

Researcher Led Canadian Initiatives

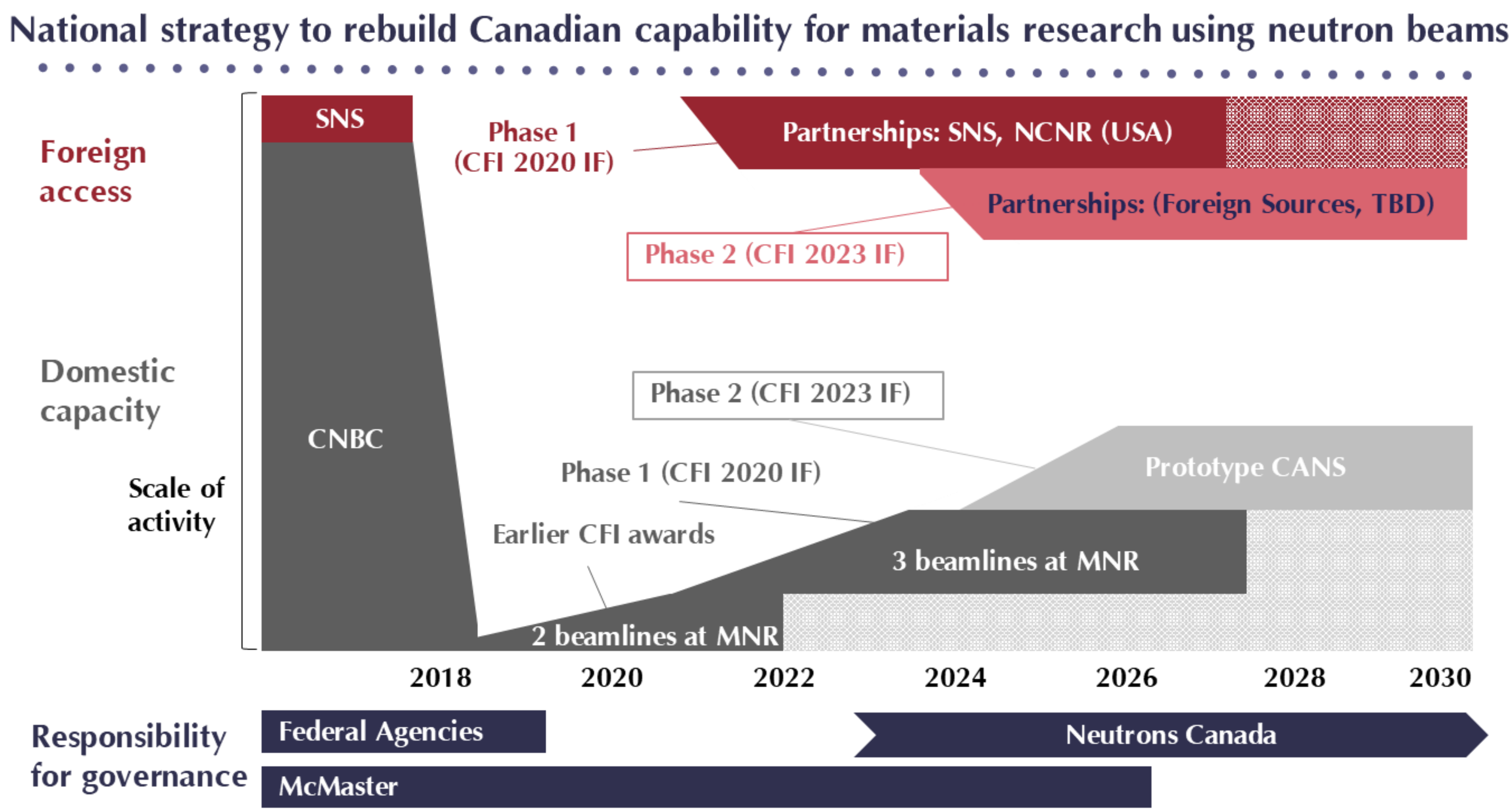
CFI-IF McMaster et al.

- $14.25M (~$47M total)
- Upgrade MNR neutron scattering facilities
- Foreign access
- Bridge the next 5-10 years

Windsor & TRIUMF et al.

- NFRF- E (awarded)
  - CANS design study
- **CFI-IF** (in preparation)
  - Construction of CANS prototype
  - Further foreign access
- Potential long-term source for Canada.

National Strategy



Sources of Neutrons

- Fission Reactor → U^{235} + *n* (thermal)
  - Expensive ~$1B
- Spallation → “blowing chunks” (*p*,*n*)
  - Expensive ~$1-2B
  - High energies
- Stripping-Reaction → Be/Li(p,n)
  - Low energy = small footprint = inexpensive
  - Modular
  - **Compact Accelerator Neutron Source (CANS)**

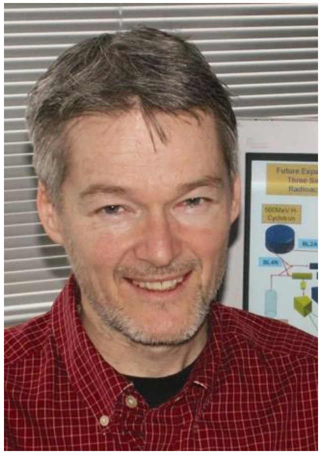
Prototype Canadian CANS (PC-CANS)

University of Windsor-led initiative to construct and operate a Compact Accelerator-based Neutron Source (CANS)

- 40 researchers from 19 institutions spanning 4 countries

Heavy Lifting

Oliver Kester (TRIUMF)

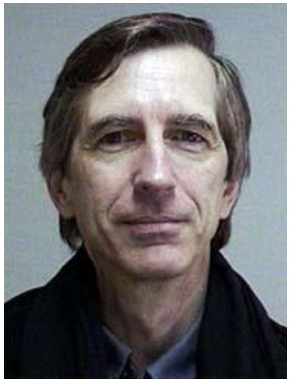


Bob Laxdal (TRIUMF)

Alex Gottberg (TRIUMF)

Mina Abbaslou (TRIUMF)

Dalini Maharaj (UWindsor)



Thomas Gutberlet (Julich)

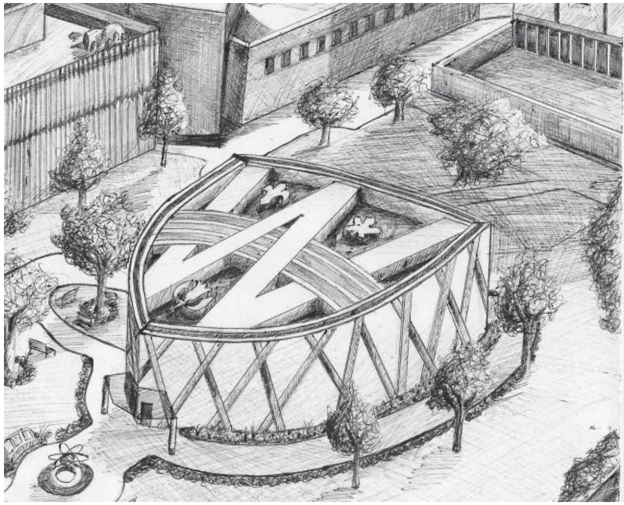
Zin Tun

PC-CANS: Missions

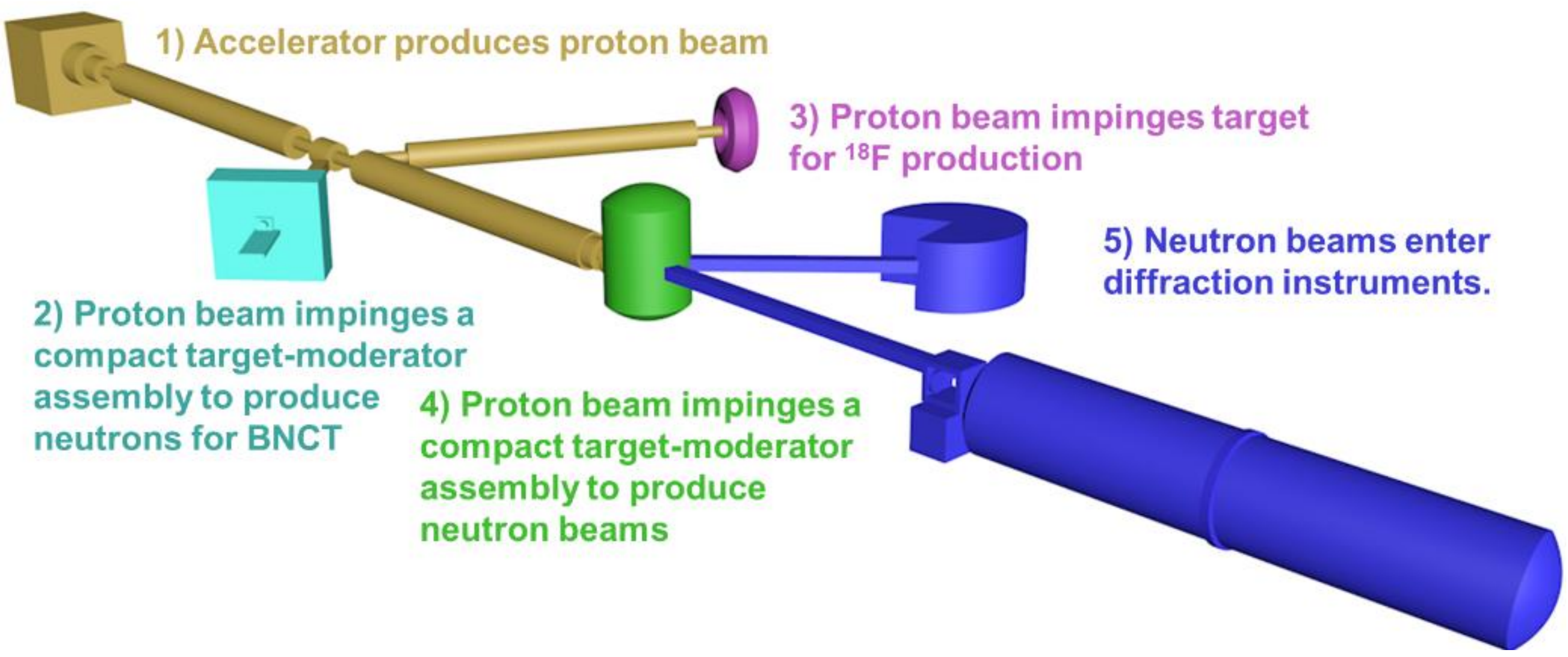
1. Construct a world-leading CANS prototype to demonstrate the potential for the technology

2. Conduct research using the following neutron methods:
   - Small-angle neutron scattering or PDF analysis
   - Diffraction/Neutron imaging
   - Boron Neutron Capture Therapy (BNCT)

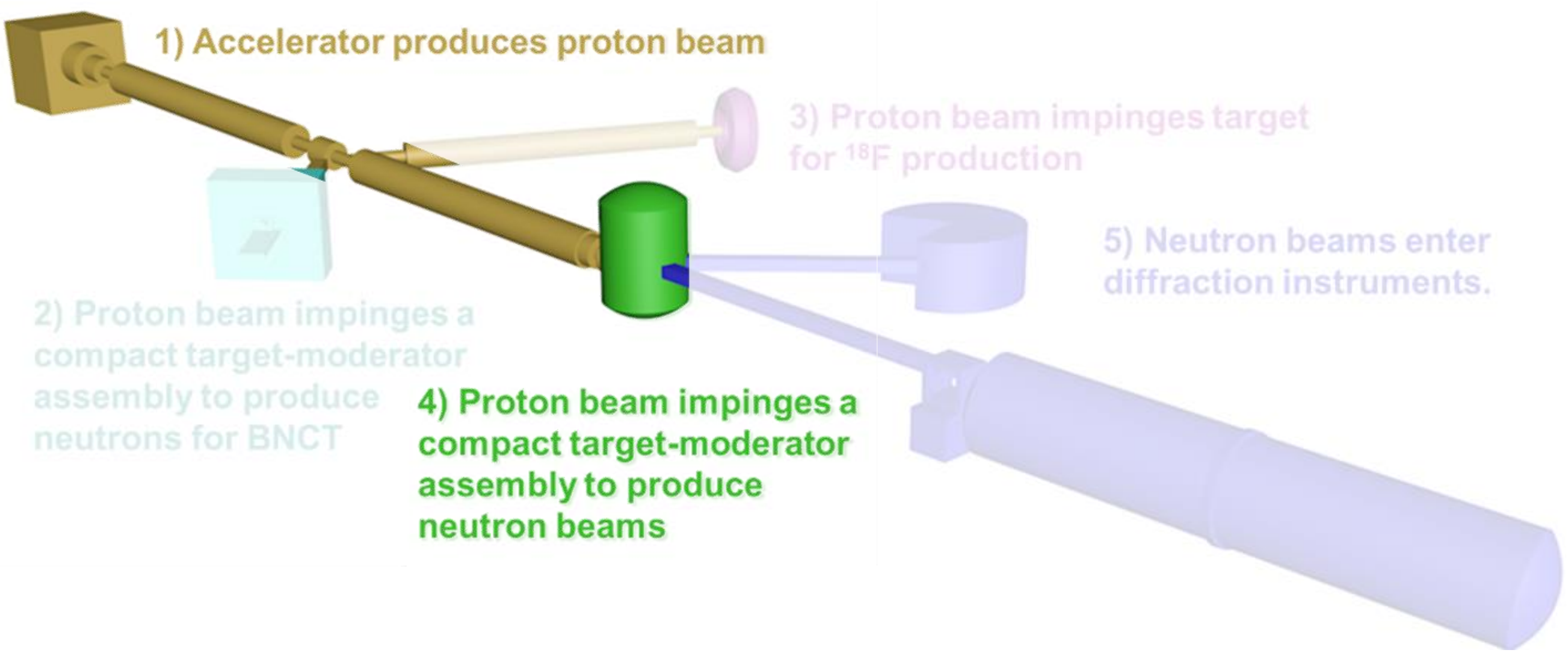
3. Supply Windsor Regional Hospital with Fluorine-18 isotope for the PET scanner



Prototype Canadian CANS: PC-CANS



PC-CANS: Neutron Production

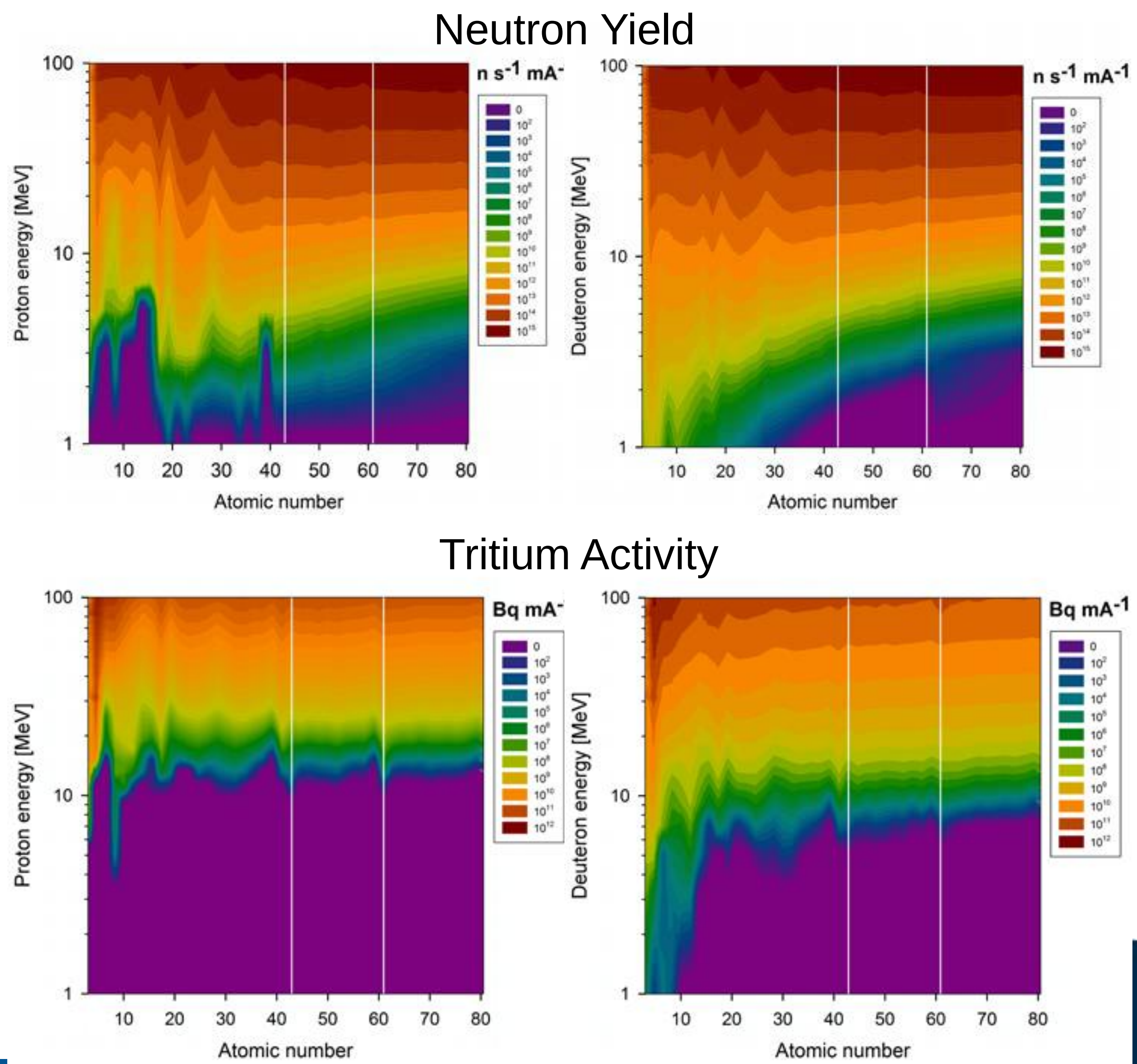


Target-Moderator Research

- Accelerator requirements for:
  - Neutron scattering
  - BNCT
  - Isotope production
- Target material and geometry
  - How to handle the high powers on target
  - Multiple targets?
  - Optimized extraction strategy
- Build from our friends at Julich and in Japan

Energy-Ion-Target Considerations

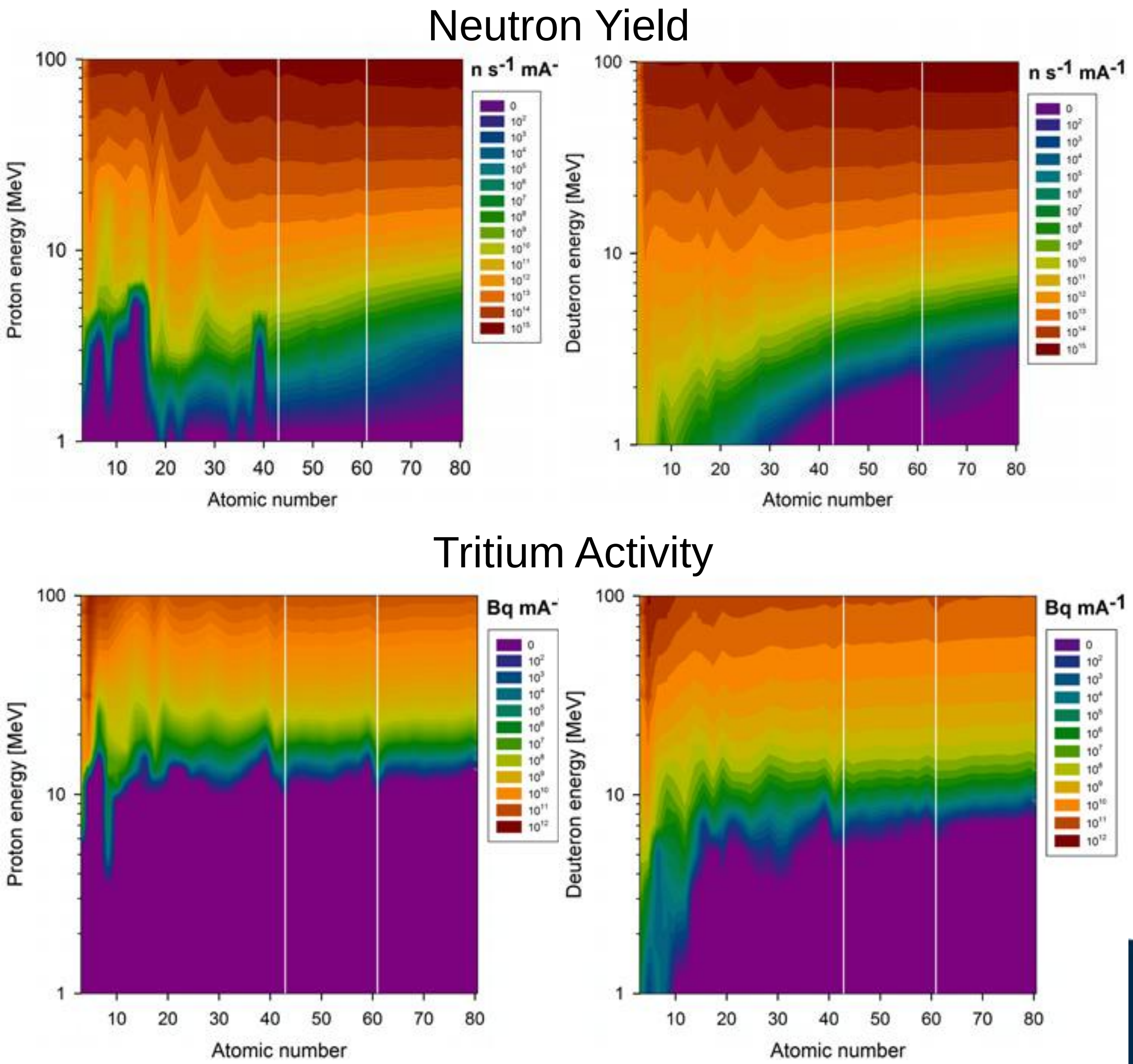
- Energy
  - ^{18}F production
  - Radiation safety
- Ion
  - Proton or deuteron
  - Accelerator needs
- Material
  - Handling needs



Conceptual Design Report Jülich High Brilliance Neutron Source (HBS)
T.Brückel, T. Gutberlet (Eds.)

Energy-Ion-Target Considerations

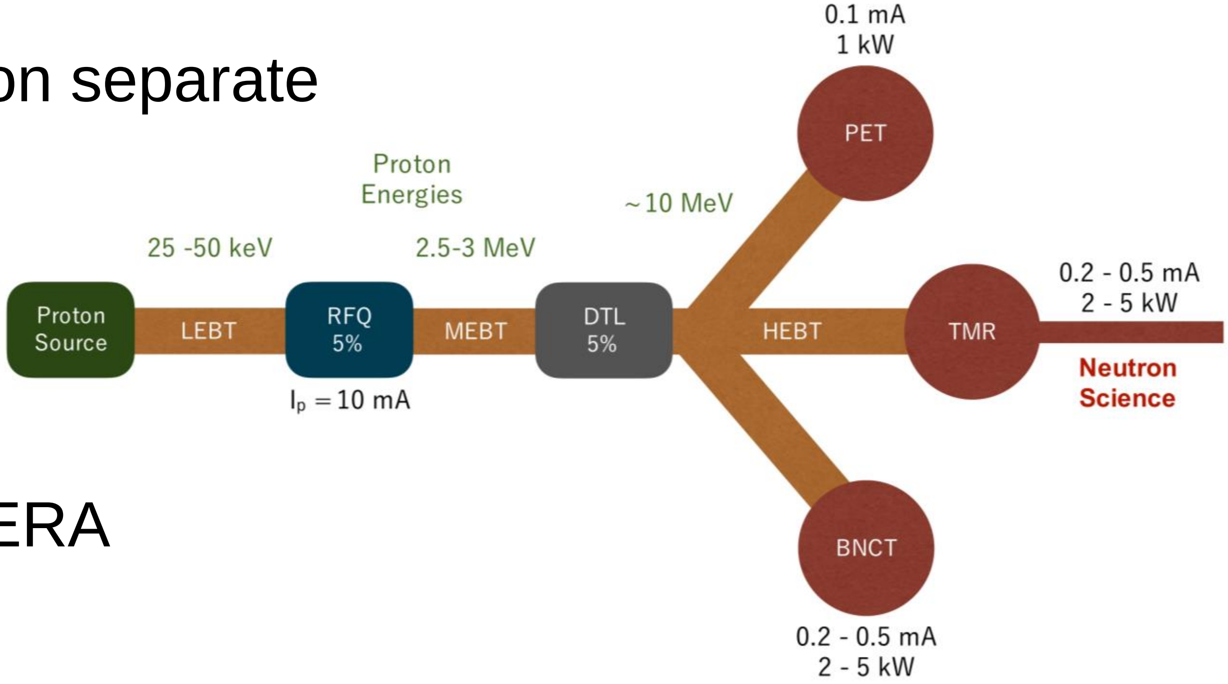
- **10 MeV**
  - Competitive ^{18}F yield
  - No tritium activity
- **Protons**
  - Simpler accelerator
  - Less tritium activity
- **Beryllium (Be) target**
  - Liquid lithium too hazardous for a university campus



Conceptual Design Report Jülich High Brilliance Neutron Source (HBS) T.Brückel, T. Gutberlet (Eds.)

Vision for PC-CANS

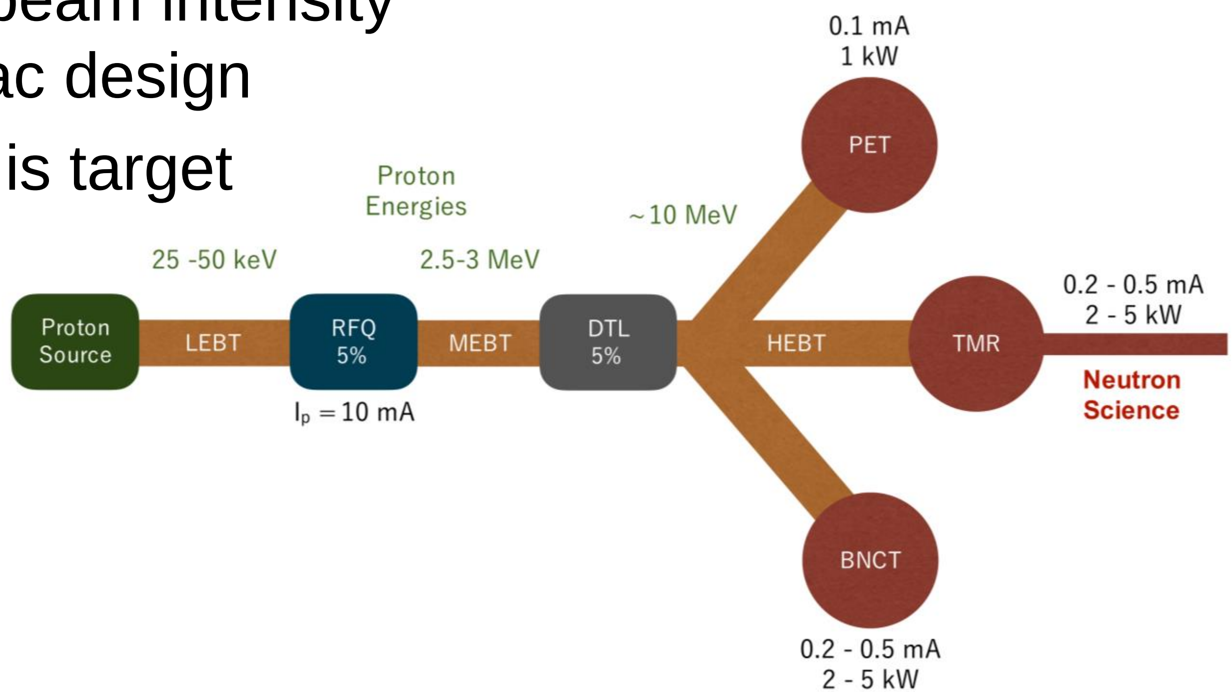
- Simultaneous or on separate operation
    - 1/5 NRU
    - 5-12 x NOVA ERA



Relative Performance		Conventional Sources	CANS
High	5–10+	SNS ($2B); ESS ($3B)	
Medium	1	ISIS ($850M); NRU (>$500M)	Canada-scale facility* ($100–$200M)
Medium–Low	1/5	MNR (>$100M)	**Our prototype*** ($10–$12M** + 3 instruments)
Low	1/25		NOVA ERA* ($6M** + 6 instruments); LENS; RANS

Vision for PC-CANS

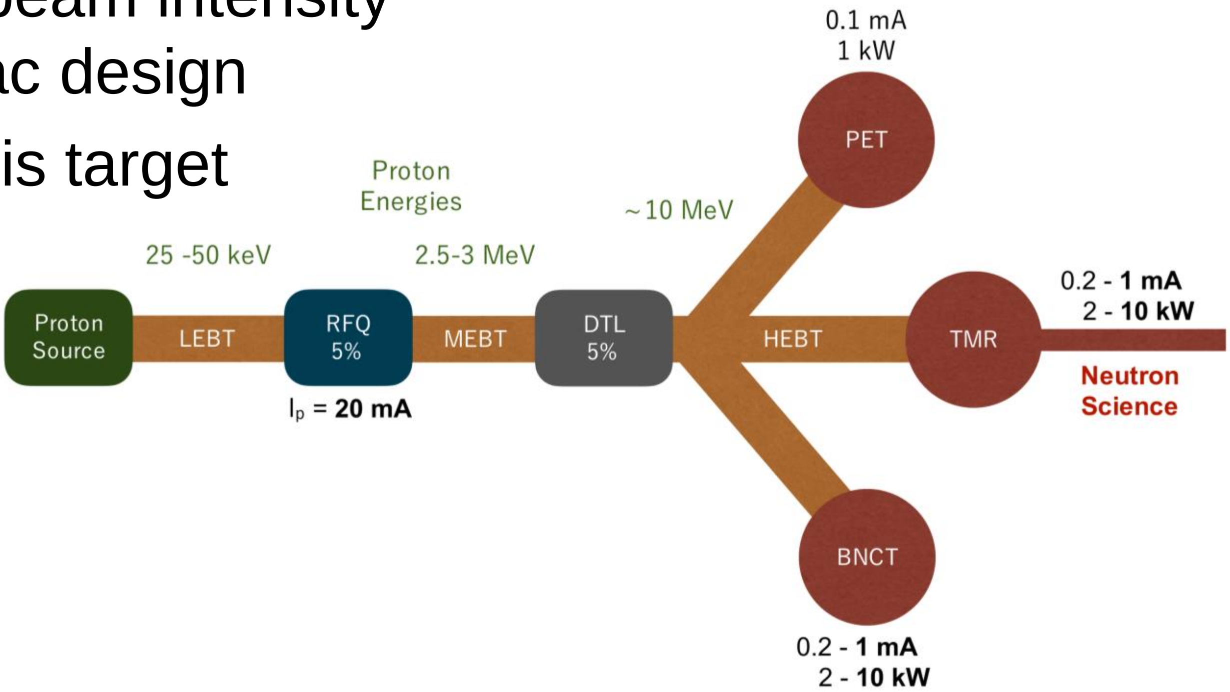
- Could double all beam intensity parameters in linac design
  - Limiting factor is target technology



Relative Performance		Conventional Sources	CANS
High	5–10+	SNS ($2B); ESS ($3B)	
Medium	1	ISIS ($850M); NRU (>$500M)	Canada-scale facility* ($100–$200M)
Medium–Low	1/5	MNR (>$100M)	**Our prototype*** ($10–$12M** + 3 instruments)
Low	1/25		NOVA ERA* ($6M** + 6 instruments); LENS; RANS

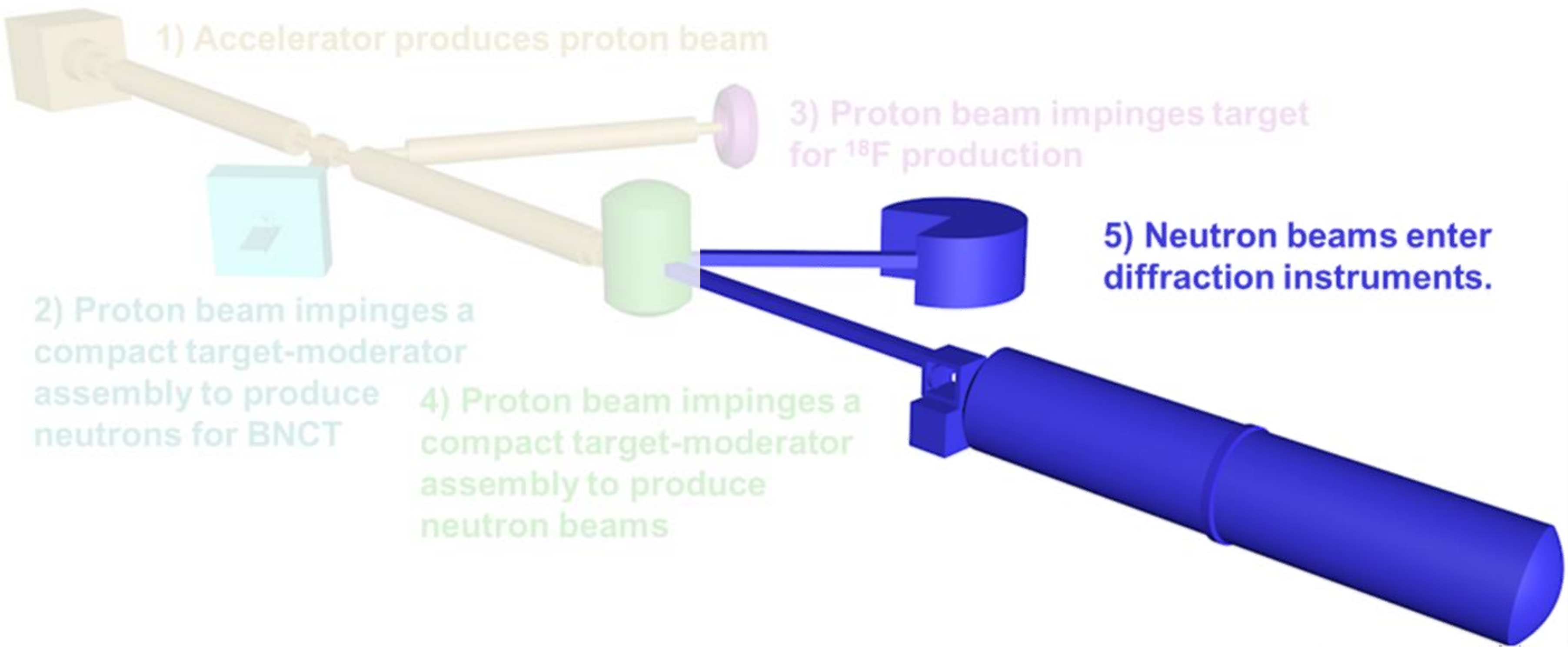
Vision for PC-CANS

- Could double all beam intensity parameters in linac design
  - Limiting factor is target technology
- **<u>1 NRU</u>**
- 10-25 x NOVA



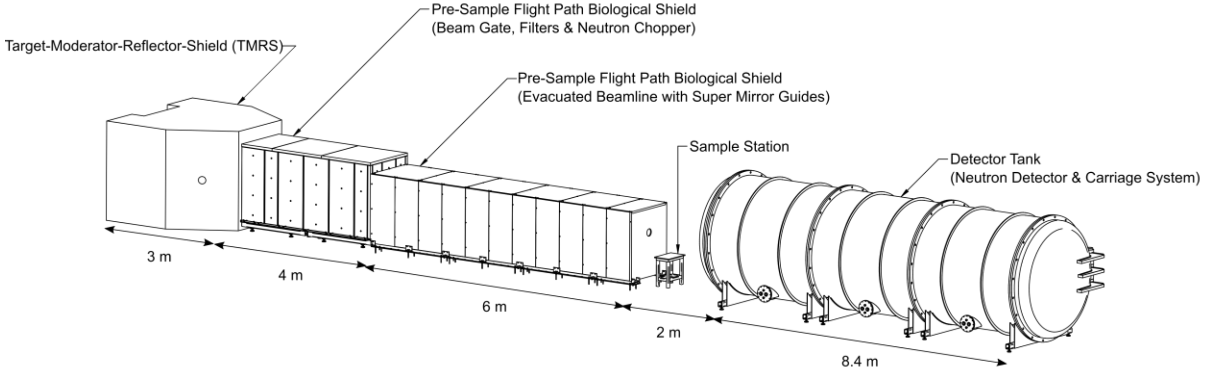
Relative Performance		Conventional Sources	CANS
High	5-10+	SNS ($2B); ESS ($3B)	
Medium	1	ISIS ($850M); NRU (>$500M)	Canada-scale facility* ($100–$200M)
Medium-Low	1/5	MNR (>$100M)	**Our prototype*** ($10–$12M** + 8 instruments)
Low	1/25		NOVA ERA* ($6M** + 6 instruments); LENS; RANS

Materials Science Research



Neutron Scattering Instruments

- Small Angle Neutron Scattering (SANS) Instrument
  - Large demand for SANS
  - Different from MacSANS with a pulsed, cold source.



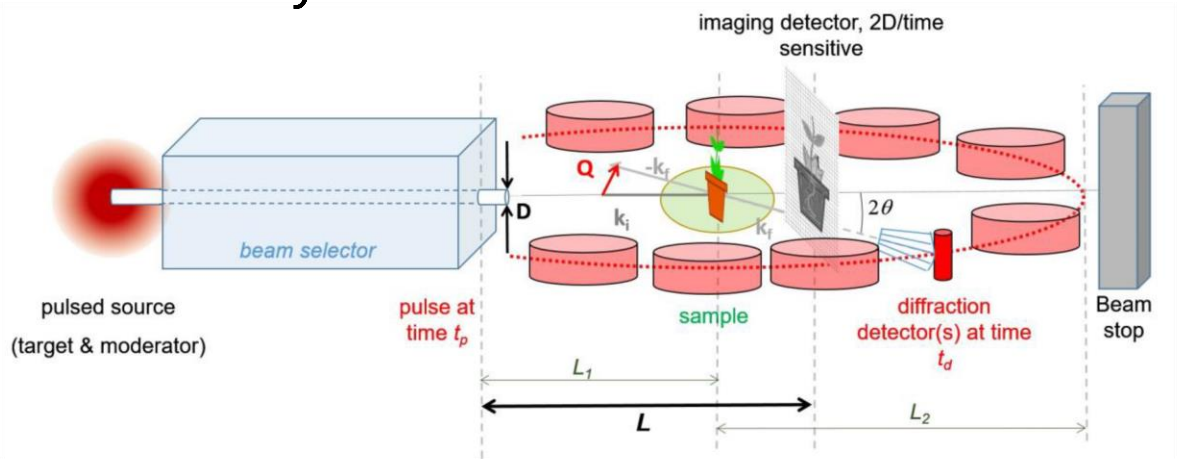
<u>OR</u>

- Pair Distribution Function (PDF) Analysis Instrument
  - Compliment Canadian Light Source capabilities
  - Take advantage of epithermal neutrons

Laxdal et al. *J. Neutron Res.* 2021, submitted

Neutron Scattering Instruments

- Diffraction/Imaging Instrument
  - The imaging beamlines at McMaster are generally not accessible for academic research
  - Canadian Nuclear Laboratory driven



- Potential 3rd beam port
  - Future upgrade or R&D.

Laxdal et al. *J. Neutron Res.* 2021, submitted

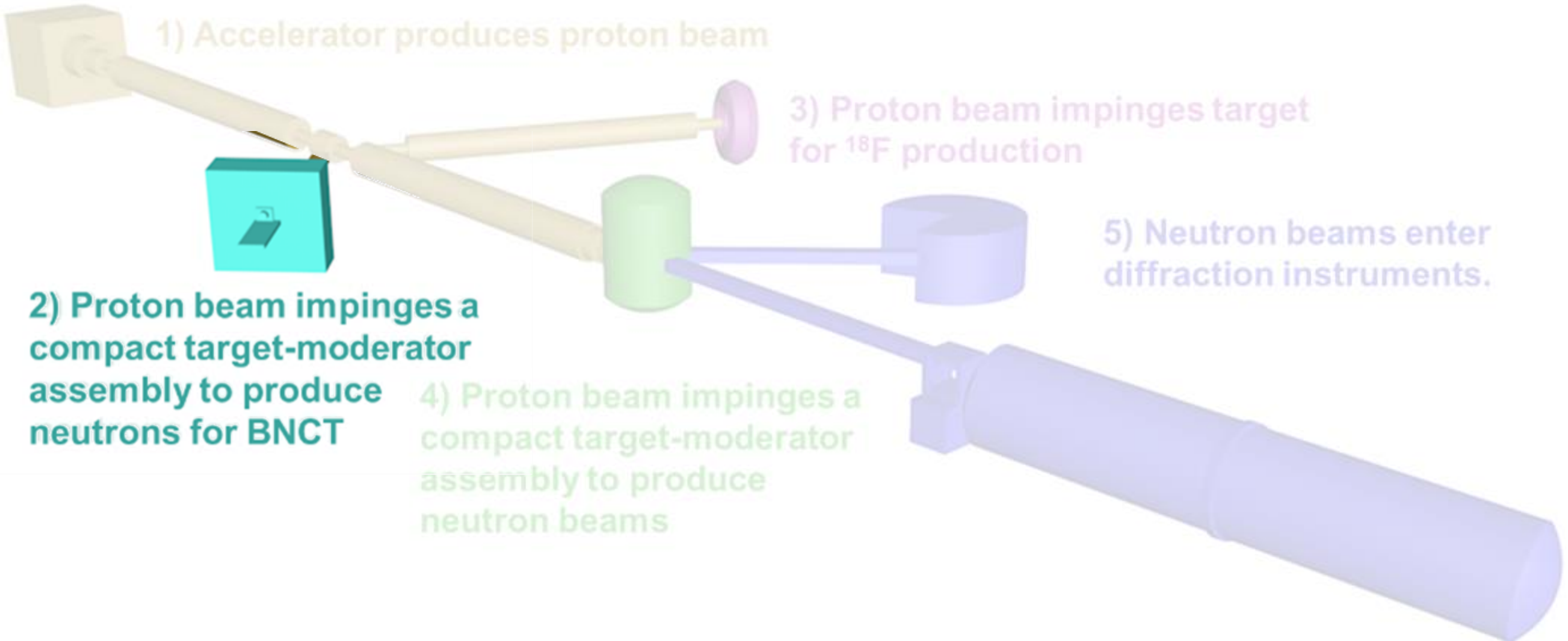
Neutrons for Materials Research

- Examine the stresses deep inside industrial materials that X-rays cannot penetrate.
- Unravel the structures of biological systems under physiological conditions.
- Sensitivity to H to develop technologies such as fuel cells and hydrogen storage materials.
- Magnetic property to develop superconductive, magnetic and quantum materials.

Neutron Imaging and Radiography

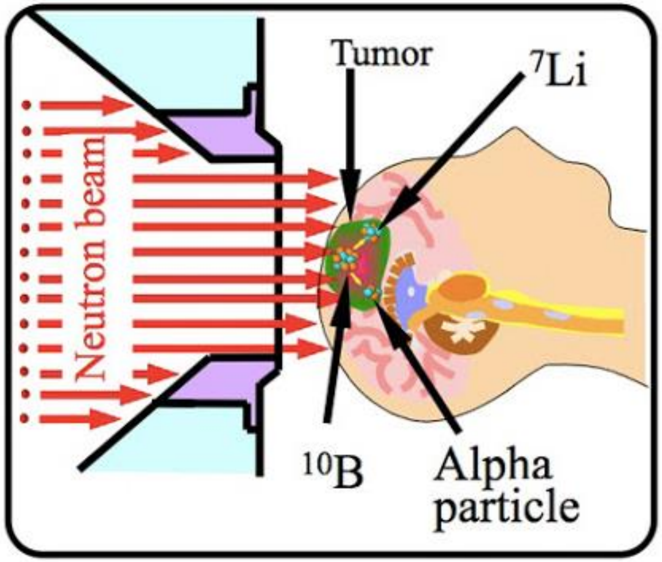
- Internal flaws of metal products
  - cracks, inclusions, voids, bubbles, foreign materials, density variations & misalignments
- Corrosion within aluminum products
- Radioactive objects in its shielding
- Authentication of artifacts from archeological digs
- Hydrogenous foreign substances in sealed units

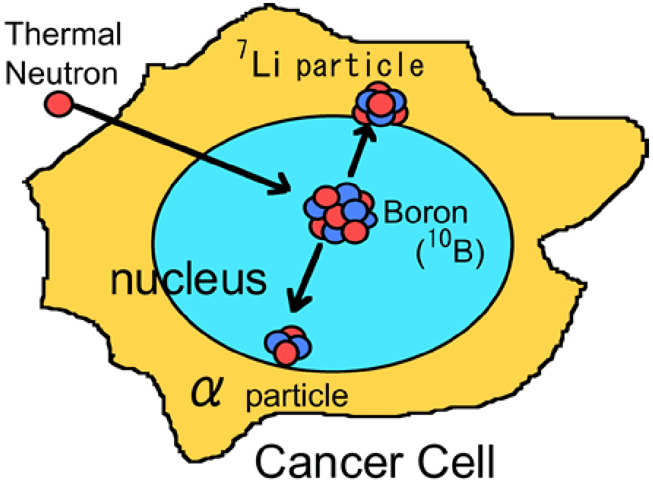
Boron Neutron Capture Therapy

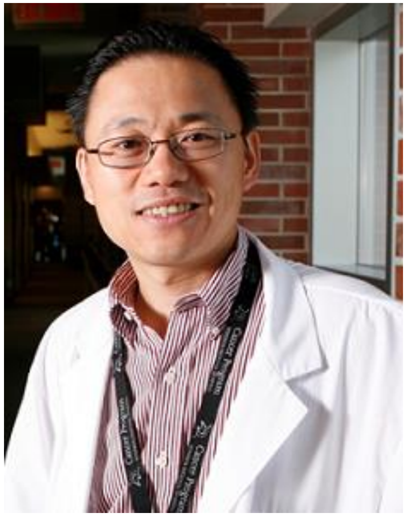


Boron neutron capture therapy (BNCT)

- BNCT is a Powerful, highly targeted therapy
- **PC-CANS will be *first* & only BNCT facility in Canada.**







Dr. Ming Pan
(Windsor Regional Hospital & UWestern)

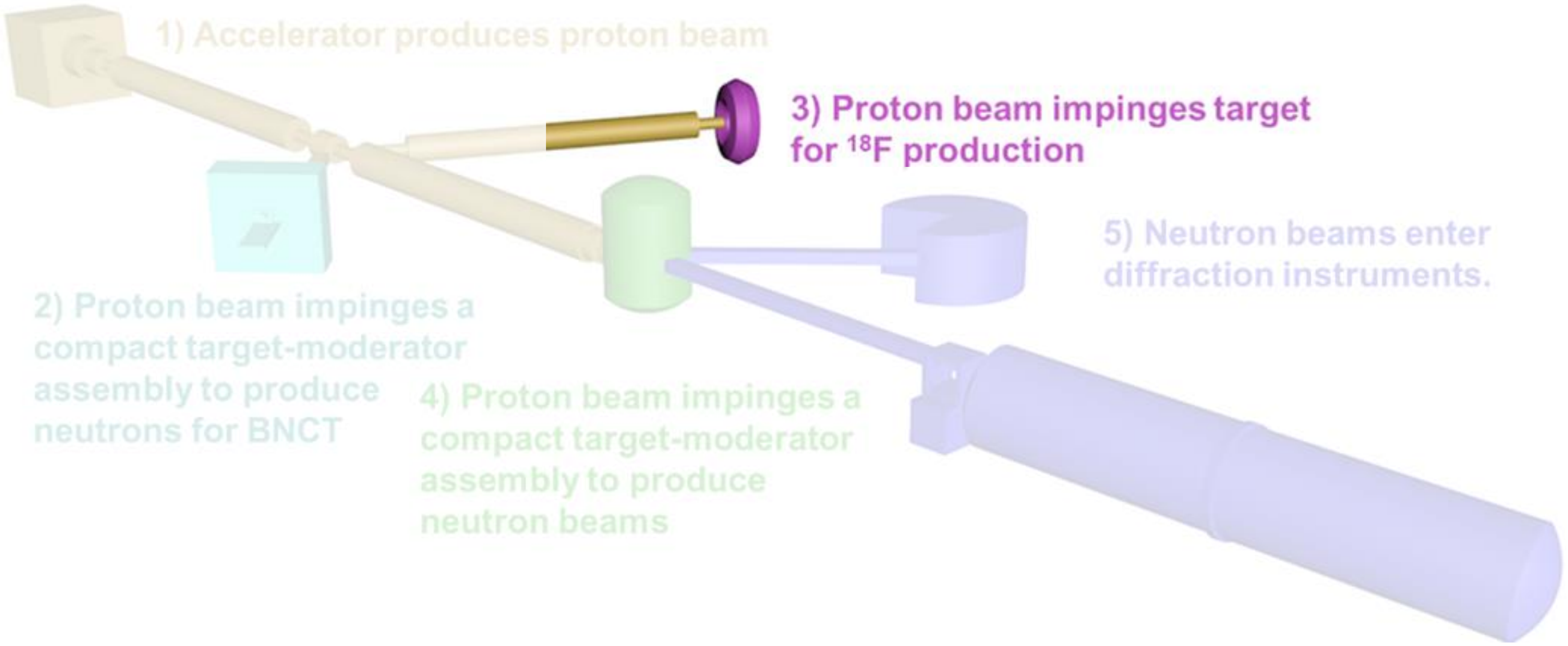
Japan Atomic Energy Agency
https://www.jaea.go.jp/english/news/p06071001/index.shtml

Boron neutron capture therapy

- Initially, an entry level beamline will provide a development path for a high performance BNCT therapy machine while
  - Still providing reasonable quantities of neutrons for BNCT R&D

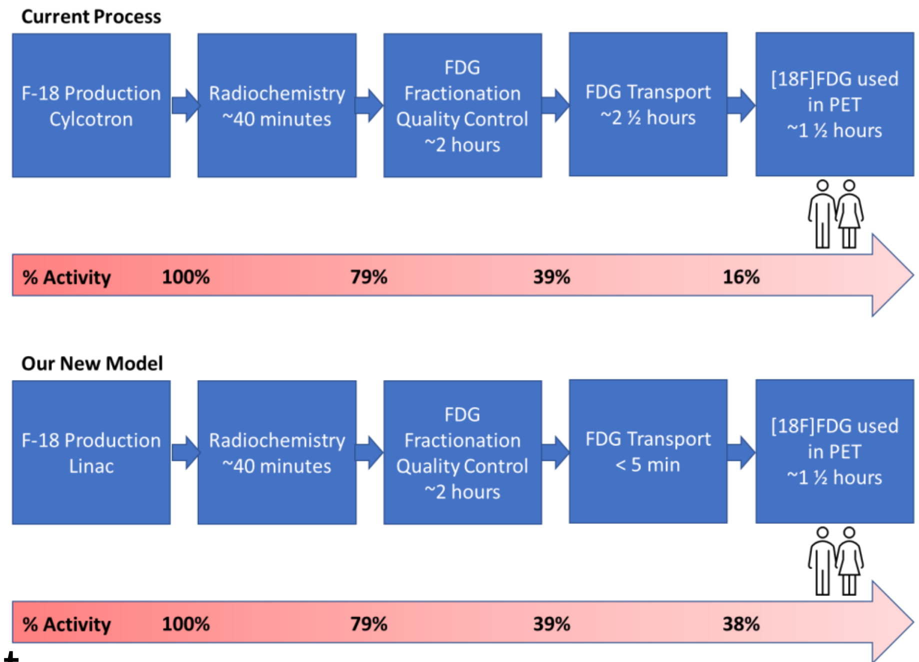
- Linac design has the option for more current to be supplied to a particular station should the target design or beam spot size allow

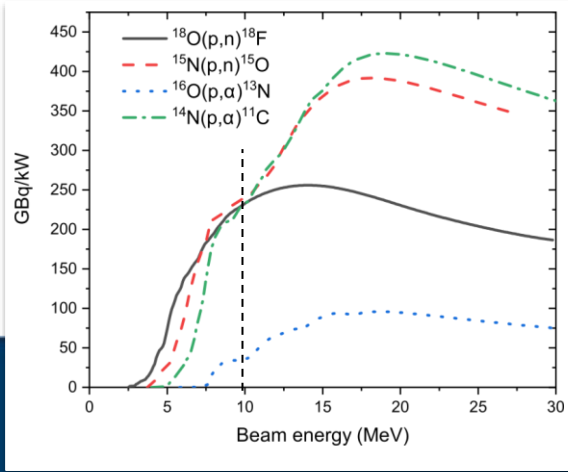
Medical Isotope Production



Supplying WRH PET Scanner with FDG

- PET scanning requires FDG:
  - [^{18}F]-fluorodeoxyglucose
  - ^{18}F has a $t_{1/2} \approx 120$ min.
- Current patient load
  - ~700 patients/year
- 2030 projected patient load
  - ~2500 patients/year
  - not sustainable with current model
- Access to even $t_{1/2}$
  - ^{15}O (2 min), ^{13}N (10 min), & ^{11}C (20 min)





PC-CANS and Beyond

- PC-CANS Prototype fully operational
  - Active materials and BNCT research
  - Ongoing and reliable source of FDG for WRH and surrounding
  - **Further target-moderator research and optimization**

- How can CANS technology best serve Canada?
  - Large scale national user facility
  - A series of university sized CANS distributed throughout Canada

- Governance
  - National governance structure

https://images.app.goo.gl/pJH19hQWbhL1CNjb6

Acknowledgements

- Dalini Maharaj (UWindsor/TRIUMF)
- Mina Abbaslou (UVic/TRIUMF)
- Ming Pan (WHR)
- Oliver Kester (TRIUMF)
- Bob Laxdal (TRIUMF)
- Alex Gottberg (TRIUMF)
- Beatrice Franke (TRIUMF)
- Zin Tun (McMaster/TVB)
- Thomas Gutberlet (Julich)
- Daniel Banks (TVB)
- Windsor Regional Hospital
- Canadian Neutron Initiative
- NFRF Team

New Frontiers in Research Fund
Fonds Nouvelles frontières en recherche

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

TRIUMF

CINS
CANADIAN INSTITUTE FOR NEUTRON SCATTERING