A Prototype Compact Accelerator-based Neutron Source for Canada for Medical and Scientific Applications

Dalini D. Maharaj

2022 Science Week – Monday 18th July 2022

TRIUMF

University of Windsor

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Overview

- Why does Canada need neutrons?
- Overview of Compact Accelerator-based Neutron Sources (CANS)
- The Prototype Canadian CANS
- Objectives of Target Moderator Reflector Optimization
- Current Studies, Timeline & Impact

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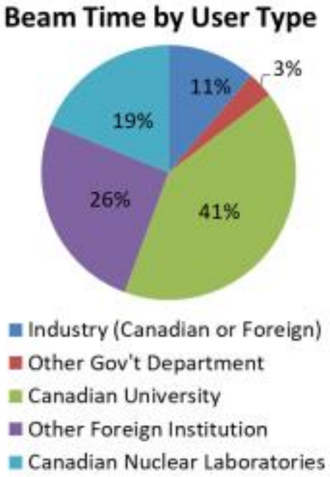
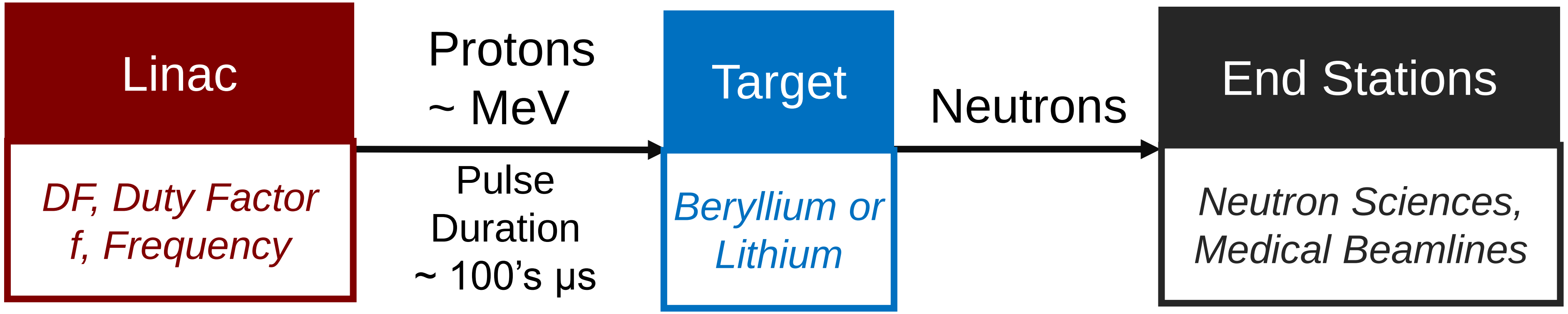
Current Status of Neutron Beams in Canada

- **Neutron Gap** - National Research Universal (NRU) reactor shut down in 2018
- McMaster Nuclear Reactor - only source of neutron beams in Canada



- Similar story globally - major research reactors closed e.g. BER-II, JEEP and Orphée
- Need new (affordable) pathways for neutron production
- Demand for high brilliance, pulsed neutron beams in Canada

The Compact Accelerator-based Neutron Source (CANS) Concept



Linac

DF, Duty Factor
f, Frequency

Protons
~ MeV

Pulse
Duration
~ 100’s μs

Target

Beryllium or
Lithium

Neutrons

End Stations

Neutron Sciences,
Medical Beamlines

Advantages

I. **Compact -** less shielding required

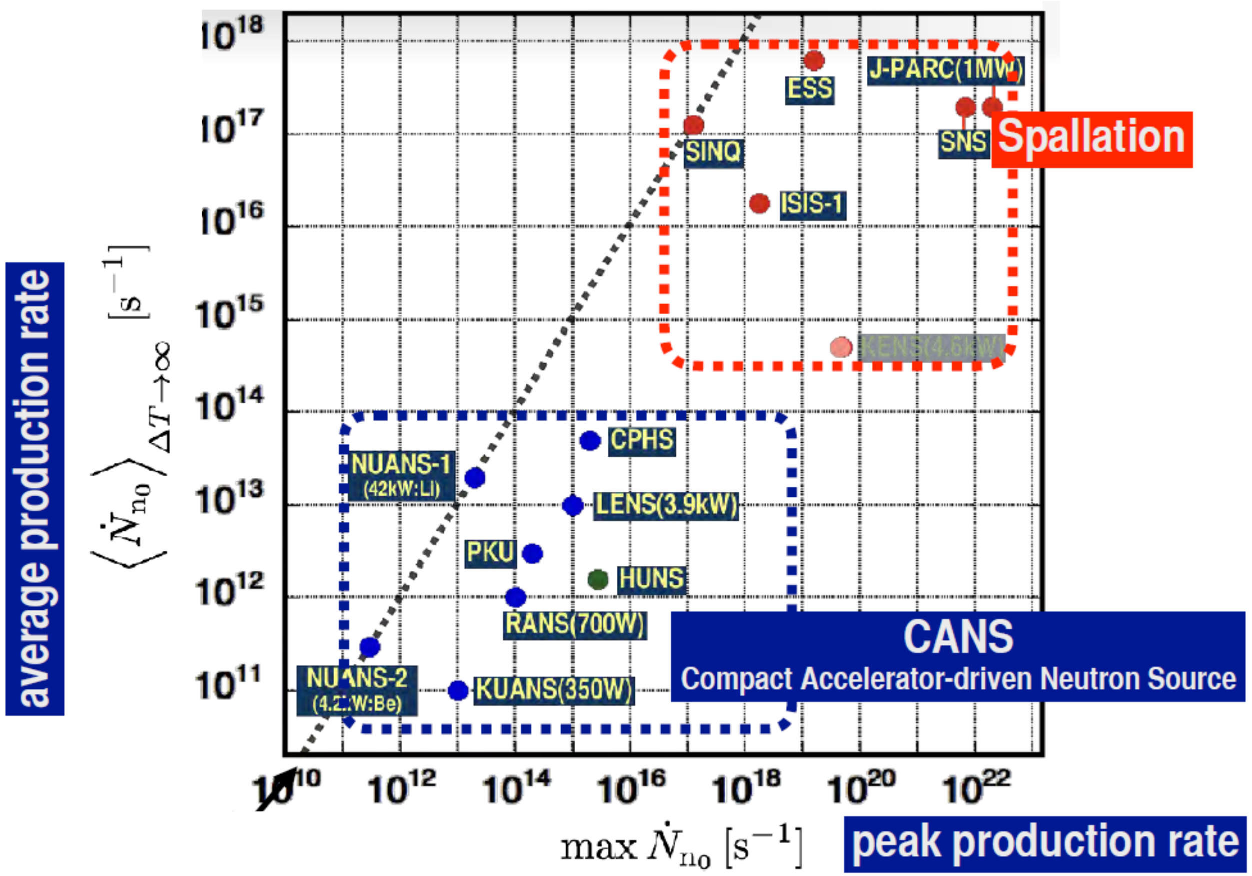
II. **Lower cost** when compared with reactor and spallation sources

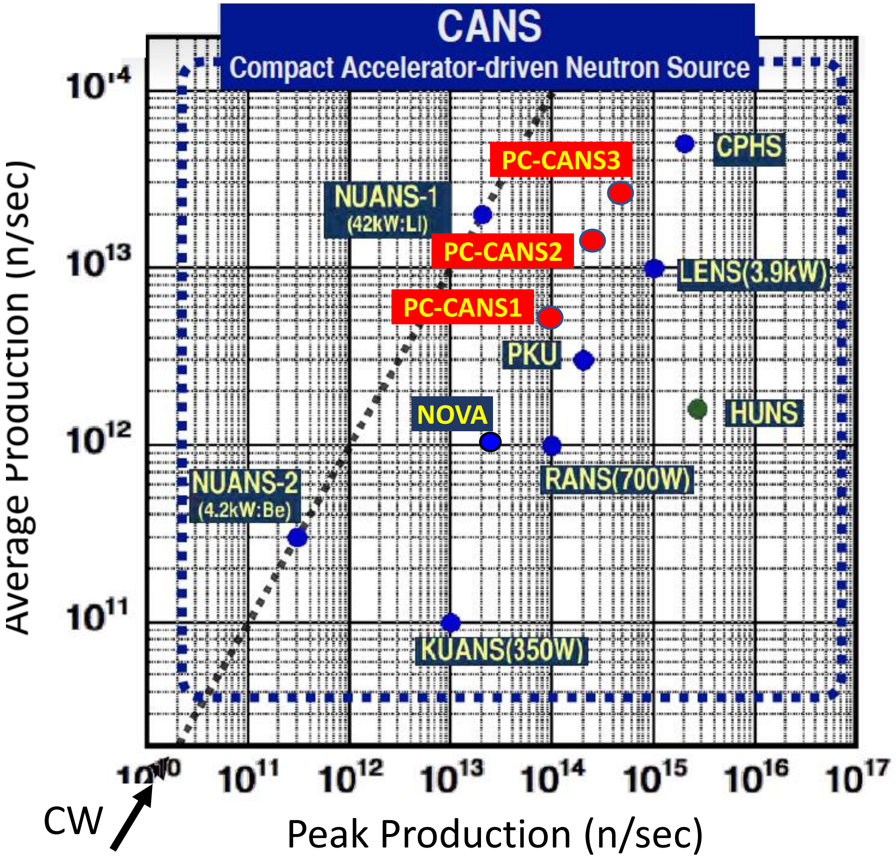
III. **High brilliance, pulsed neutron beams** realized

IV. **Scalable** technology via

  - Boosting proton energy
  - Increasing accelerator current

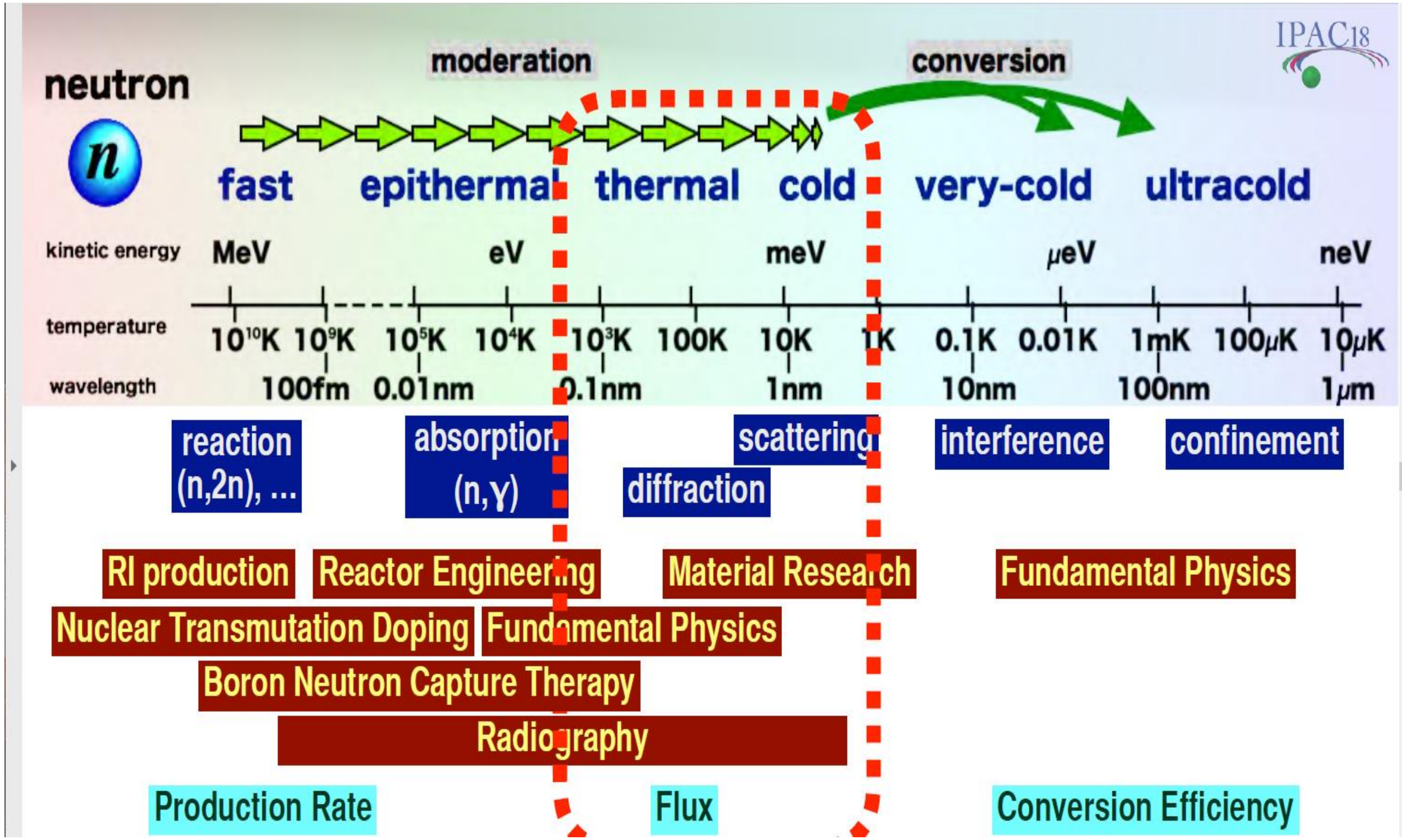
Global Neutron Landscape





- CANS provide neutrons to serve **most** user needs
- PC CANS designed to be competitive against similar scale sources

Neutron Beam Applications



Neutron Sciences

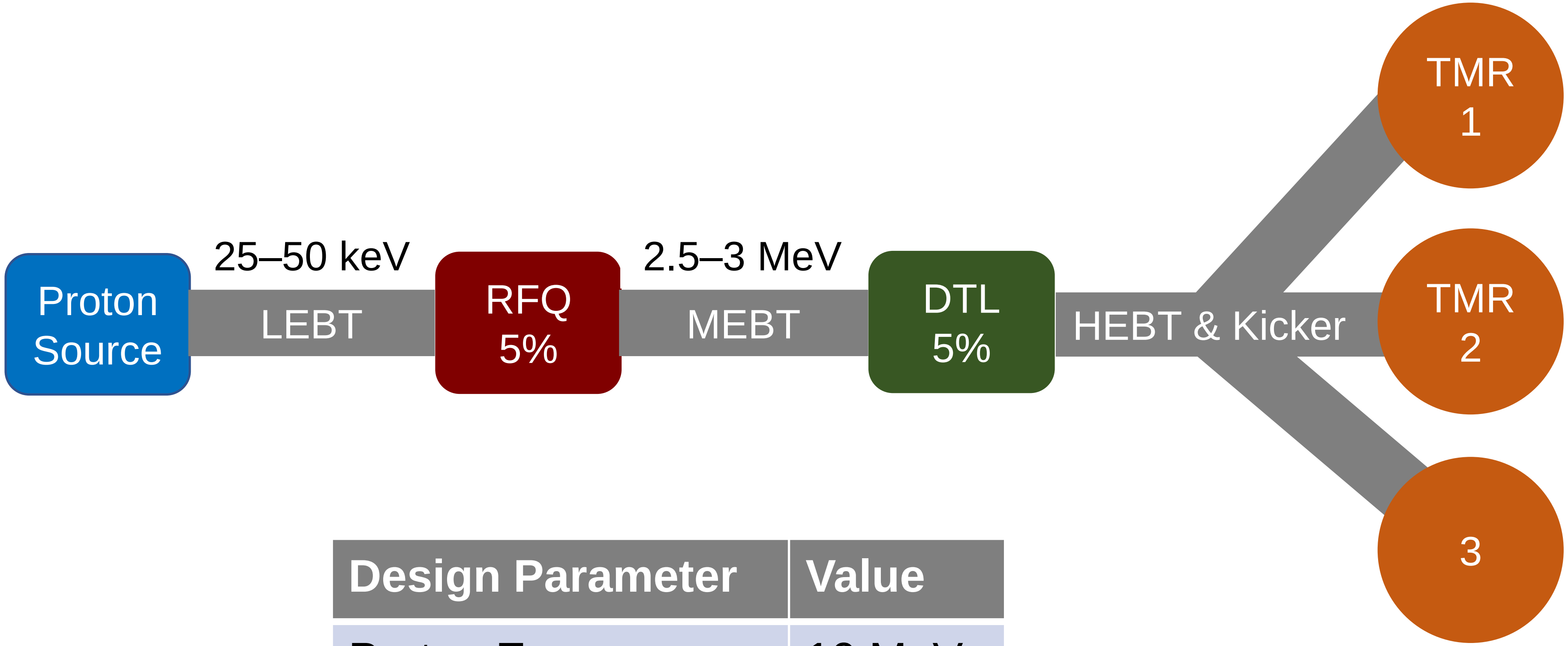
I. Thermal Neutrons
10 meV < E < 100 meV
e.g. diffraction to resolve crystal structures ~ Angstroms

II. Cold Neutrons
E < 10 meV
e.g. large scale structures

Boron Neutron Capture Therapy (BNCT)

Epithermal Neutrons
0.5 eV < E < 10 keV

Overview and Objectives of the PC CANS



Neutron Sciences
(Cold Neutrons)
0.2 – 0.5 mA
2 – 5 kW

Boron Neutron Capture Therapy
(Epithermal Neutrons)
0.2 – 0.5 mA
2 – 5 kW

F-18 for PET
0.1 mA
1 kW

Design Parameter	Value
Proton Energy	10 MeV
Duty Cycle	5%
Total Peak Current	20 mA

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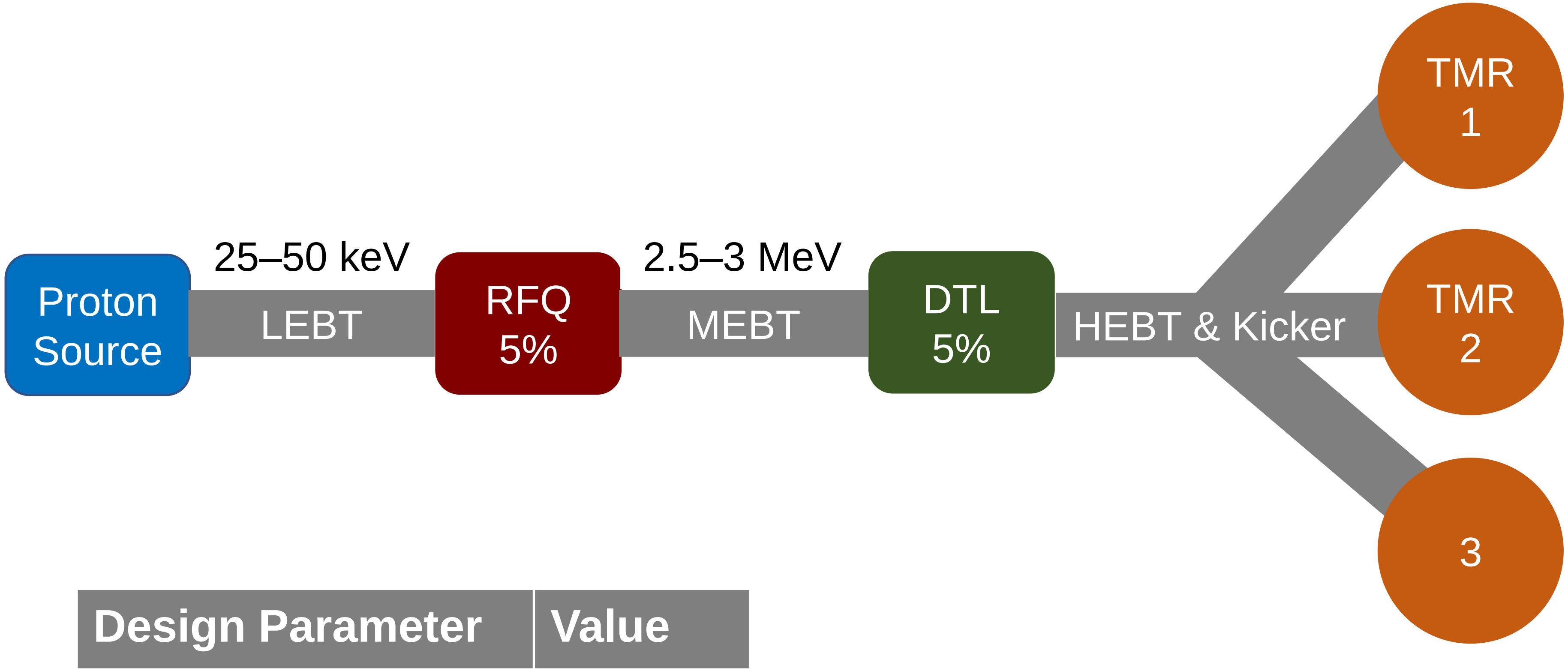

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Details of linac conceptual designs - see Mina Abbaslou’s poster during tomorrow’s poster session at 3:30pm

Performance at End Stations

Application		**I_{avg}/I_{pk}**			
		PC-CANS 1		**PC-CANS 2** **0.5/10**	**PC-CANS 3** **1/20**
		0.1/2	**0.2/4**		
Neutron Science	Cold Yield ($n/cm^2/s$)	-	$2.8 \times 10^5/5.6 \times 10^6$	$7 \times 10^5/1.4 \times 10^7$	$1.4 \times 10^6/2.8 \times 10^7$
	Thermal Yield ($n/cm^2/s$)	-	$1.3 \times 10^6/2.6 \times 10^7$	$3.3 \times 10^6/6.5 \times 10^7$	$6.5 \times 10^6/1.3 \times 10^8$
BNCT	Epithermal Yield ($n/cm^2/s$)	-	1×10^8	2.5×10^8	5×10^8
PET	Saturation Yield (GBq)	240	-	-	-

I. Small-angle neutron scattering - High brilliance, pulsed, cold neutron beams of duration, 0.1-0.8 ms, at repetition rates of ≈ 50 Hz

II. Boron Neutron Capture Therapy - Therapeutic epithermal neutron flux of $> 1 \times 10^8$ n/s are possible, enabling a BNCT R&D station

III. F-18 Isotope Production for PET - Competitive rates for F-18 production

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TMR Optimization Important

III. F-18 Isotope Production for PET - Competitive rates for F-18 production

Baseline Target Moderator Reflector (TMR) System for Neutron Sciences

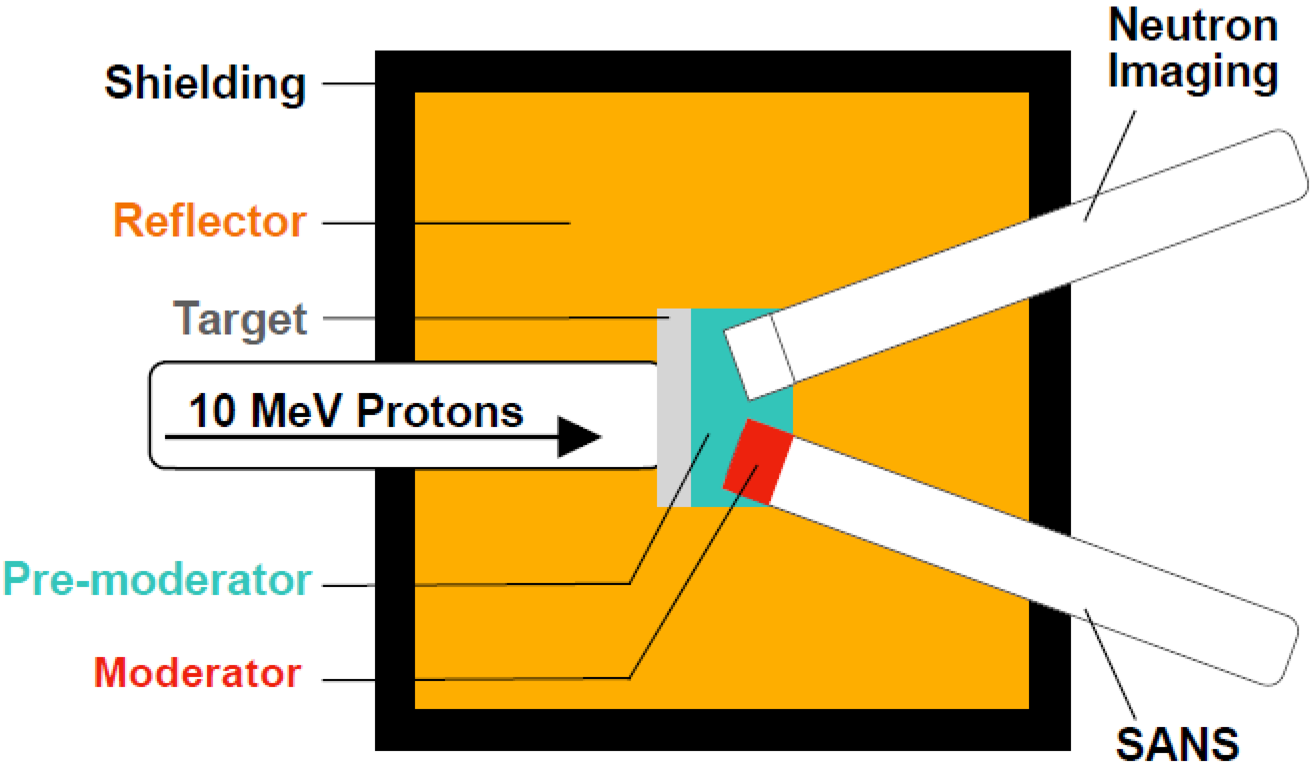
Beryllium Target – Produces neutrons via stripping reactions

Pre-moderator – slows neutrons from ~ MeV to thermal energies ~10-100 meV

Moderator – slows thermal neutrons to cold energies < 10 meV

Reflector – backscatters high energy neutrons for further moderation

Shielding – protects users from exposure to harmful radiation

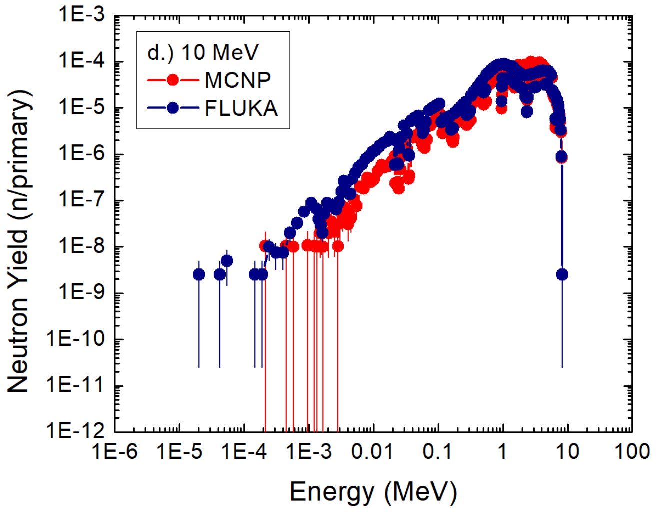


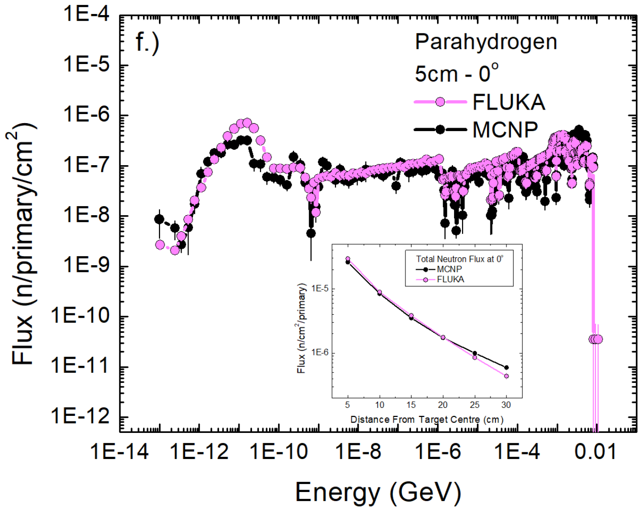
Tools Utilized

FLUKA & MCNP

Simulation Tools for Target Moderator Optimization

- FLUKA optimized for high energy particle transport but agrees well at 10 MeV
- Custom cross sections for moderator materials in MCNP
- Target-Moderator-Reflector studies for cold neutron beamlines in MCNP
- Target development and shielding studies in FLUKA





[1] R. Laxdal, Journal of Neutron Research **23** 99-117, (2021).

[2] D. D. Maharaj *et al*, arXiv:2205.01662v1 [physics.acc-ph] (2022).

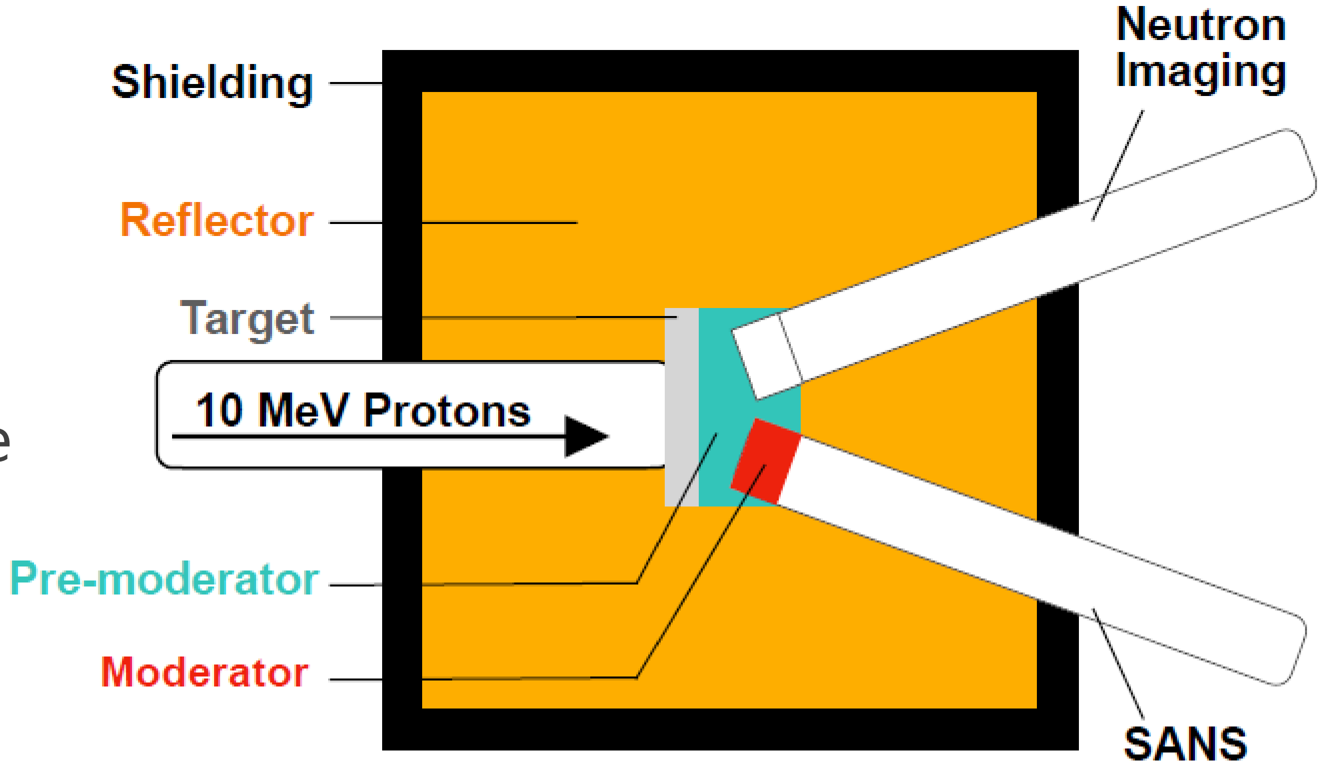
Objectives of Target Moderator Reflector Design & Optimization

- **Optimize neutron yields**
- **Optimize neutron time structure and spectra**

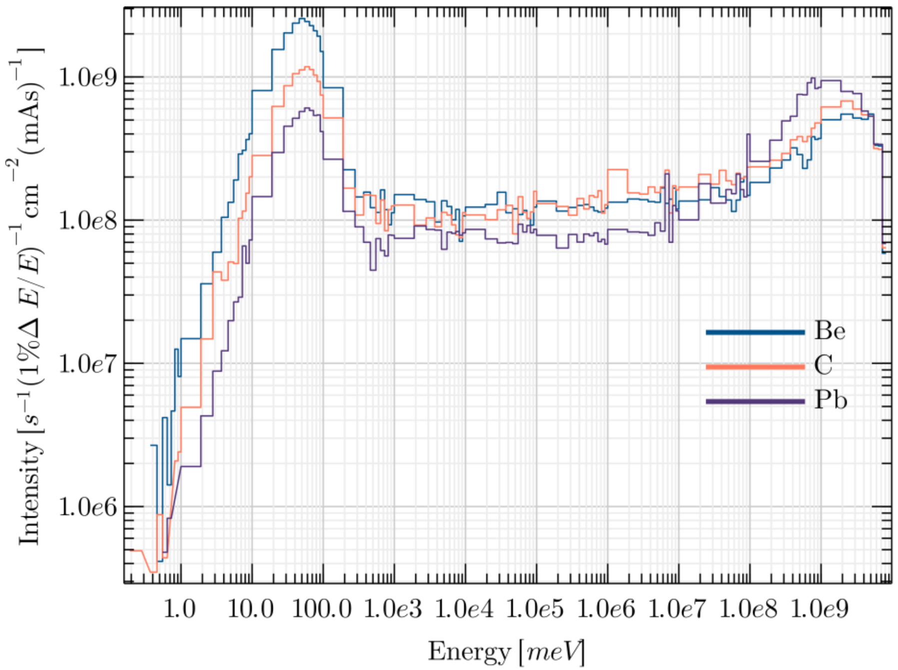
(i) Each neutron instrument has its own requirements for pulse structure

(ii) Influence of proton time structure on neutron time structure

(ii) Materials selected for TMR affect neutron time structure and neutron spectrum delivered



Influence of Reflector Selection on Neutron Yield

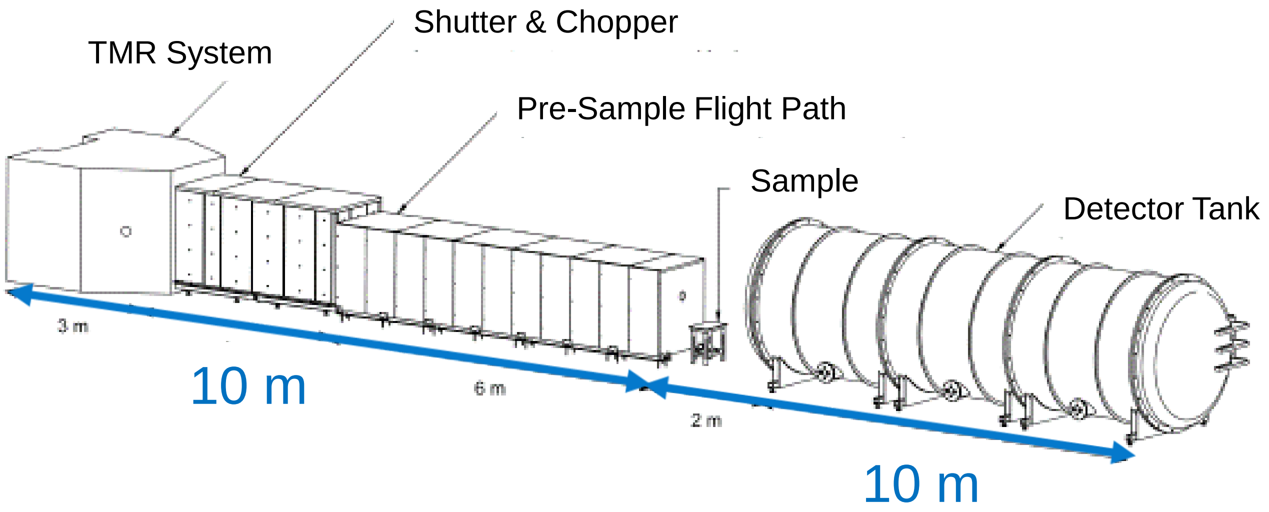


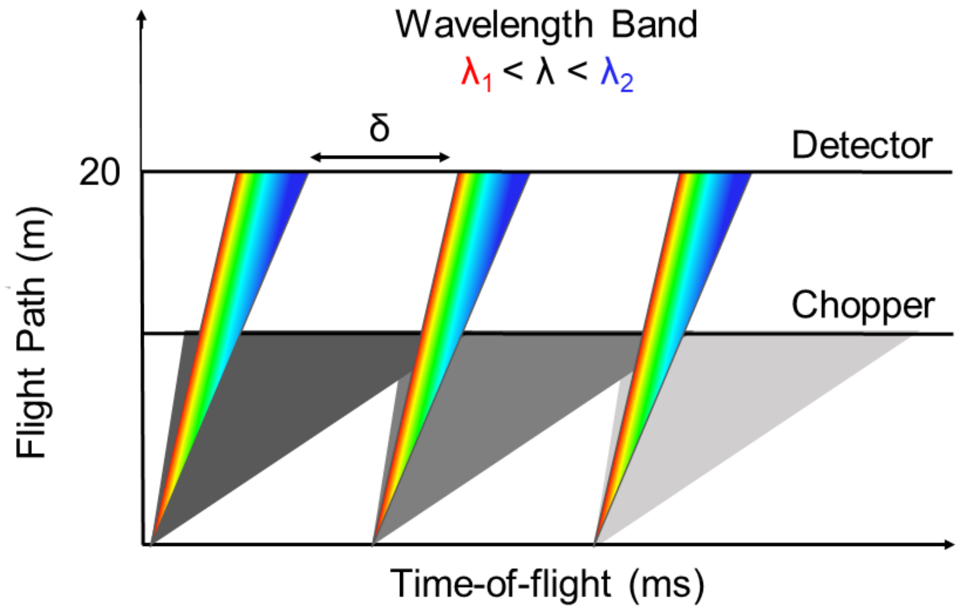
Neutron flux for Mesitylene cold moderator (n/cm²/mC/s)

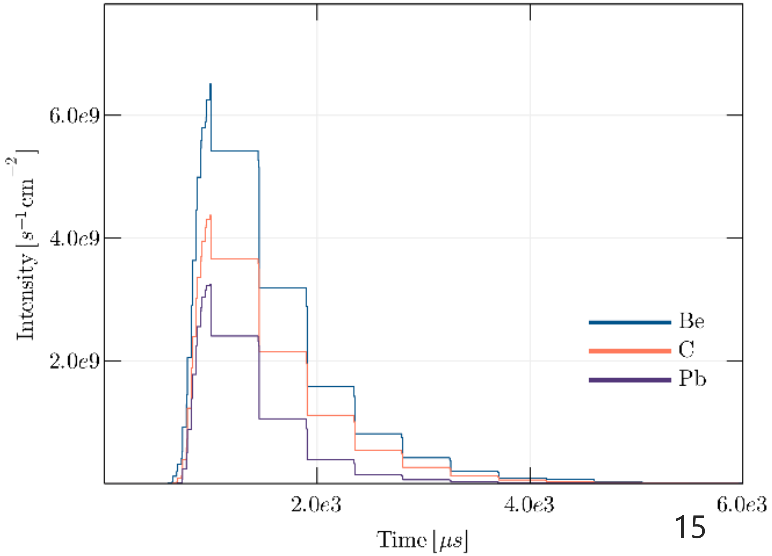
	Lead	Graphite	Beryllium
Cold Flux	3.92×10^7	1.09×10^8	2.68×10^8
Thermal Flux	8.07×10^8	1.70×10^9	3.88×10^9
Total Flux	4.39×10^9	5.82×10^9	7.99×10^9

- Performance Be > C > Pb with respect to neutron yield
- Beryllium and graphite,
  - Fast neutron spectrum is significantly suppressed
  - Thermal neutron yields are higher

Matching Proton Pulse Structures with SANS Requirements







- 20 m SANS instrument delivers cold neutron bandwidth, $\lambda_1 < \Delta\lambda < \lambda_2$
- Proton pulse duration, source frequency and duty factor, chosen to ensure neutron pulses (or frames) are well separated when they arrive at the detector

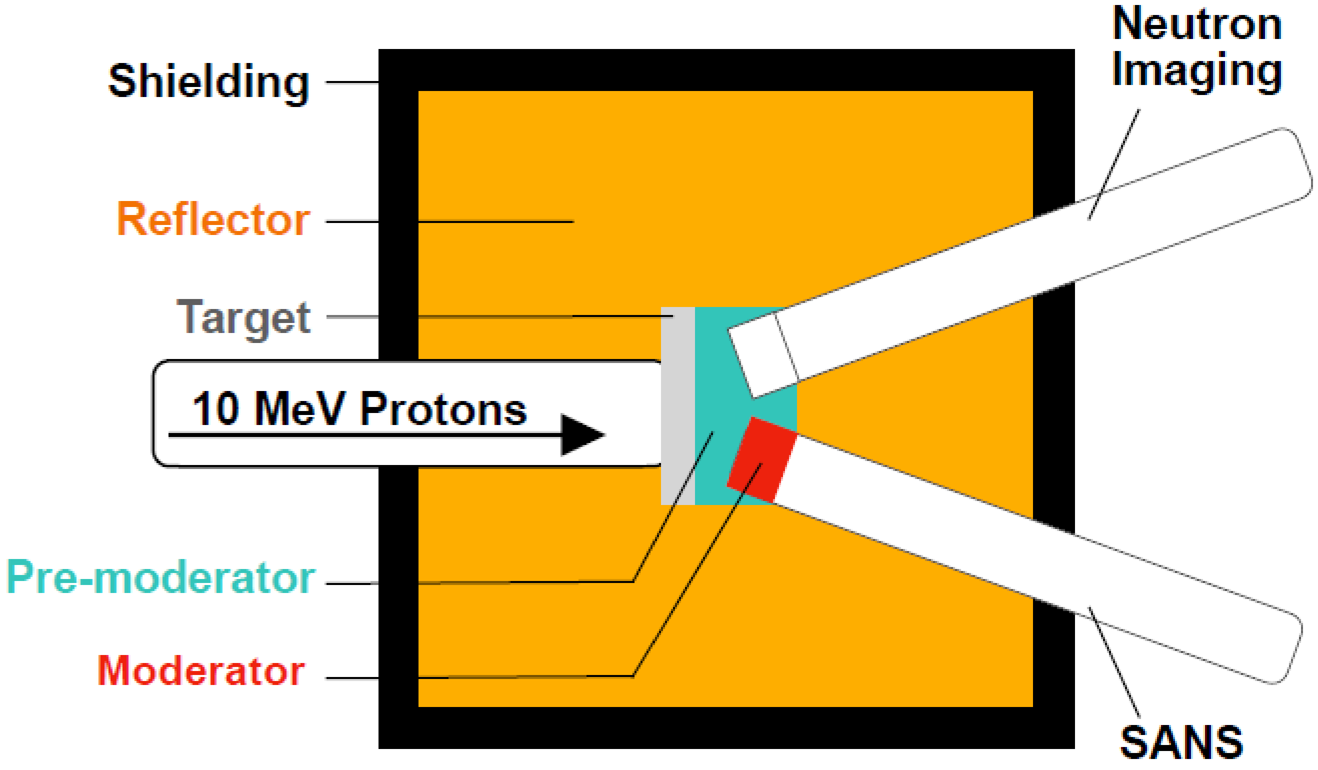
Summary of TMR Objectives & Funding Prospects

I. Current Activities in TMR Optimization

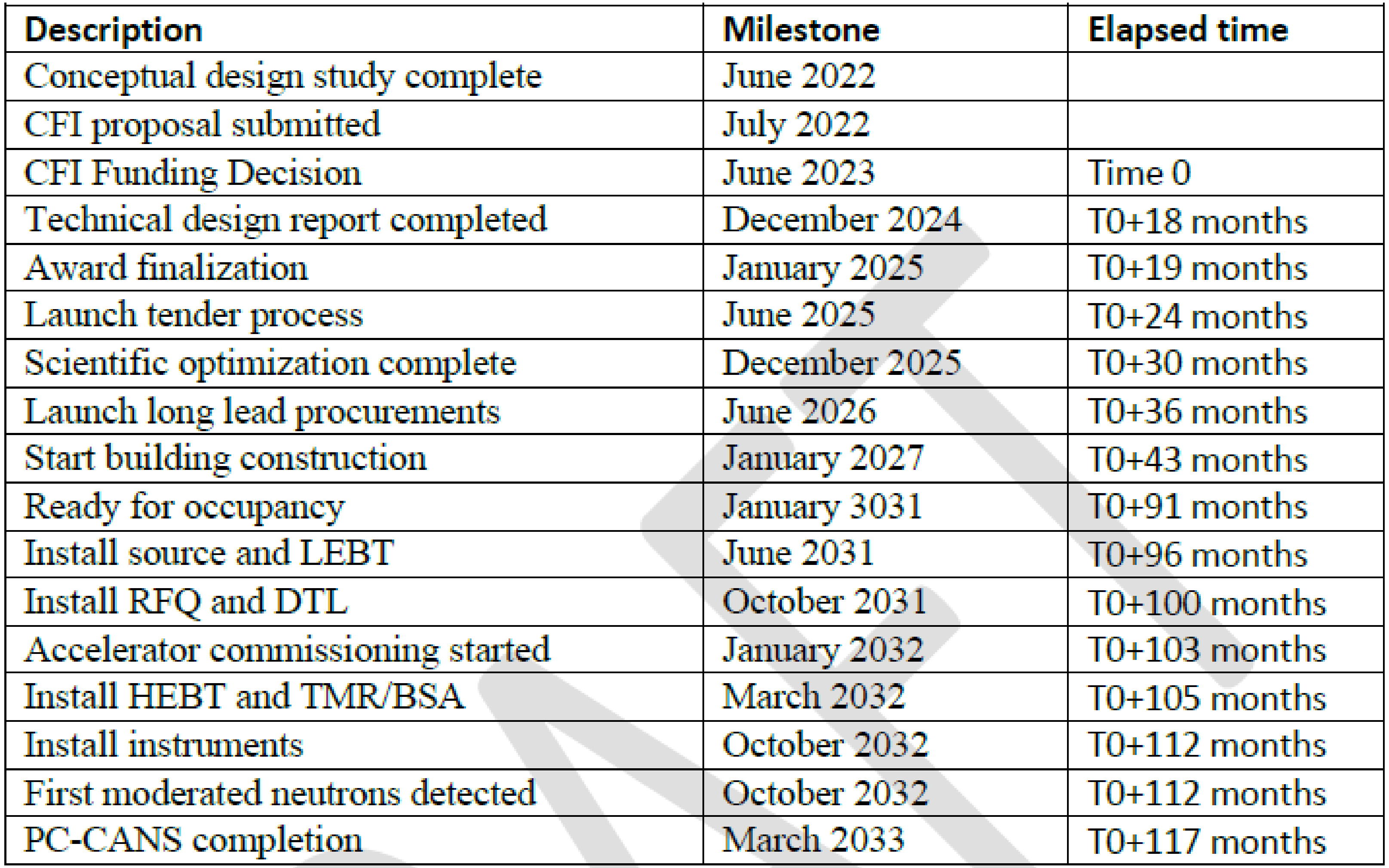
- Optimization of neutron pulse duration for SANS instrument
- Optimize material thicknesses for baseline design for two tube arrangement
- Evaluate SANS instrument performance based on optimized solution

II. CFI application submitted in July 2022

III. Conceptual design report (see link) released in July 2022.



PC CANS Timeline & Scientific Impact



Description	Milestone	Elapsed time
Conceptual design study complete	June 2022	
CFI proposal submitted	July 2022	
CFI Funding Decision	June 2023	Time 0
Technical design report completed	December 2024	T0+18 months
Award finalization	January 2025	T0+19 months
Launch tender process	June 2025	T0+24 months
Scientific optimization complete	December 2025	T0+30 months
Launch long lead procurements	June 2026	T0+36 months
Start building construction	January 2027	T0+43 months
Ready for occupancy	January 3031	T0+91 months
Install source and LEBT	June 2031	T0+96 months
Install RFQ and DTL	October 2031	T0+100 months
Accelerator commissioning started	January 2032	T0+103 months
Install HEBT and TMR/BSA	March 2032	T0+105 months
Install instruments	October 2032	T0+112 months
First moderated neutrons detected	October 2032	T0+112 months
PC-CANS completion	March 2033	T0+117 months

Institutional Benefits

- Enhance core competence in target and accelerator science and technology

Societal Impact

- Advance Canadian science and industry in high-power hadron accelerators
- Open doors to diversity of applications in clean-tech, medicine, and security

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