Yorktown Clean Energy Center in Partnership with an Indian PPP

SMR and Advanced Subcritical Micro-Reactors (ASMR)

Ganapati Myneni

Virginia ADS Consortium
Director, VT-India Nuclear Energy Partnership

BSCE Systems, Inc.
Yorktown, Virginia, USA

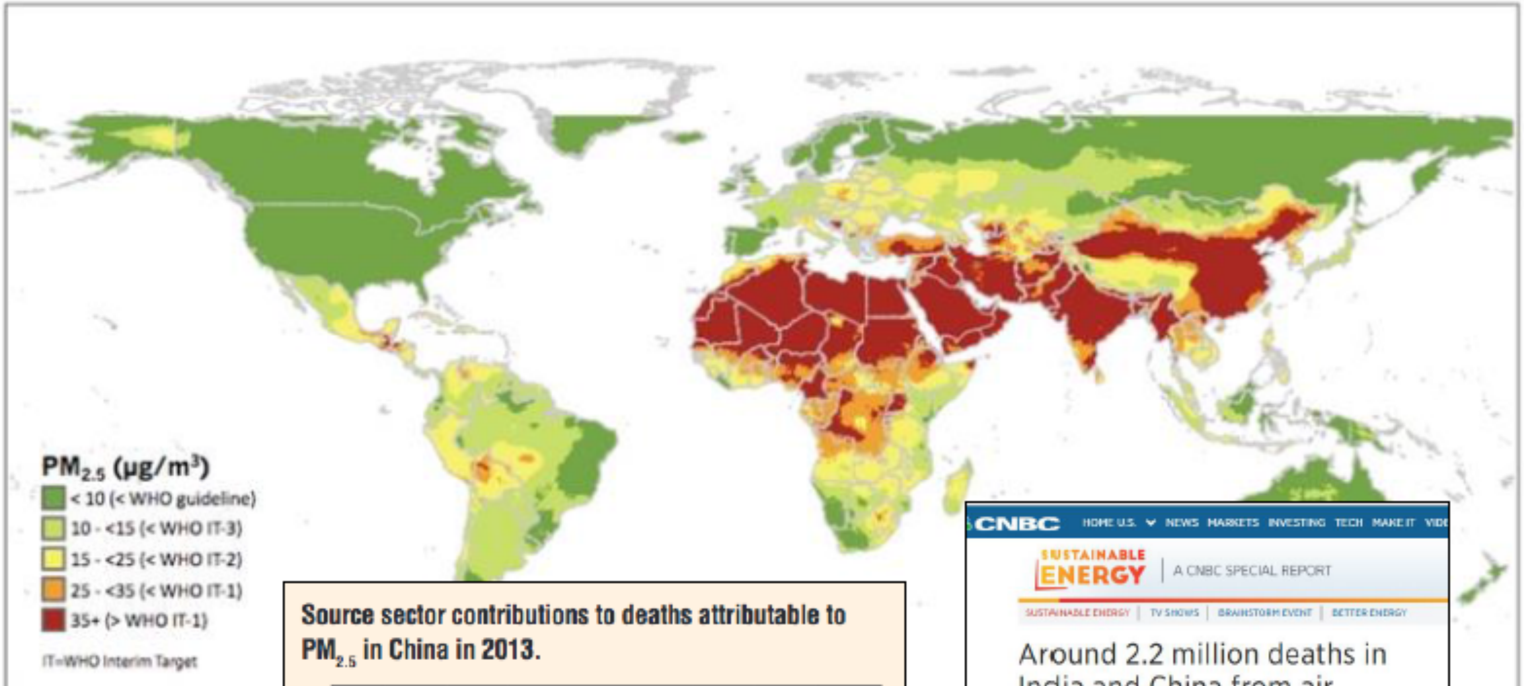
November 6, 2019
5th ADS & ThU International Workshop
SCK-CEN, Mol, Belgium

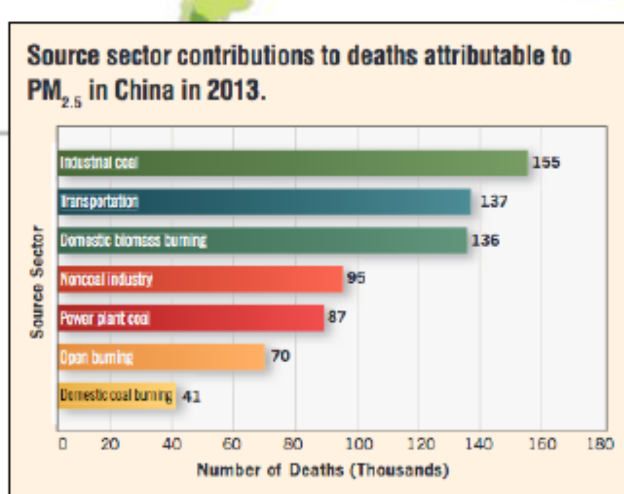
Overview

- Clean air & water - sustainable clean nuclear energy
- Critical & subcritical NE technologies
- Accelerator driven subcritical systems (ADS)
- Electron linacs for ADS
- Summary

Driver for Nuclear in Asia: Deadly PM 2.5 Pollution

Comparison of annual average $PM_{2.5}$ concentrations in 2015 with WHO Air Quality Guidelines.





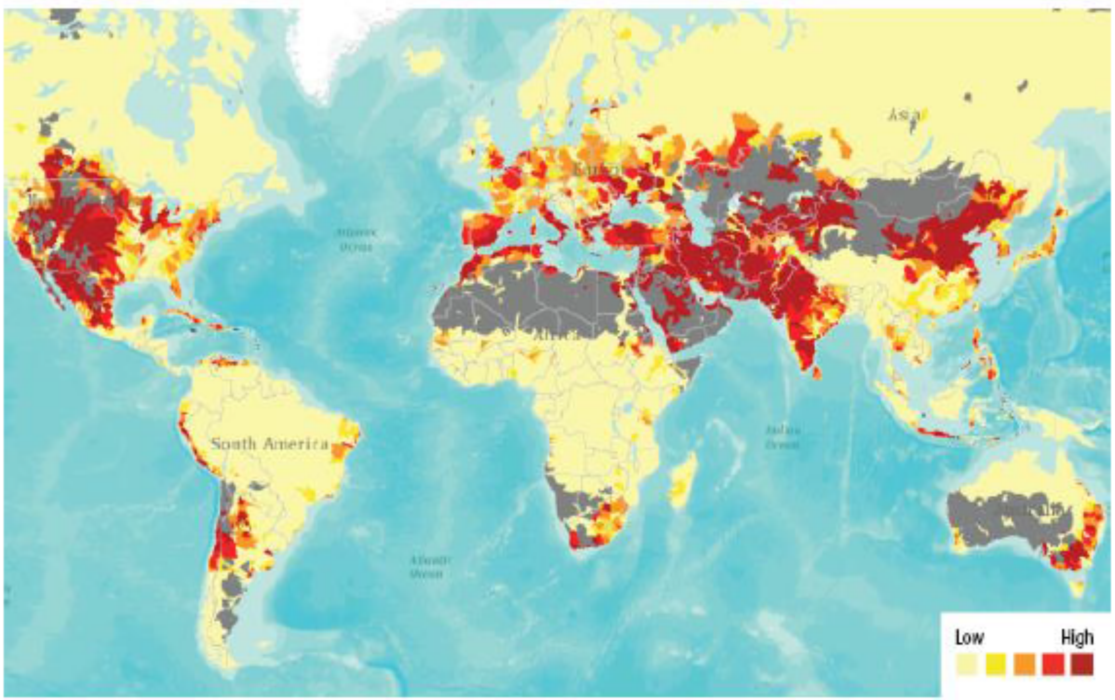
www.meo.life/state-of-global-air-2017/

Could Advanced Reactors bolster Desalination in large volumes for Cities?

WRI: Global Water Stress – and National Security

WRI: Water stress is not just a Developing World problem. Western USA.
WHO: Impact of urbanization -- "By 2025, half of the world's population will be living in water-stressed areas." Could Nuclear boost fresh water supply?

Projected Water Stress in 2030



Business as usual scenario
aqueduct.wri.org

AQUEDUCT WORLD RESOURCES INSTITUTE

Battle for Nile River Resources

200m people affected

6.5 GW Renaissance Dam [Ethiopia]

WRI (2017) www.wri.org/blog/2017/02/what-does-water-have-do-national-security

Andrew Paterson

Critical - Subcritical Nuclear Energy Technologies

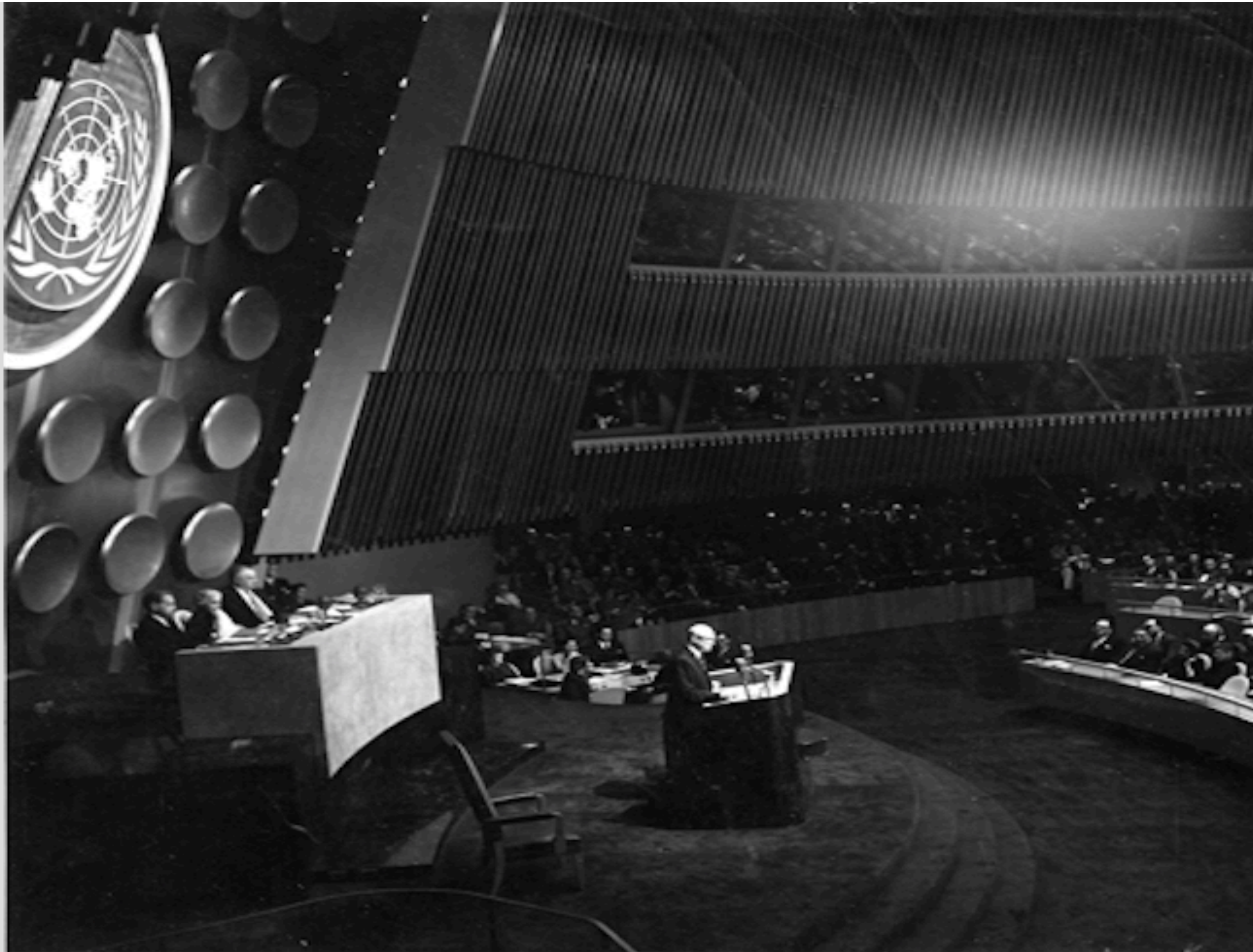
Nuclear technology began with the development of nuclear weapons in the 1940s based on an uncontrolled and growing chain reaction with *neutron multiplication greater than one* ($k>1$).

Nuclear technology advanced into electricity production in the 1960s with the introduction of today's light water reactors (LWRs) operating in chain reaction mode with controlled *neutron multiplication equal to one ($k=1$)*.

LWR technology supplies 20 % of the world's electricity and dominates in worldwide nuclear power production. However maintaining the neutron equilibrium in an LWR requires several design features that introduce safety issues that have given rise to capital costs for new nuclear reactors that have priced them out of business in the U. S.

Accelerator Driven Sub-critical (ADS) MSR nuclear energy technology ($K<1$)

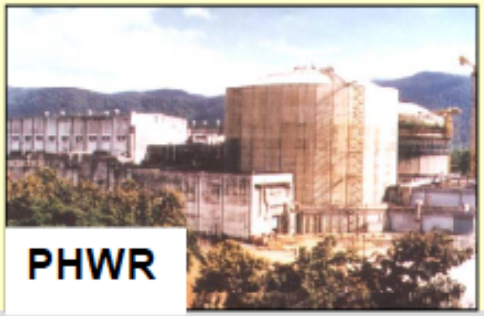
Proliferation resistant, meltdown proof, ultra safe, super clean

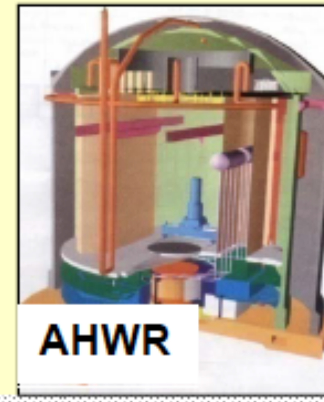


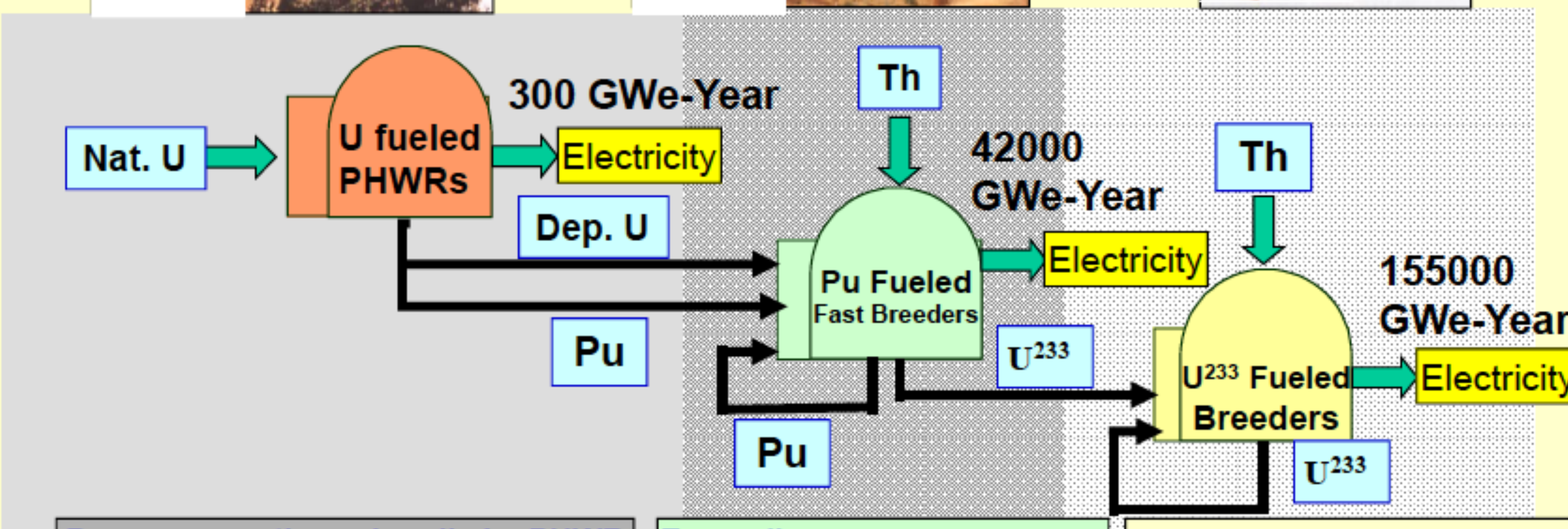

PRÉSIDENT

Three-Stage Indian Nuclear Programme

Thorium in the centre stage







Power generation primarily by PHWR
Building fissile inventory for stage 2

Stage 1

Expanding power programme
Building U^{233} inventory

Stage 2

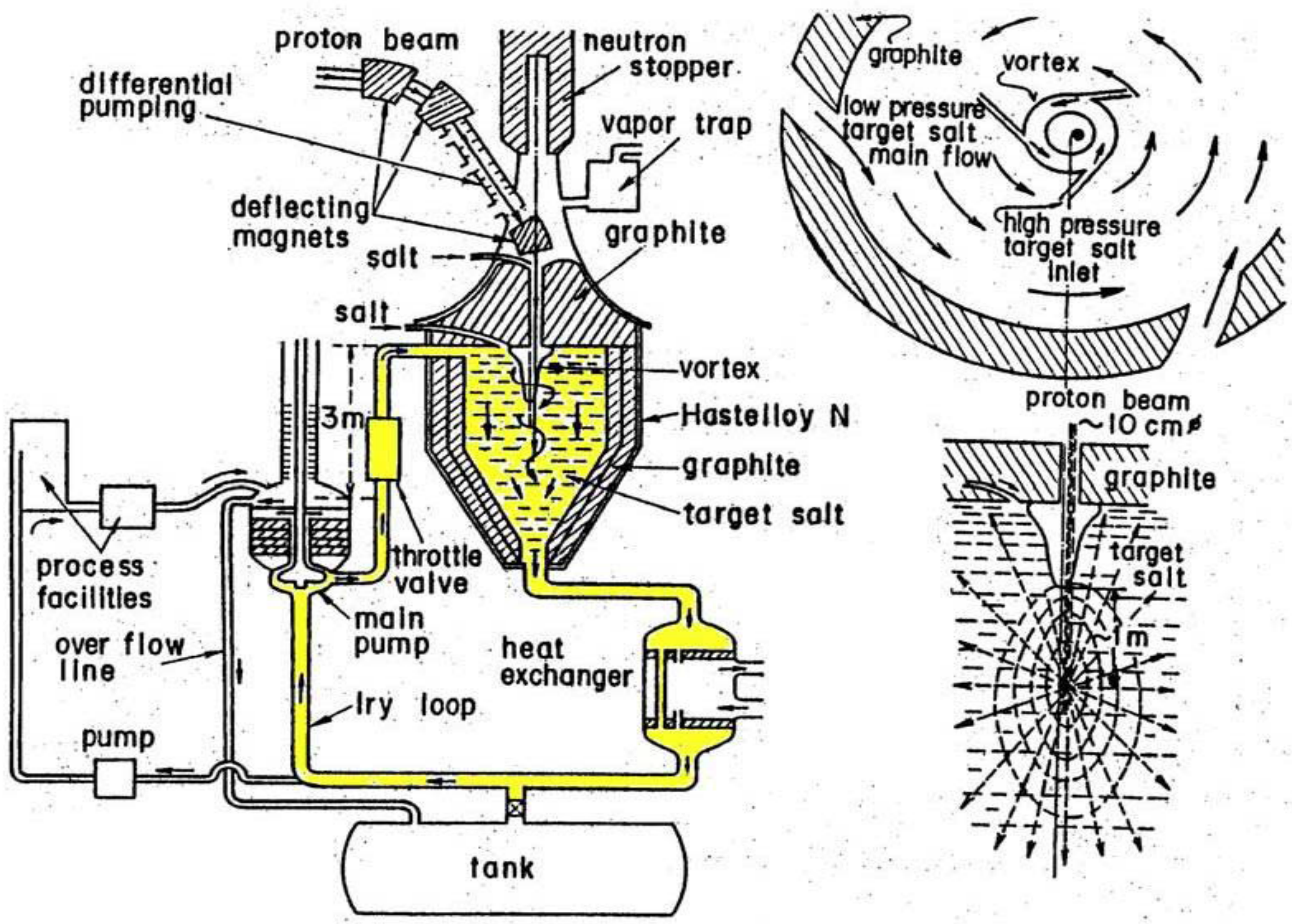
Thorium utilization for
Sustainable power programme

Stage 3

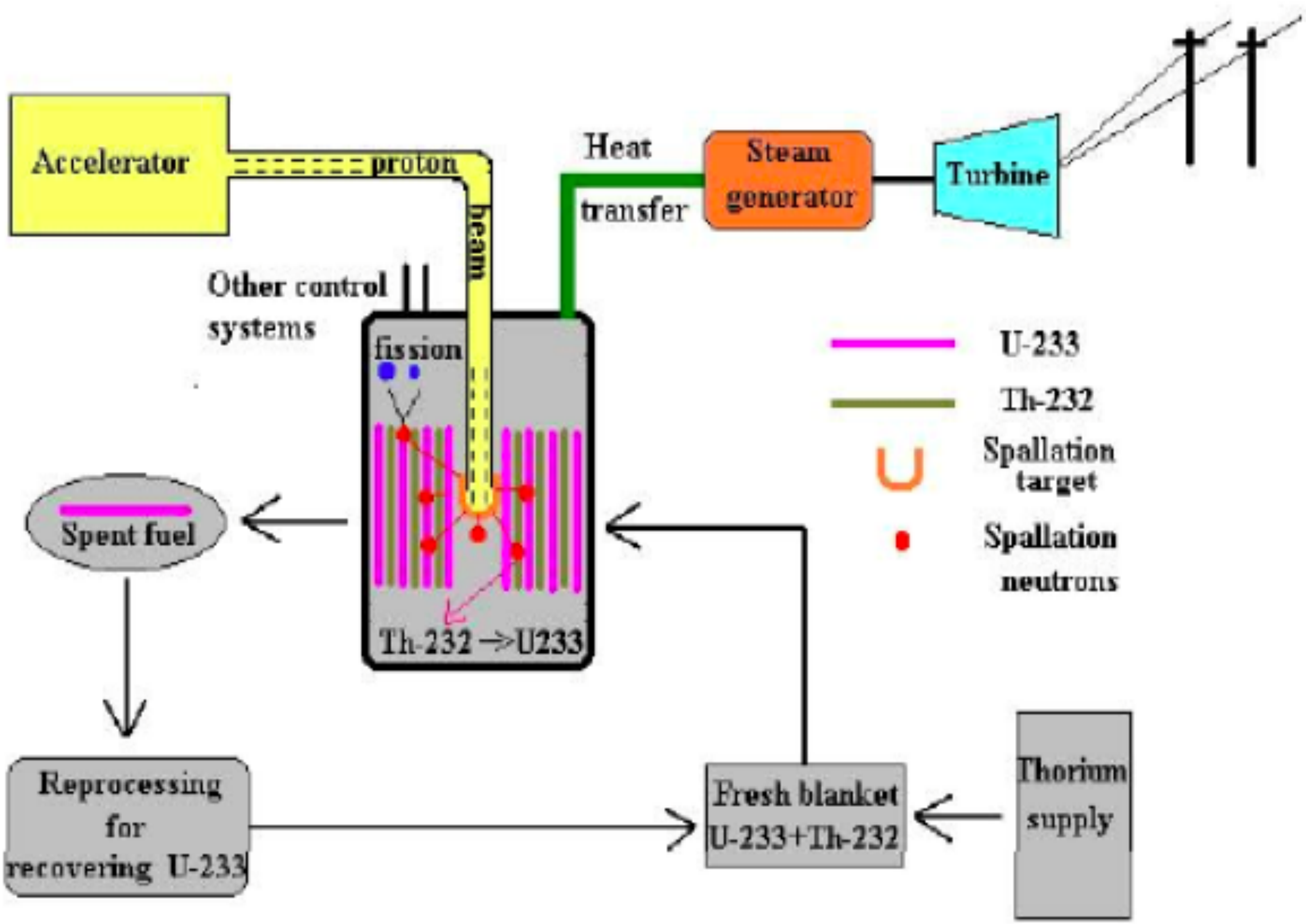
Accelerators & fissile materials

- 1950 – U. E. O. Lawrence, high power accelerators for producing fissile materials
  - Accelerator Molten-Salt Breeders, Kazuo Furukawa et al, Energy Conversion and Management 49 (2008) 1832-1848
- 1952 – W. B. Lewis, proposed use of thorium with intense neutron generators
  - India’s ADS Program with proton linac
  - BSCE Systems, Inc. ADS sub-critical micro-reactors with high power electron linacs

K. Furukawa's AMSB



India’s Thorium utilization scheme



Dr. S. Banerjee, University of Virginia Presentation, May 2010

Virginia ADS Consortium Partners

- **BSCE Systems, Inc.**
- **Indian Smart Grid Forum (a PPP initiative of Govt. of India)**
- **International Symposium On Hydrogen In Matter (ISOHIM)**
- **Jefferson Lab**
- **Longwood University**
- **Oak Ridge National Laboratory**
- **Old Dominion University**
- **South Dakota School of Mines and Technology**
- **University of Virginia**
- **Virginia Commonwealth University**
- **Virginia Tech**

ADS&ThU International Workshops

1st International ADS&ThU Workshop 2010, USA

- http://www.phys.vt.edu/~kimballton/gem-star/workshop/index.shtml

2nd International ADS&ThU Workshop 2011, India

- http://www.ivsnet.org/ADS/ADS2011/

3rd International ADS&ThU Workshop, 2014, USA

- http://adsthu.org/index.html

4th International ADS&ThU Workshop 2016, UK

- https://indico.cern.ch/event/509528/contributions/

5th International ADS&ThU Workshop 2019, Belgium

- https://events.sckcen.be/event_website_pages/view/5c87a995-edd4-4c2e-9c19-041f0a340409/5c87a990-a15c-4fa4-946c-041f0a340409/9f207fff04

6th International ADS&ThU Workshop, July/August 2021

Yorktown, Virginia, USA

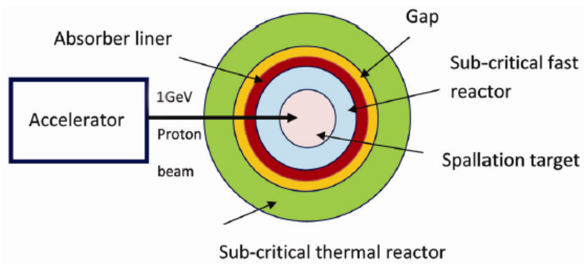
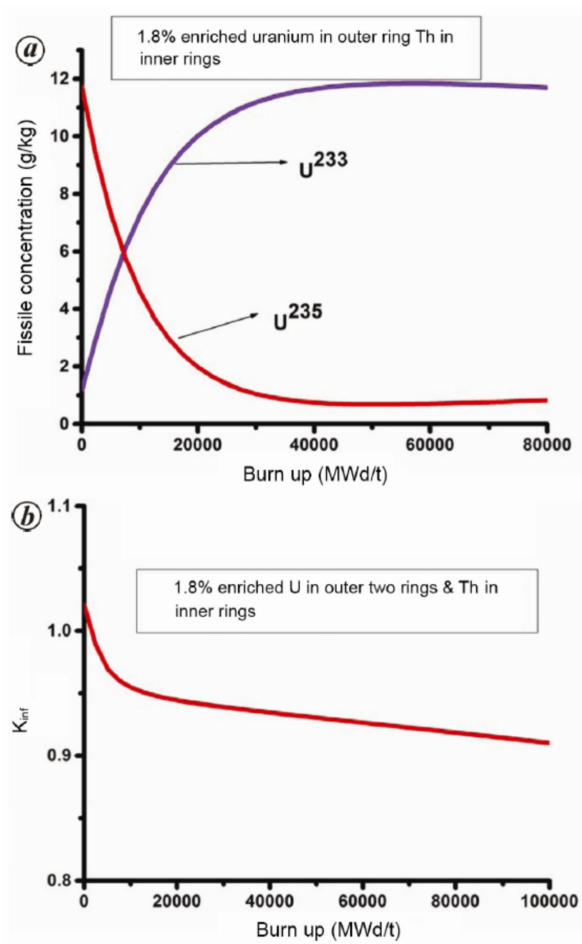


Figure 15. One-way coupled accelerator driven sub-critical system.



Sli

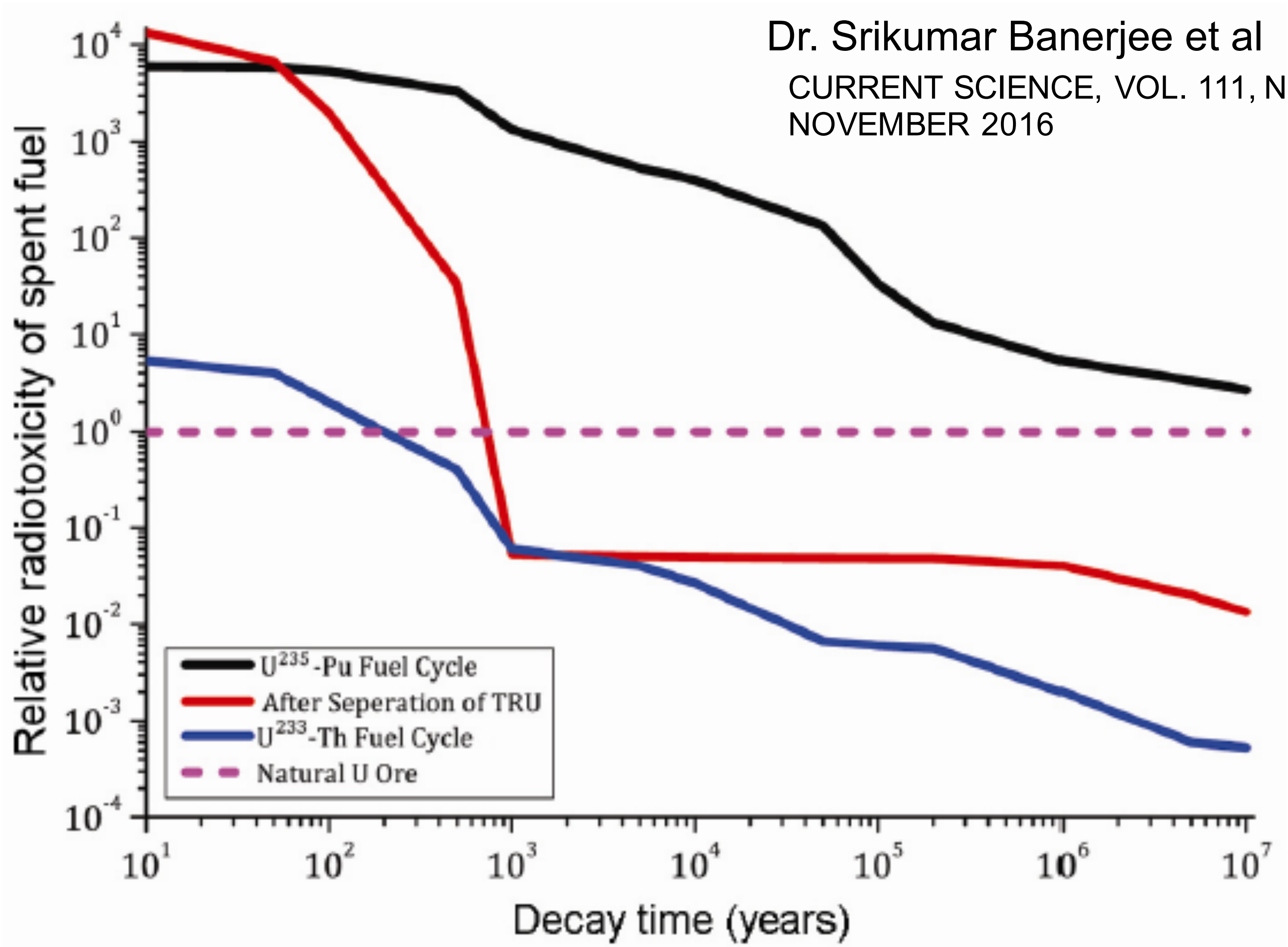
Figure 16. *a*, variation of fissile concentration with burn-up; *b*, Variation of k_∞ with burn-up.

Natural uranium or slightly enriched (1.6%) is the Start up fuel for each plant and U^{233} will be bread and used for for ever closing the fuel cycle

Electricity costs will be reduced considerably

Dr. Srikumar Banerjee et al

CURRENT SCIENCE, VOL. 111, NO. 10, 25 NOVEMBER 2016



Dr. Srikumar Banerjee et al

CURRENT SCIENCE, VOL. 111, NO. 10, 25 NOVEMBER 2016

Figure 3. Relative radiotoxicity of nuclear waste in different fuel cycles as function of time.

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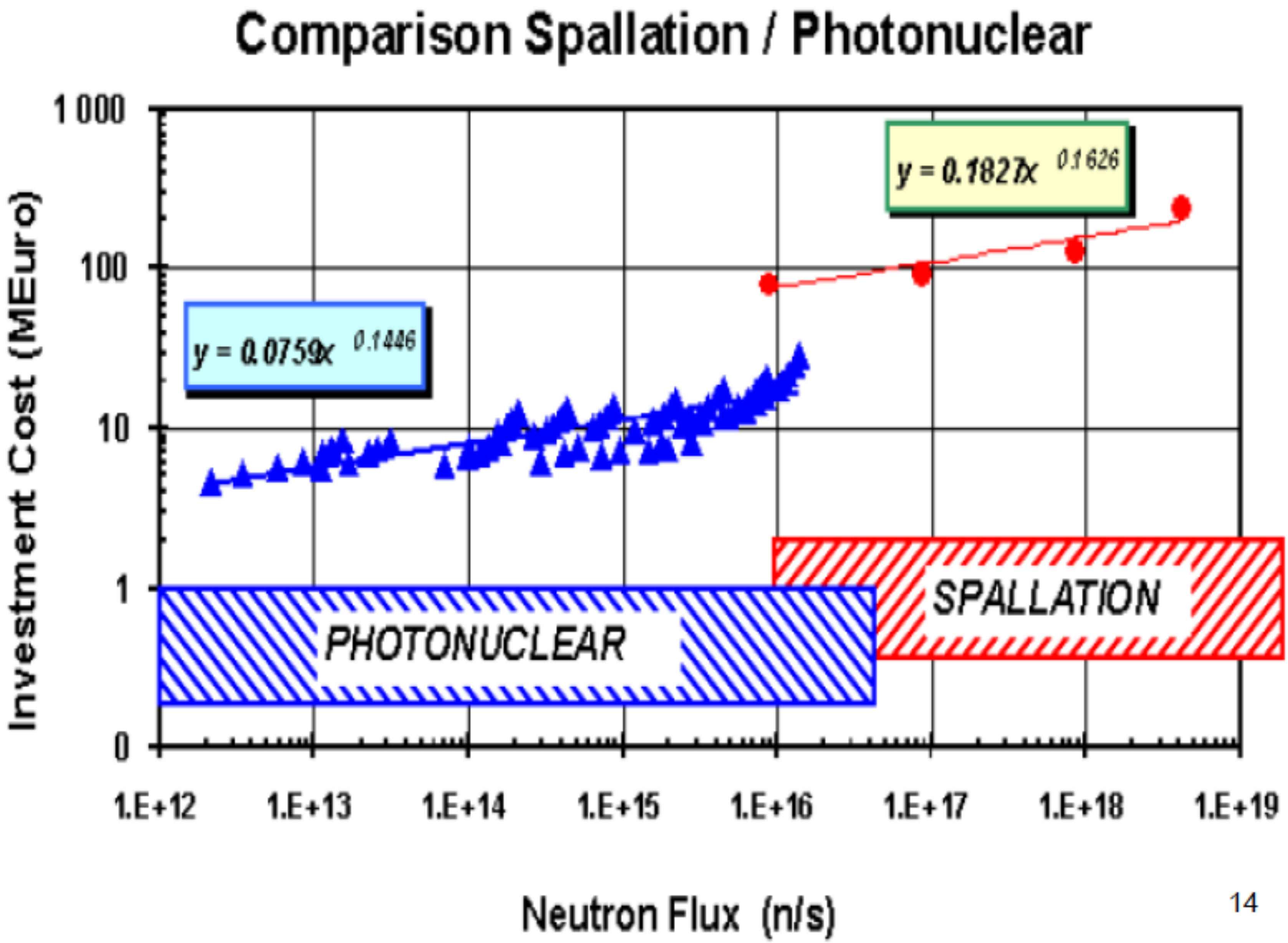


BARC-APPD Presentation at 1st ADS&ThU Intl. Workshop, Blacksburg, USA,2010

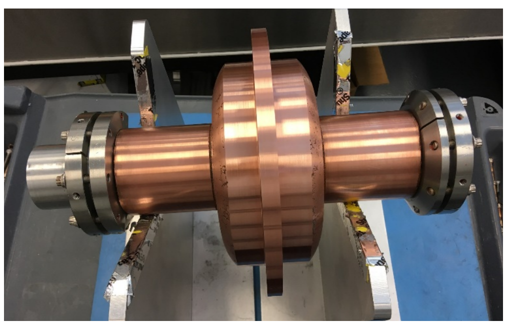
Neutron yield comparison of 10 MeV vs 100 MeV electron beam of equal power

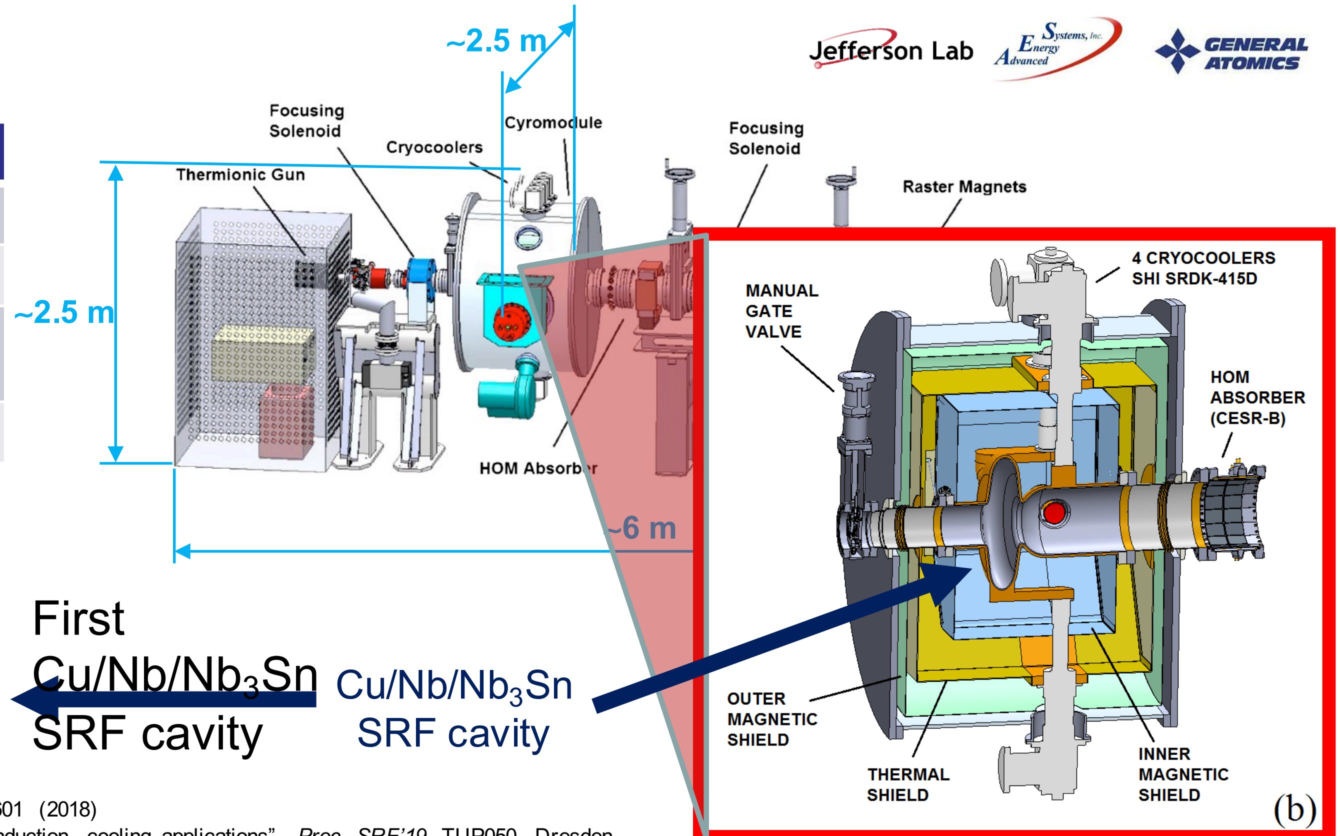
S. N0	Neutron Yield n/s in 4π solid angle for 1 Ampere x 10^{15}						Neutron Yield n/s ($x10^{15}$) at 100 MeV for W/Ta for Equal Beam Power
		Be	D_2O	LiD	CD_4 (liquid) /BeD_2	W/Ta	
1	8 MeV	2.1	4.4	7.5	11.5	-	-
2	10MeV	5.5	9.3	12.5	15.0	1	20
3	15MeV	10.2	**14.0**	**22.3**	**34.3**	**3.5**	**30**
4	20MeV	14.9	**20.0**	**28.6**	**44.8**	**20**	**40**

K.C. Mittal Presentation this morning

Design of a compact, low-cost SRF LINAC for Environmental Remediation

Beam current (mA)	1000
Final energy (MeV)	1
Beam power (kW)	1000
Fundamental RF (MHz)	750
Source energy (keV)	100





First Cu/Nb/Nb$_3$Sn SRF cavity

G. Ciovati *et al.*, *Phys. Rev. Accel. Beams* **21**, 091601 (2018)
G. Ciovati *et al.*, “A multi-layered SRF cavity for conduction cooling applications”, *Proc. SRF’19*, TUP050, Dresden, Germany, July 2019

A-1. Niobium material preparation (with new processing for sheeting and piping)

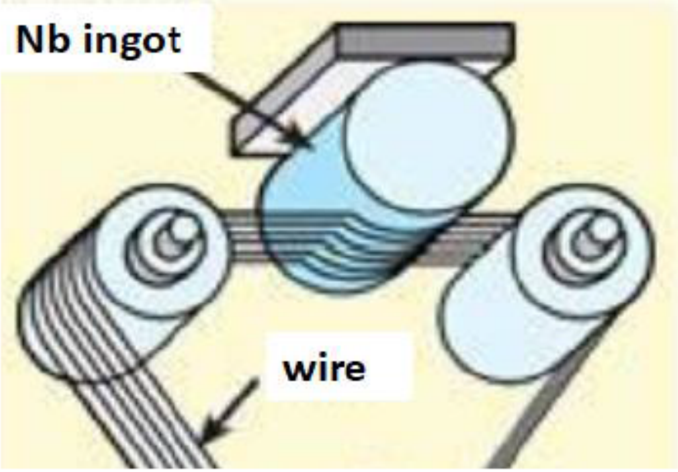
International Linear Collider plan

Motivation

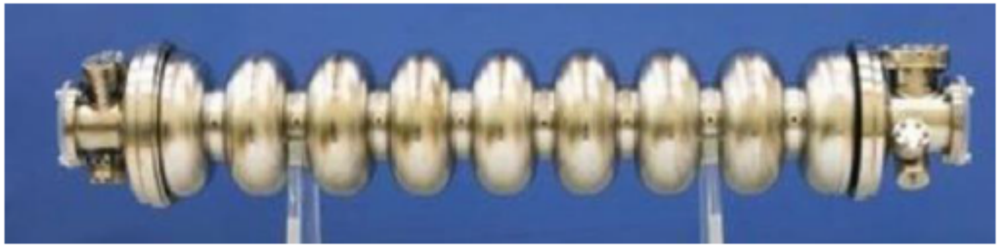
- Niobium material cost for fabricating SRF cavity cell and end-groups is relatively high.
- If we can accept lower residual resistivity ratio (RRR) material, the ingot cost becomes cheaper.
- We will try to simplify the manufacturing process (like direct slicing from the ingot).

Niobium ingot

US Patent 8,128,765 Large grain cavities from pure niobium ingot G. Myneni, P. Kneisel, and T. Cameiro



Forged ingot Nb Technology
A collaboration between
ATI, BSCE Systems, Inc. &
KEK



International Symposium On Hydrogen In Matter (ISOHIM) Publications

Hydrogen in Materials and Vacuum Systems AIP CP 671

http://www.virtualjournals.org/dbt/dbt.jsp?KEY=APCPCS&Volume=671&Issue=1

Hydrogen in Matter AIP CP 837

http://www.virtualjournals.org/dbt/dbt.jsp?KEY=APCPCS&Volume=837&Issue=1

Single Crystal Large Grain Niobium AIP CP 927

http://www.virtualjournals.org/dbt/dbt.jsp?KEY=APCPCS&Volume=927&Issue=1

Superconducting Science and Technology of Ingot Niobium AIP CP 1352

http://scitation.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1352&Issue=1

Science and Technology of Ingot Niobium For Superconducting Radio Frequency Applications AIP CP 1687

https://aip.scitation.org/toc/apc/1687/1?expanded=1687

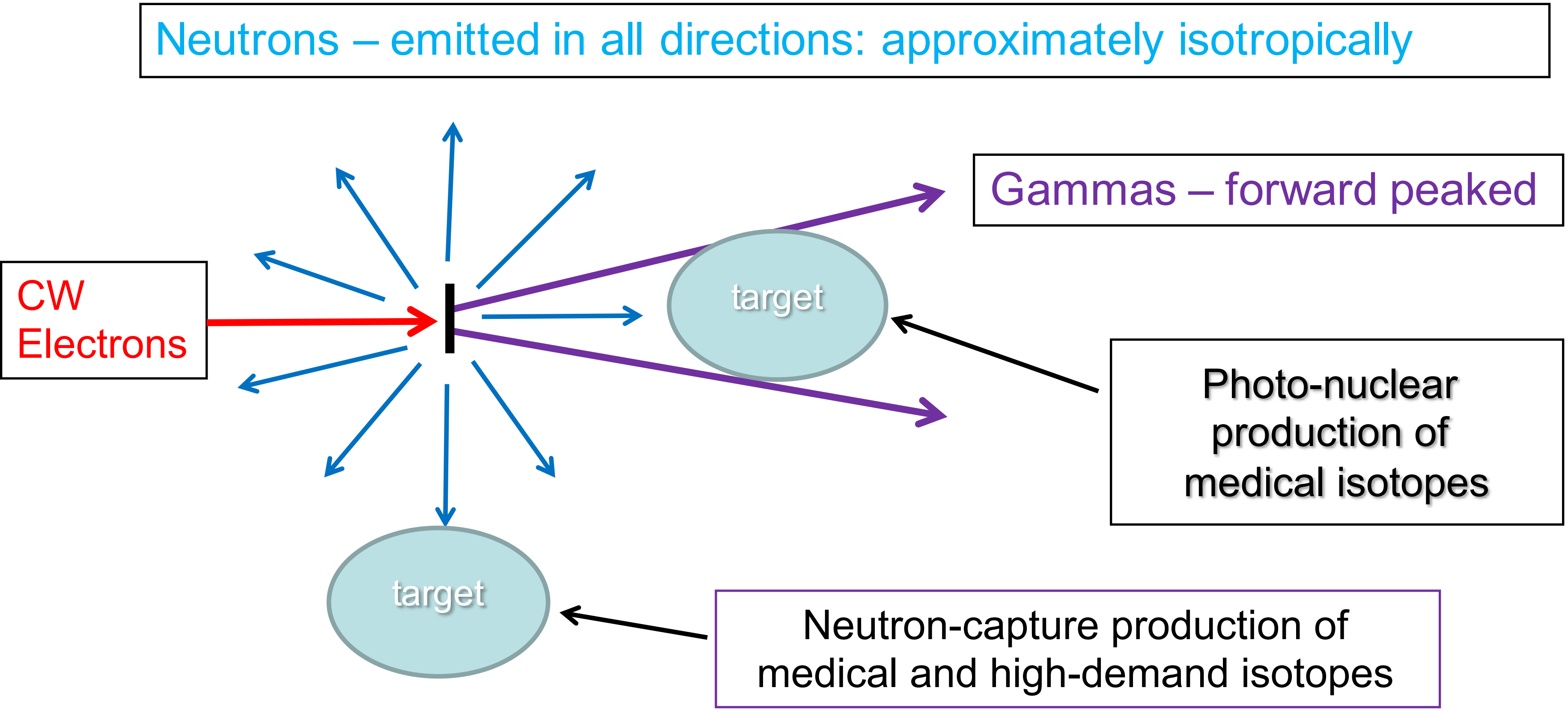
Specifications of the one way coupled sub-critical micro-reactors

- CW Electron Linac
  - Energy 10 -15 MeV
  - Current 1 to 3 A
  - Frequency 915 MHz
  - Thermionic gun
  - Operating temperature 4.25 K
  - Forged ingot Nb cavity with Nb3Sn inner surface

- Sub-critical Core
  - Molten salt burner/breeder
  - Breeding and burning in equilibrium
  - Thorium in the central breeding zone
  - ^{233}U in the outer zone

- Applications
  - High temperature heat sources
  - Medical isotope generators in parallel
  - Water desalination plants
  - Back up to renewable energy sources close to cities and townships

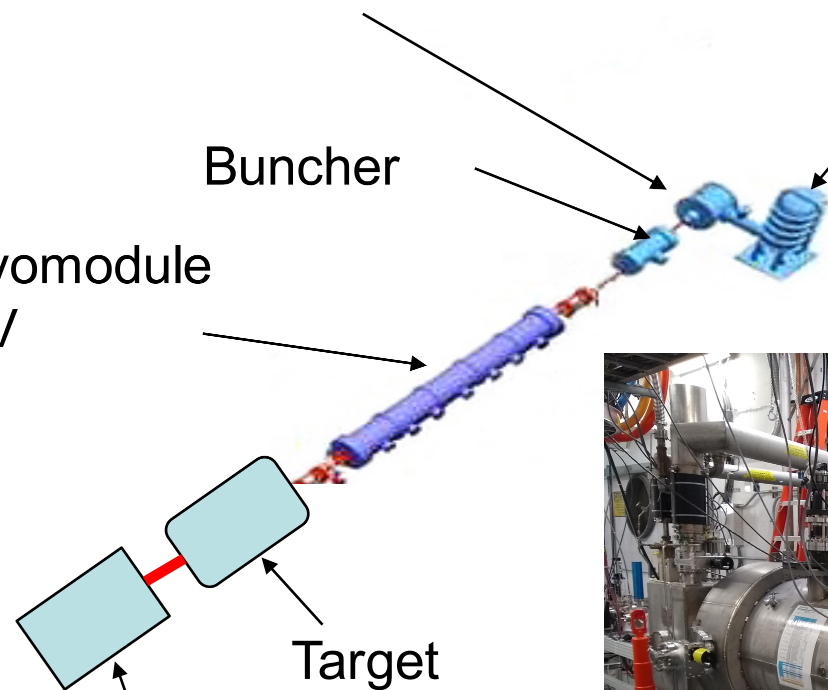
Neutron/gamma source for isotope developments



A 100 kW, 100 MeV electron linac is capable of producing 100% of the U.S. demand for many high-priority research isotopes for medical, industrial and other kinds of research. Such a device could also produce nearly 10% of the entire U.S. demand for ^{99}Mo.

Virginia ADS Consortium Proposal 2012

Schematic of the VNEFRC 100 MeV, 100 kW system for Technetium

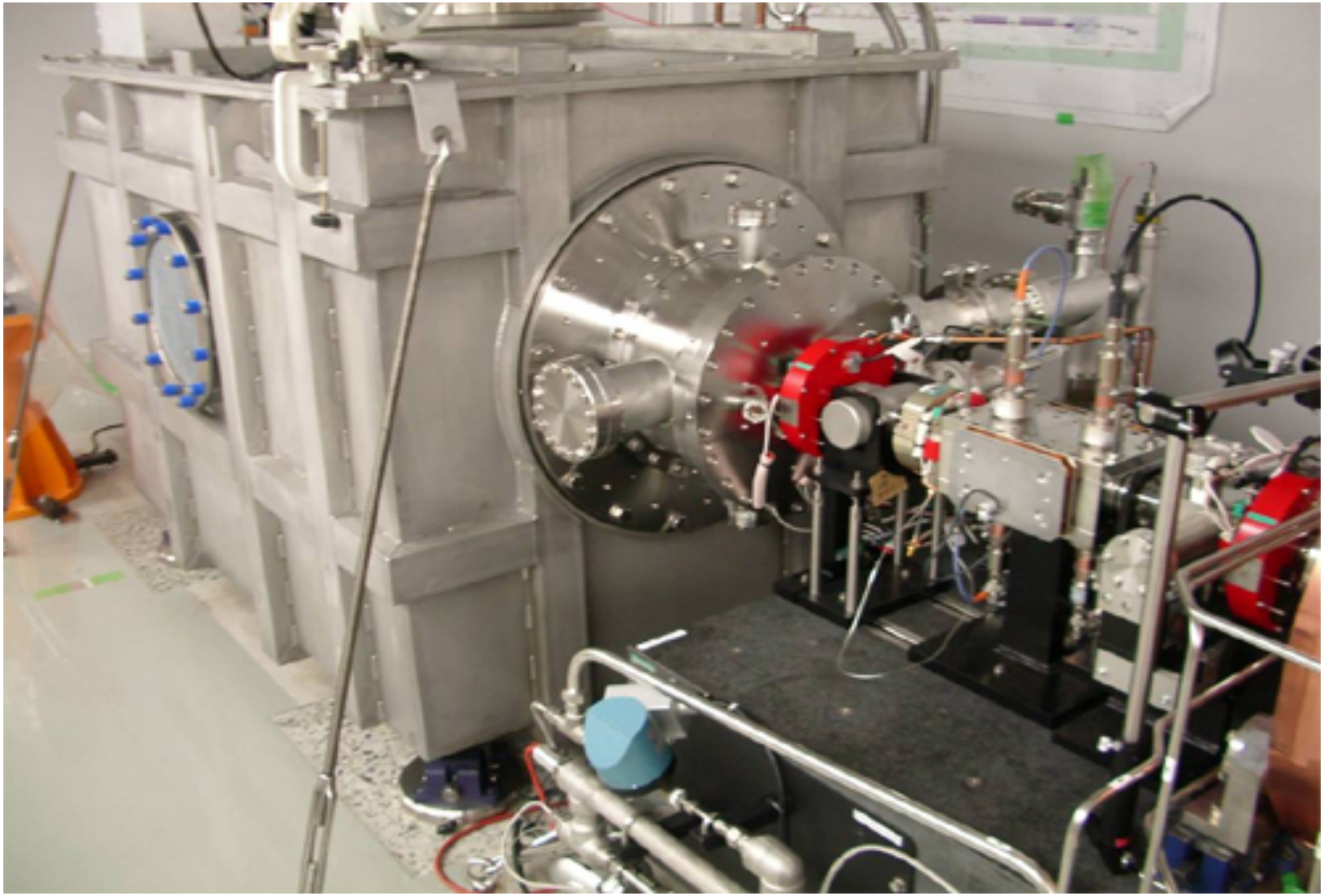


10 MeV CW SRF Linac

Virginia ADS Consortium Proposal 2012

JLab's 100 MeV CW SRF Linac Cryomodule

JLab Thermionic Gun

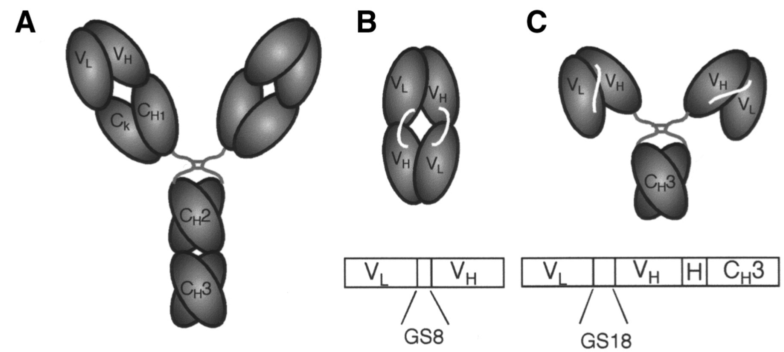


Cu-67 for Theranostic applications

Half Life: 2.58 days (61.83 hours)
Radiation: Decay Mode: Beta
Gamma Constant: 0.97 mR/hr per 1 mCi at 30 cm

Max. Beta Range in Air : 200 cm
Max. Beta Range in Water : 0.21 cm

β^- (MeV)	γ (MeV)
0.377 (57 %)	0.093 (16.1 %)
0.468 (22 %)	0.185 (48.7 %)
0.562 (20 %)	0.3 (0.8 %)



Antibody Diabody
Minibody

^{67}Cu is the longest living copper radioisotope

- **^{67}Cu is one of the best suited isotopes for radioimmunotherapy**
- **Its long half-life is similar to biological half-life of many monoclonal Antibodies (mAbs)**
- **Gamma radiation can be used for Single-Photon Emission Computed Tomography (SPECT)**
- **Simple radiolabeling procedure**

Dynamic growth of radioimmunotherapy applications can increase demand for this isotope

JLab collaboration with Virginia Commonwealth University, initiated by ADS Consortium

Summary

Let us Walk the Talk

Declining Coal - Enthroning Nuclear - Fizzling out Gas -
Enabling Renewables – Pathway to Zero Carbon

We propose to build a one way coupled Advanced Subcritical MSR ^{233}U &Th Micro-Reactor (ASMR) under a PPP in Yorktown, Virginia in collaboration with Indian Partners while a similar ASMR could also be built in parallel at Visakhapatnam BARC

These micro-reactor’s linacs have dual use for the production of ^{225}Actinium for medical applications