Nuclear Research Program at AANL by Modern Electron Accelerators: Rhodotrons

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ECONOMIC ASPECTS OF ACCELERATOR IMPLEMENTATION

Producer (accelerator type)	Energy [MeV]	Beam [mA]	Power [kW]	Price [M$]	Price [$/W]
IBA, Belgium (UHF)	10	15	150	6.1	40.7
RDI, U.S.A. (DC)	5	50	250	4.9	19.6
NHV, Japan (DC)	5	30	150	5.0	33.3
Vivirad,France(DC)	5	200	1000	4.4	4.4
INP, Russia (UHF)	5	10	50	1.2	24.0
NIIEFA,Russia (DC)	1	500	500	1,9	3.8
INP, Russia (DC)	1	400	400	2.0	5.0


iba

Electron Accelerator (Rhodotron)

Accelerators Rhodotron type, IBA, Belgium

Starting date: December 1991

TT100 Compact 10 MeV

40kW, 4mA

TT200 Standard 10 MeV

100kW, 10mA

Models available from 35 kW to 100 kW

TT300 High power 10 MeV

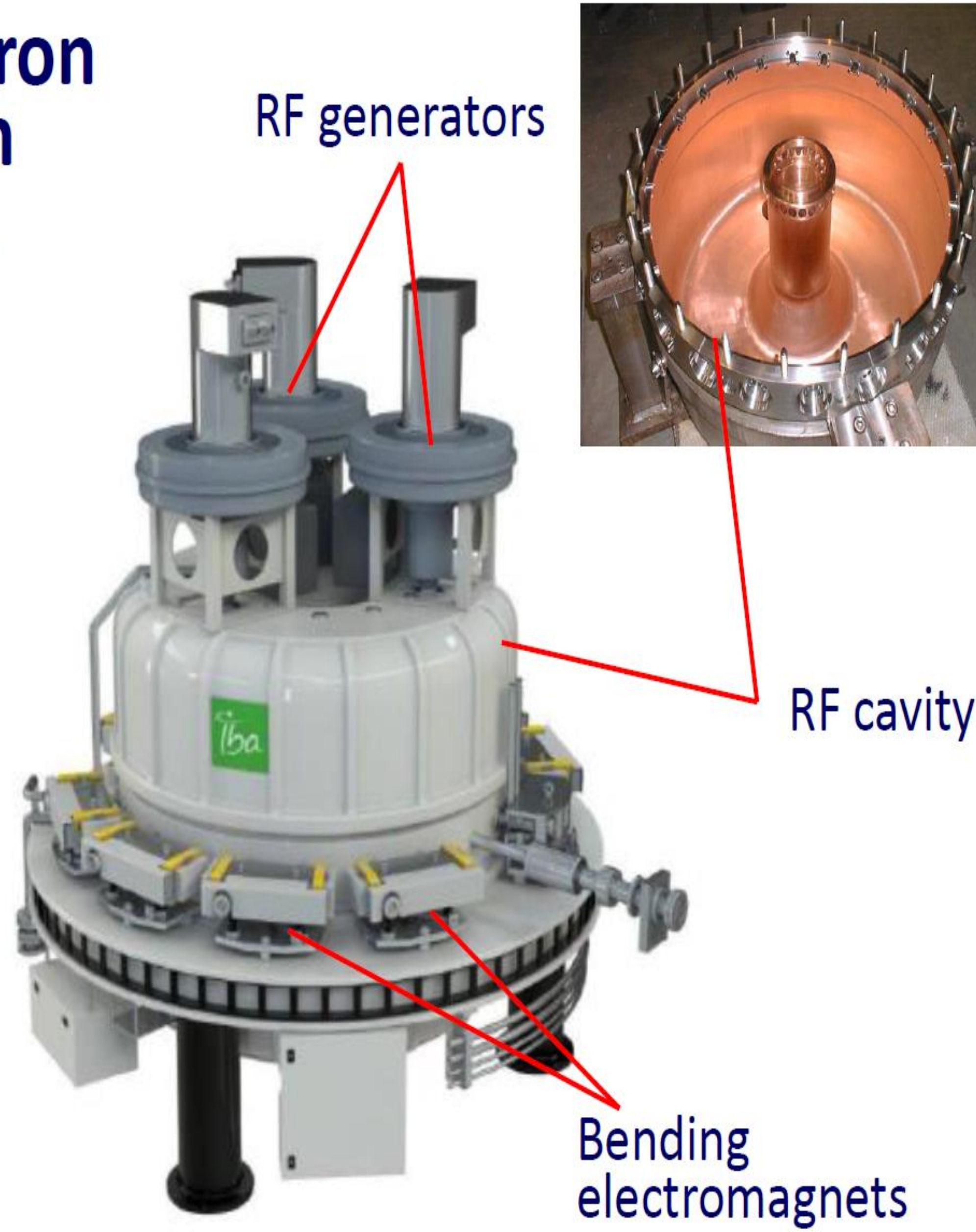
245kW, 35mA

Models available from 50 kW to 245 kW

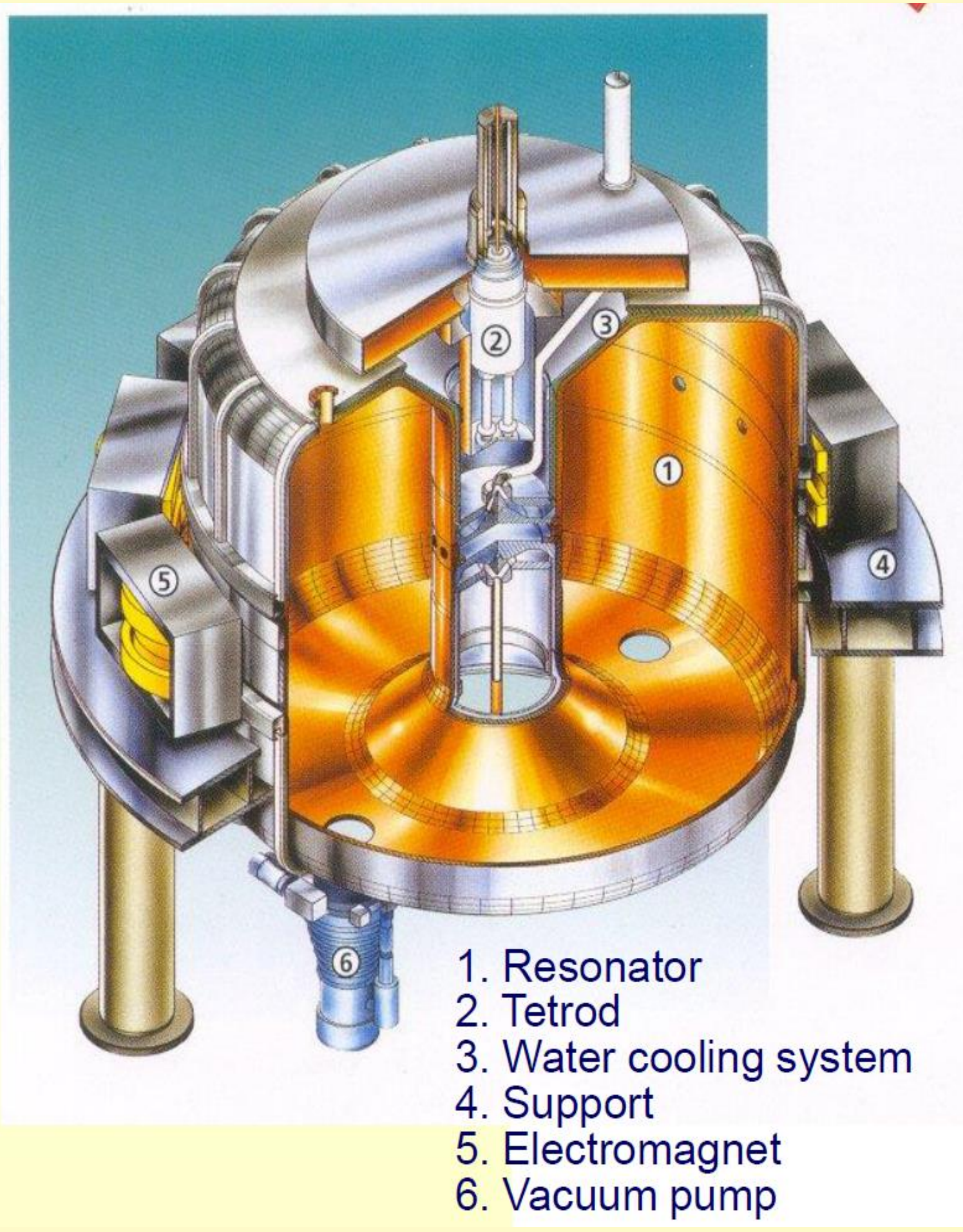
TT1000 High power 7 MeV

560kW, 80mA

Models available from 100 kW to 560 kW



10 MeV ELECTRON ACCELERATOR RHODOTRON TYPE



TT 1000:
do 700 kW; 7 MeV (100 mA)
do 500 kW; 5 MeV (100 mA)
TT 300:
do 200 kW; 10 MeV (20 mA)
do 135 kW; 5 MeV (27 mA)
TT 200:
do 100 kW; 10 MeV (10 mA)
do 100 kW; 5 MeV (20 mA)
TT 100
35 kW; 10 MeV (3.5 mA)

Frequency 107.5 MHz

	TT 100	TT 200	TT 300	TT 1000
Energy	2.5 to 10 MeV	2 to 10 MeV	2 to 10 MeV	5 or 7 MeV
Power Range	up to 40 kW	40 to 100 kW	40 to 420 kW	100 to 560 kW
Diameter	1.6 m	3 m	3 m	3 m
Height	1.7 m	2.4 m	2.4 m	3.4 m
MeV/Pass	0.833	1	1	1.166
Number of Passes	12	10	10	6

RHODOTRON PRODUCT RANGE AND SPECIFICATIONS

	TT 100	TT200	TT300	TT1000
Energy (MeV)	3-10	3-10	3-10	3-10
Max. Beam Power (kW)	40	80	420	560 (7 MeV)
Full Diameter (m)	1.60	3.00	3.00	3.00
Full Height (m)	1.75	2.40	2.40	2.40
Weight (T)	2.5	11	11	11
MeV/Pass	0.833	1.0	1.0	1.0
Number of Passes	12	10	10	7
Primary Mode	E-Beam	E-Beam	E-Beam/X-ray	X-ray
Max Line Power (kW)	<210	<260	<440	<1300 (560kW)

RHODOTRON TECHNOLOGY

1. *Operating Principle*
2. *Accelerating cavity*
3. *Electron Gun*
4. *RF System*
5. *Deflection Magnets*
6. *Control System*
7. *Beam Delivery Systems*

Operating Principles

Every pass through the central pillar accelerates electrons by increments of 0.8 to 1.166 MeV. Once electrons have finished the acceleration process, the beam is extracted from the cavity and scanned in order to generate an “electron curtain” for product processing.

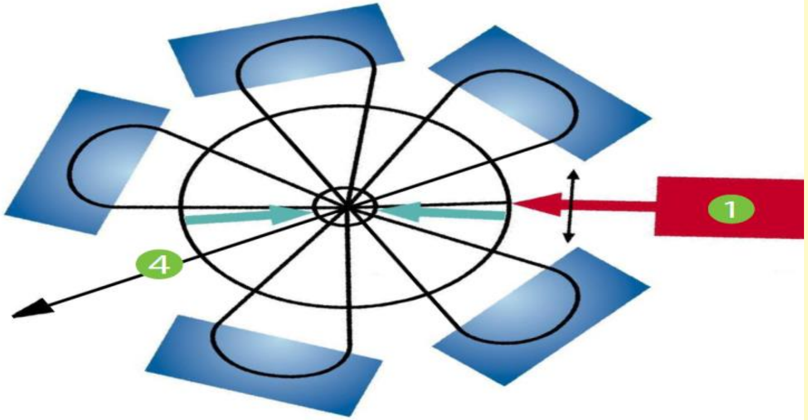
1. Electrons are fired by the heated filament of the electron source located in the outer wall of the cavity.

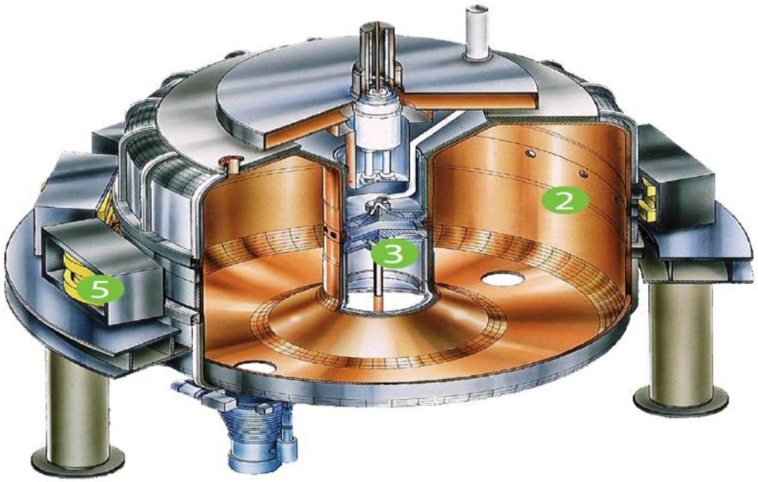
2. The electrons are introduced into the cavit, when the electric field is such that it will accelerate the electrons inwards, towards the hollow coaxial cynlinder in the center.

3. The electrons pass through openings in the inner cylinder while the electric field is reversing.

4. On emerging from the inner cylinder, the electrons are further accelerated (towards the outer cavity wall) under the influence of the new reversed field.

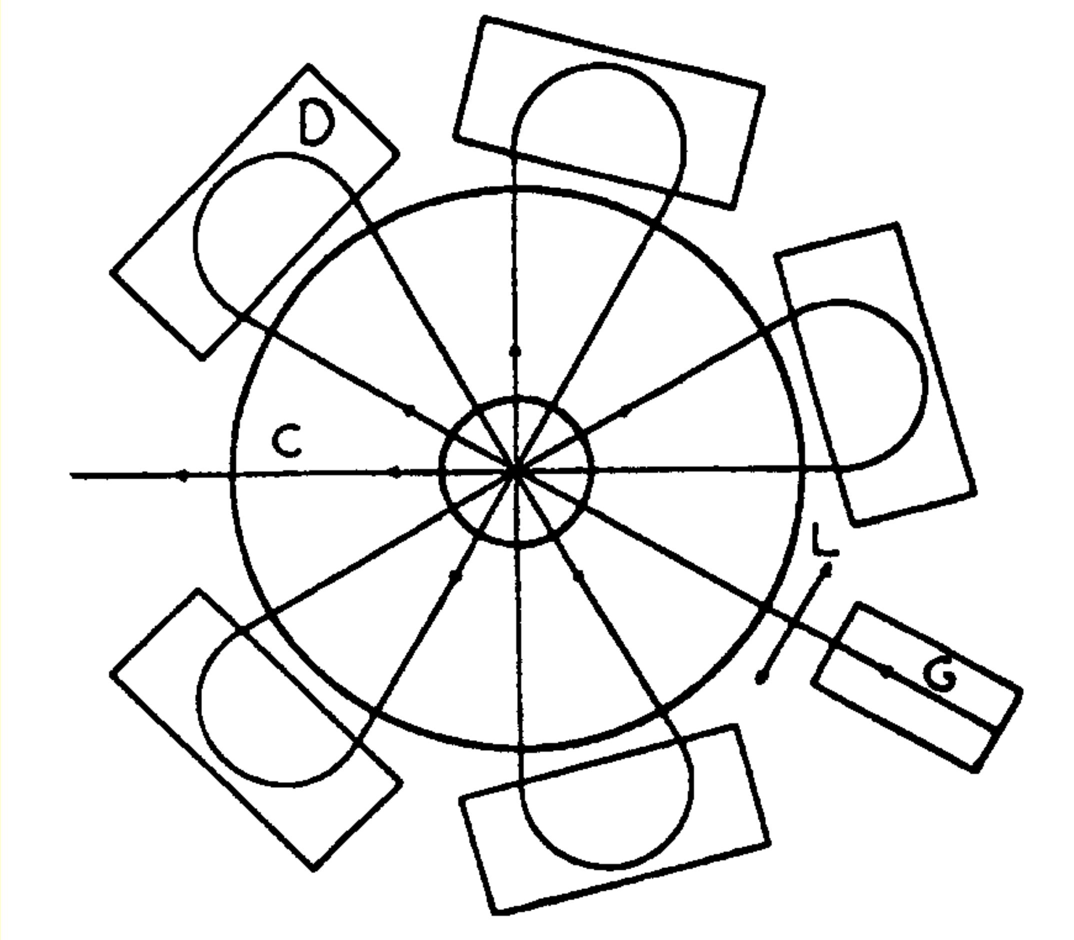
5. Using beam deflections magnets, the electrons are reintroduced into the main body of the accelerator for additional crossings of the cavity in order to reach the required energy level and leave the cavity through a beam line.





RHODOTRON ACCELERATORS FOR INDUSTRIAL ELECTRON-BEAM PROCESSING : A PROGRESS REPORT

Y. Jongen, M. Abs, T. Delvigne, Arnold Herer, J.M. Capdevila, F. Genina, A. Nguyen



Median section of the accelerator and electron Trajectory

(D: deflecting magnet,

C: accelerating cavity,

L: magnetic lens,

G: electron gun)

International regulations limit to 10 MeV the maximum energy of electrons used in industrial applications, in order to stay below the threshold of most gamma-n reactions, preventing therefore a potential neutron activation of the goods treated.

The TT200 (10MeV/80kW guaranteed power) is convenient for industrial applications where high dose or/and high irradiation throughput are required. The total height of the accelerator is 2.2 meters, including the RF power amplifier placed on the top of the cavity.

Applications

- ***Sterilization of medical devices and pharmaceuticals***

Стерилизация медицинских изделий и фармацевтических препаратов

- ***Sanitization of cosmetics and consumer products***

Санитарная обработка косметики и потребительских товаров

- ***Phytosanitary treatment of imported/exported produce***

Фитосанитарная обработка импортируемой/ экспортируемой продукции

- ***Cold pasteurization of a wide variety of foodstuff***

Холодная пастеризация широкого спектра пищевых продуктов

- ***Biohazard reduction of contaminated materials***

Снижение биологической опасности загрязненных материалов

- ***Curing of advanced and wood-plastic composites***

Отверждение современных и древесно-пластиковых композитов

- ***Crosslinking of tubing and wire & cable jacket***

Сшивание труб и оболочек из проводов и кабелей

- ***Polymer enhancements including fire and ozone resistance***

Полимерные улучшения, включая огнестойкость и устойчивость к озону

- ***Modification of melt flow index***

Изменение индекса текучести расплава

- ***Controlled scissioning of PTFE, PP and wood pulp***

Контролируемое выделение ПТФЭ, ПП (термопластик полимер) и древесной массы

- ***Coloration of glass and gemstones***

Окраска стекол и драгоценных камней

- ***Doping of semiconductors***

Легирование полупроводников

- ***Production and detection of isotopes***

Производство и обнаружение изотопов

Science:

- ***Photonuclear interaction induced by 10 MeV electron beam is an approach for generating the high intensity neutrons.***

- ***Except the nuclear reactors, the electron accelerators can be considered as the main source of neutron with some different specifications such as higher intensity, lower cost and much smaller size in compare with the nuclear reactors.***

Implementation of an Electron Driver at HRIBF

B. Alan Tatum

International Workshop on Electron Drivers for Radioactive Ion Beams, October 10th, 2007

Rhodotron Implementation

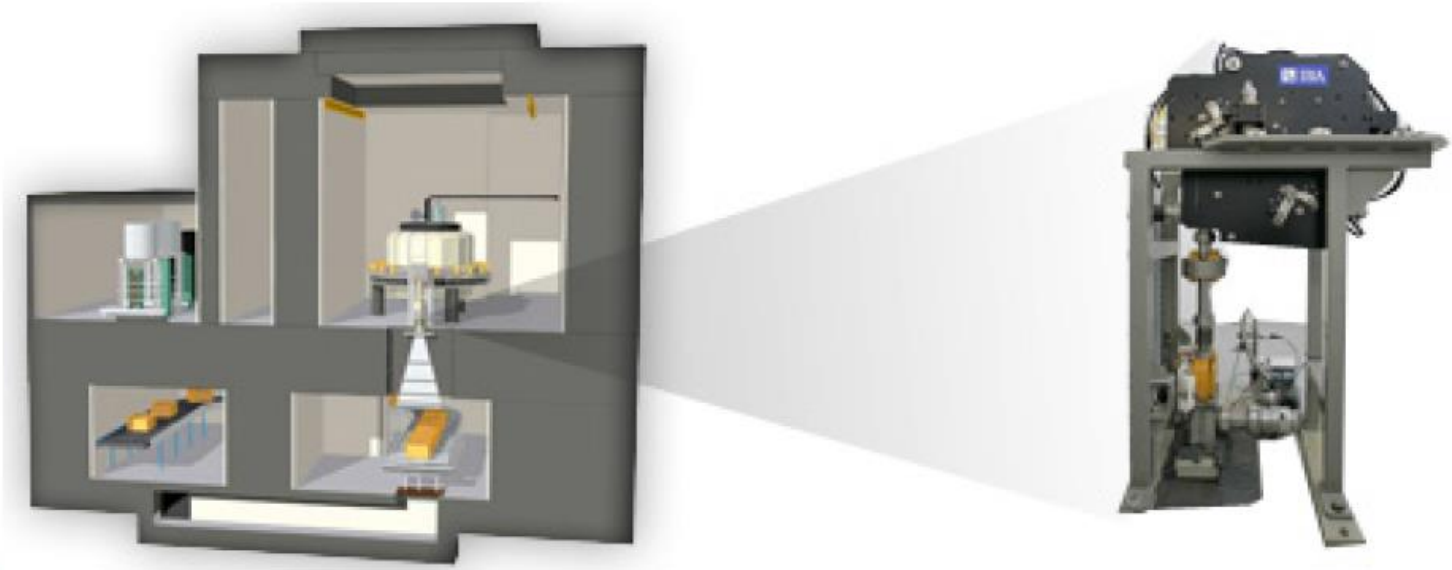
- Discussed with IBA the possibility of designing a 25MeV machine, but they believe it is too risky and requires months of extensive design effort.
- 10MeV TT200 scales easily to 12.5MeV
- IBA proposes an HRIBF layout with two 12.5MeV Rhodotron's in series
- Turnkey system includes two Rhodotrons, electron gun, scanning horn, power supplies, cooling systems, control systems, installation and commissioning at HRIBF

Technical Specifications of the various Rhodotron®'s models |

	TT100	TT200	TT300	TX400	TX1000
Energy	10 MeV	10 MeV	10 MeV	7 MeV	from 5 to 7,5 MeV
Beam Power Range	0,5 to 35 kW	0,5 to 80 kW	0,5 to 190 kW	0,5 to 280 kW	0,5 to 700 kW
Power Consumption at full energy	210 kW	310 kW	452 kW	596	1270 kW
Number of passes	12	10	10	7	6
Diameter	1,6m	3,0m	3,0m	3,0 m	3,0m
Height	1,75m	3,0m	3,0m	3,0	3,3m

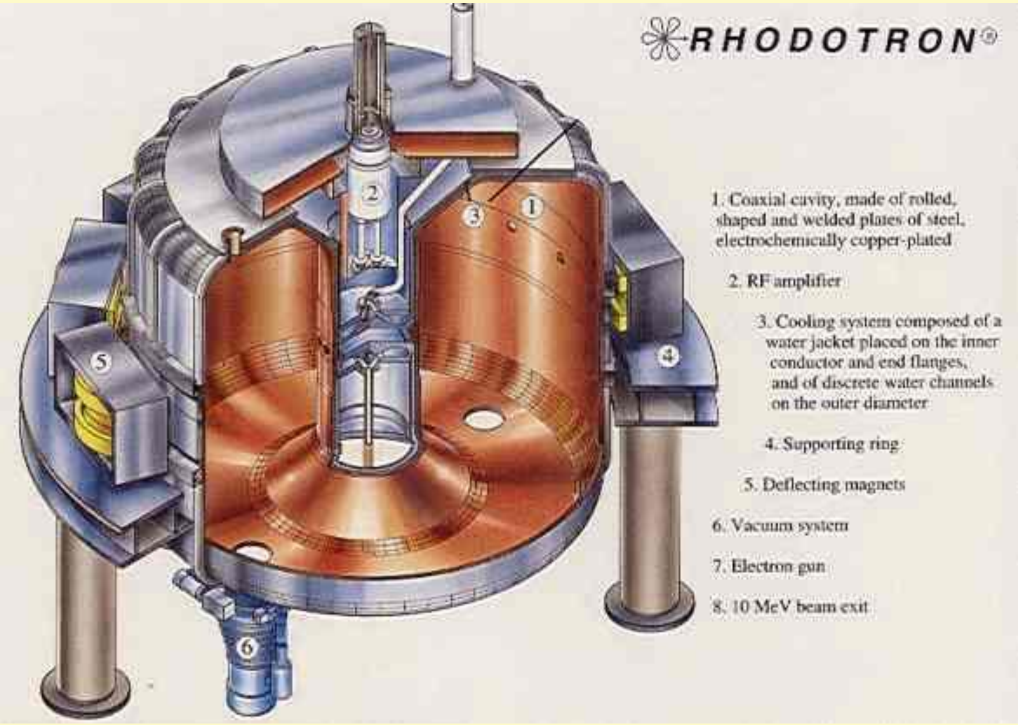
Rhodotron Overview

- An Ion Beam Applications (IBA) Rhodotron® is the preferred electron accelerator due to its compact size, high efficiency, reliability, low operating cost, and turn key implementation.
- Industrial machine typically used for medical sterilization, polymer cross-linking, food pasteurization, and mail irradiation.
- Nearly 20 of these reliable, flexible, and economical machines are installed world-wide.
- The Rhodotron® is a recirculating accelerator where electrons gain energy by crossing a coaxial-shaped accelerating cavity several times. This original design makes it possible to operate the machine in continuous mode for maximum efficiency and throughput.



A Photo-fission Facility
-Driver

- **Requirements**
  - ~25 MeV or higher, CW, turnkey
  - 100 kW or more at 25 MeV
  - 80 kW or more at 50 MeV
- **Turnkey options**
  - 25 MeV rhodotron
  - 50 MeV SC linac
- **Costs are similar**

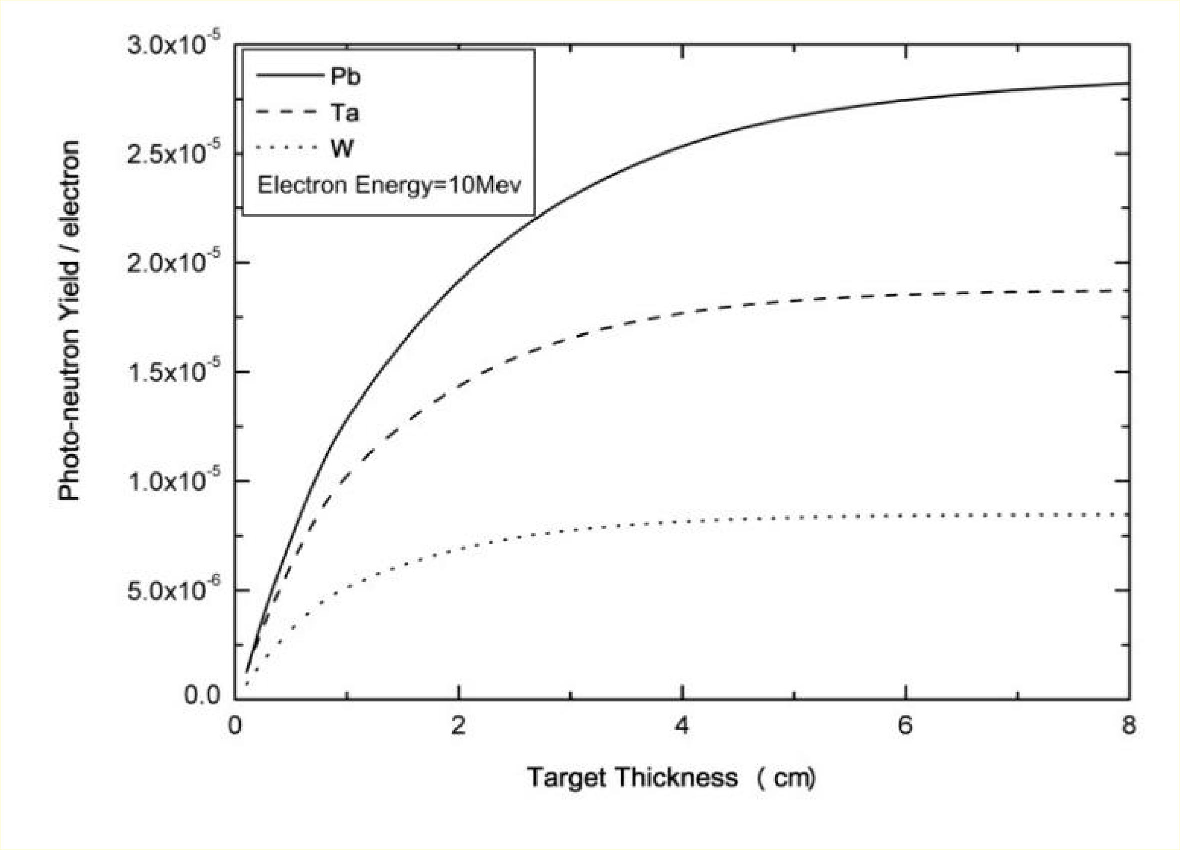


Isotope production

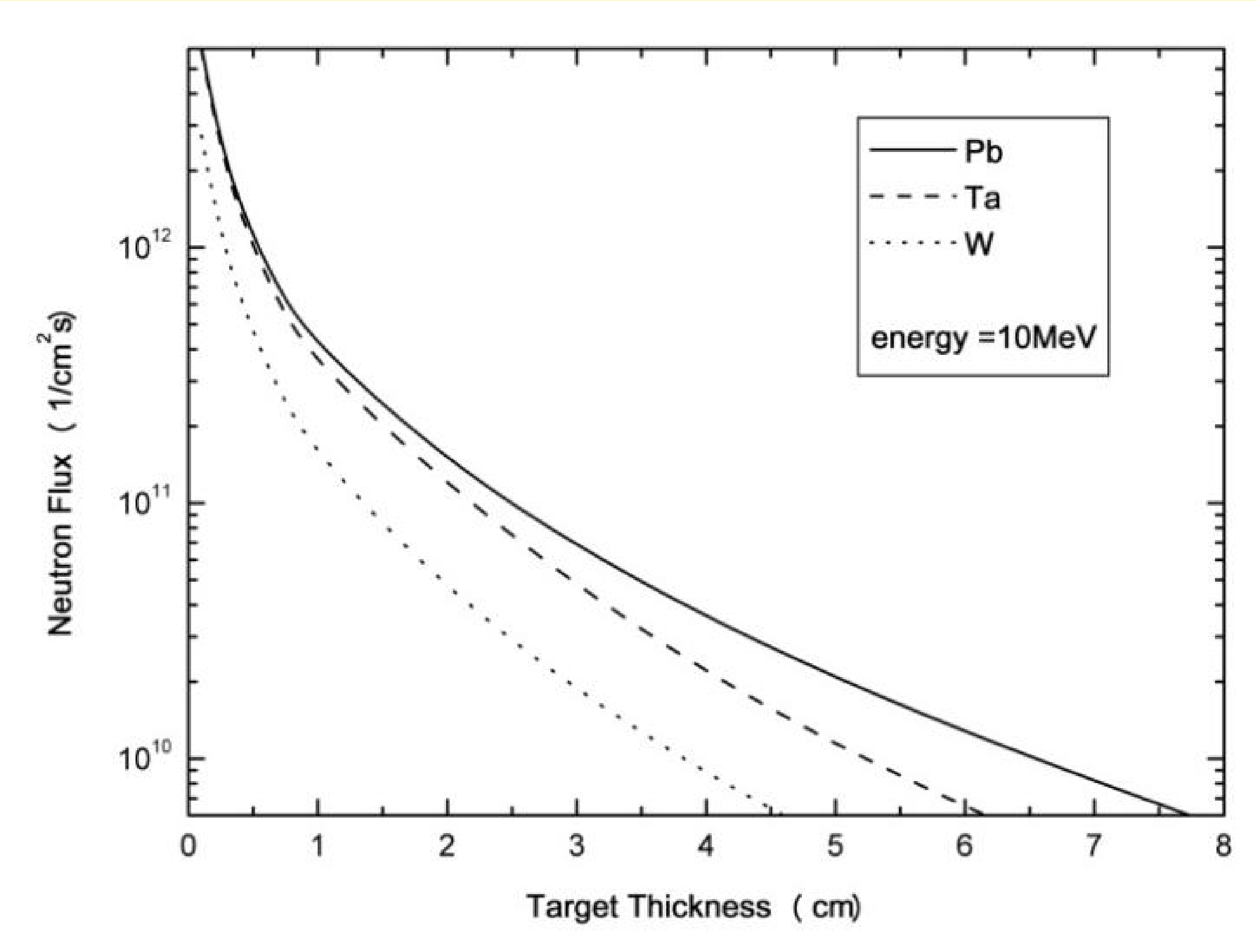
$^{98}Mo(n,\gamma)^{99}Mo$

Neutron Generation from 10 MeV Electron Beam to Produce ^{99}Mo

Borhani Zarandi, Mahmood; Tabbakh, Farshid; Amrollahi Bioki, Hojjat

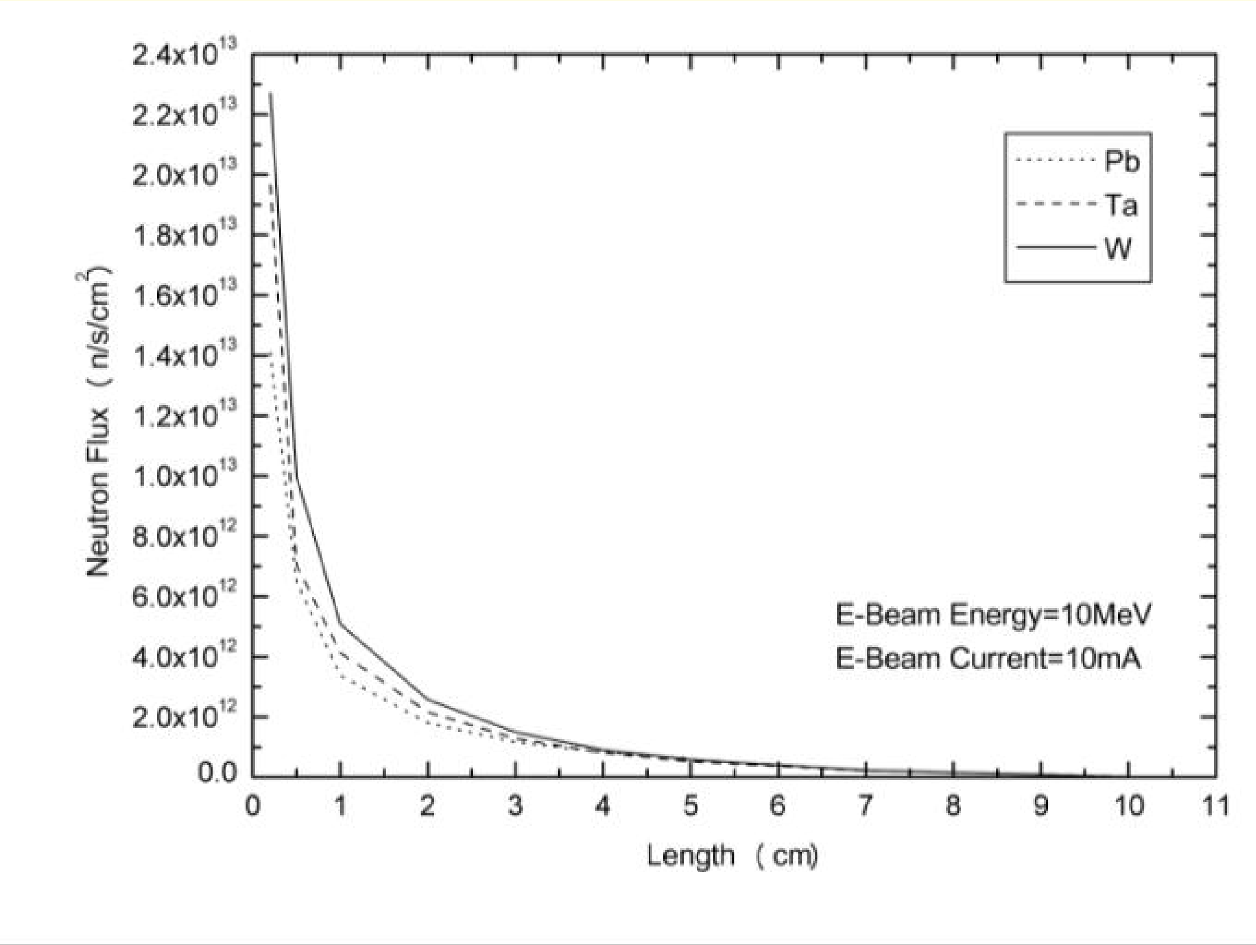


The neutron yield in terms of target thickness for Pb, Ta and W

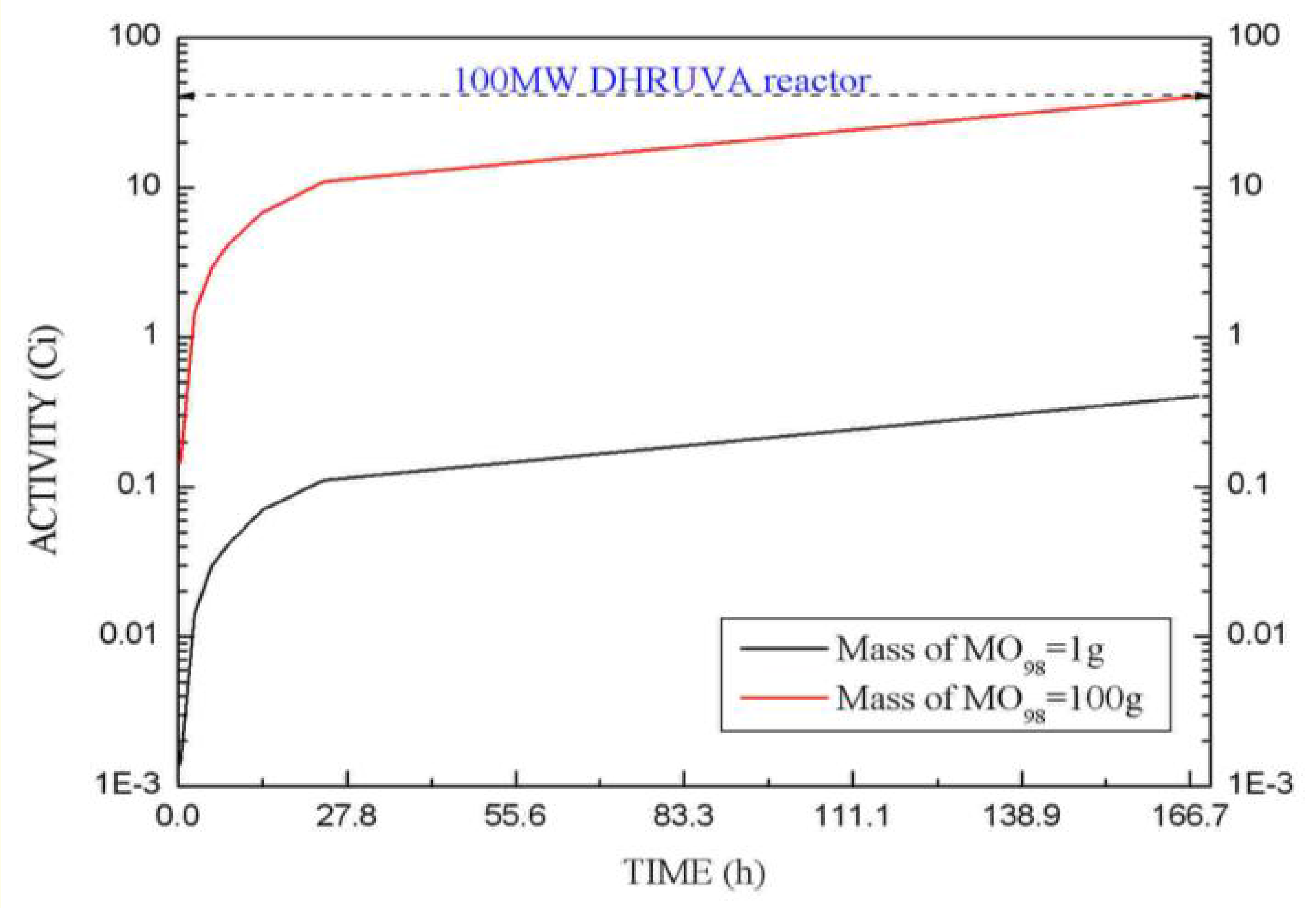


Neutron flux in the target along the beam direction
(E=10MeV and i=10mA)

The neutron flux in terms of thickness for Pb, Ta and W



Neutron flux in the target along the beam direction (E=10 MeV and I=10 mA)



Mo-99 activity produced by Rhodotron-TT200 and 100MW DHRUVA reactor in terms of duration of irradiation

FARSHID TABBAKH, MOJTABA MOSTAJAB ALDAAVATI, MAHDIEH SADAT HOSEYNIand KHADIJEH REZAEE EBRAHIM SARAEE

Induced photonuclear interaction by Rhodotron-TT200 10 MeV electron beam

For a current of 10 mA, the maximum fluxes are in the order of 10^{12} n/cm^2/s and the thickness up to 8 cm will cause the flux to drop to less than 10^{10} n/cm^2/s.

Target optimization for a 10-MeV E-beam neutron converter

Target optimization indicates that a 10 MeV electron beam is capable of producing high-intensity neutron flux of $10^{13} n \cdot cm^{-2} \cdot s^{-1}$ with average energy of 0.8 MeV.

THANK YOU!

Review of Industrial Accelerators and Their Applications

Robert W. Hamm, PhD
CEO & President
R&M Technical Enterprises, Inc.
Pleasanton, CA, USA

Paper AP/IA-12

International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators, IAEA
Vienna, May 4-8, 2009

Industrial Accelerator Business

Application	Total (2007)	Systems sold/yr	Sales/yr ($M)	System price ($M)
Ion Implantation	~9500	500	1,400	1.5 – 5.0
Electron beam modifications	~4500	100	150	0.5 – 2.5
Electron beam & X-ray irradiators	~2000	75	130	0.2 – 8.0
Ion beam analysis (including AMS)	~200	25	30	0.4 – 1.5
Radioisotope production (including PET)	~550	50	70	1.0 – 30
High energy x-ray inspection	~650	100	70	0.3 – 2.0
Neutron generators (including sealed tubes)	~1000	50	30	0.1 – 3.0
Total	18,400	900	1780	

Total accelerators sales increasing almost 10% per year.

E-beam

Throughput

	TT100	TT200	TT300	TT1000
Energy	10 MeV	10 MeV	5, 7, 10 MeV	5 or 7 MeV
Power range	Up to 40kW	35 to 100 kW	35 to 420 kW	100 to 560kW
Max throughput • 10 MeV E-beam	**68.000 m³/y** *2.3 Mci*	**168.000 m³/y** *5.8 Mci*	**700.000 m³/y** *24.3 Mci*	N/A
				

X-ray
Throughput

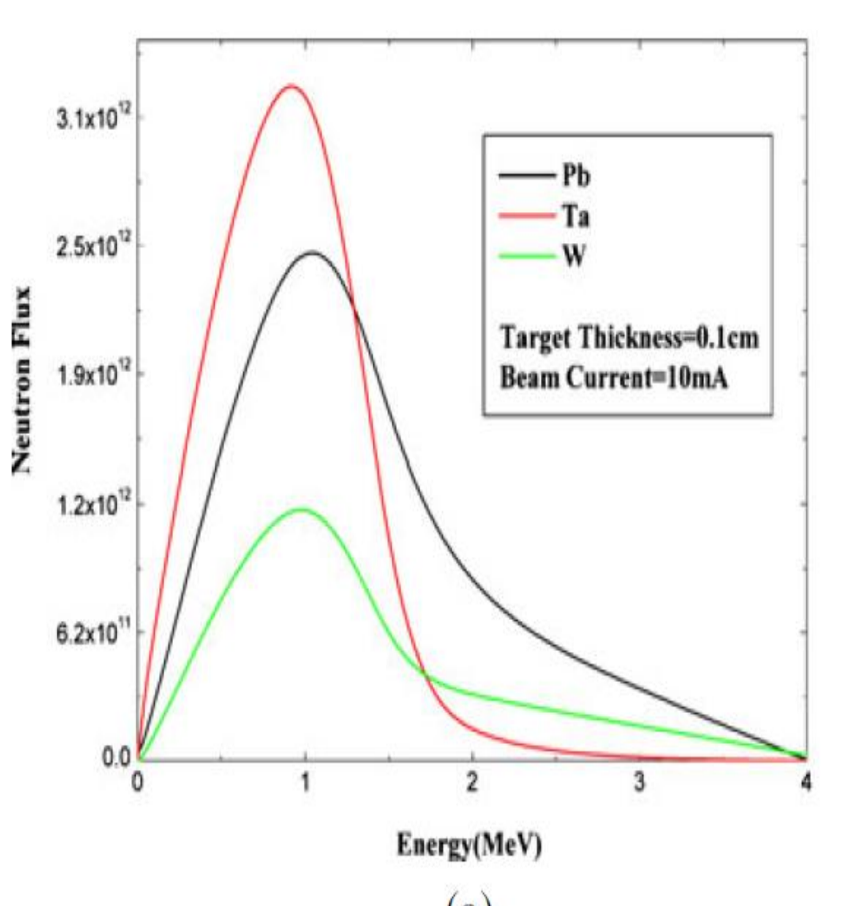
	TT100	TT200	TT300	TT1000
Energy	10 MeV	10 MeV	5, 7, 10 MeV	5 or 7 MeV
Power range	Up to 40kW	35 to 100 kW	35 to 420 kW	100 to 560kW
Max throughput • 10 MeV E-beam	68.000 m³/y *2.3 MCi*	168.000 m³/y *5.8 MCi*	700.000 m³/y *24.3 MCi*	N/A
• 7 MeV X-ray 0.15 gr/cc, 8000 hours/year, 25kGy	**8.000 m³/y** *280 kCi*	**22.000 m³/y** *770 kCi*	**93.000 m³/y** *3.2 MCi*	**124.000 m³/y** *4.3 MCi*
				

Project Cost

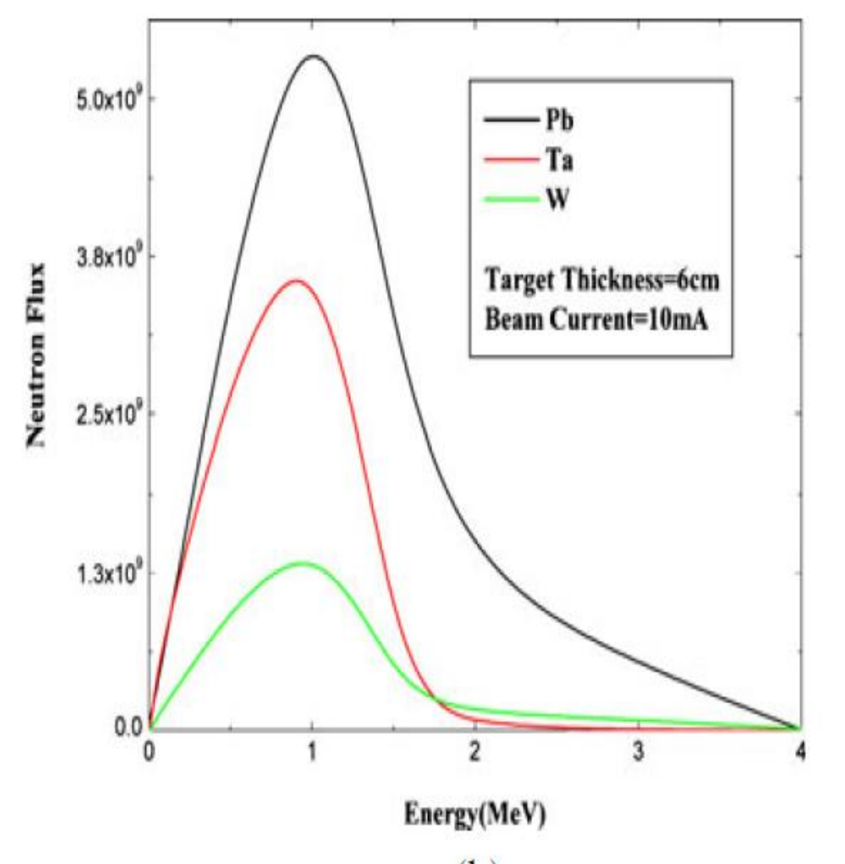
- Dual-Rhodotron option (preferred): $35M (accelerator cost is ~$10M)
- Single-Rhodotron option: $24M (accelerator cost is ~$5M)

- Cost of other possible accelerators:
  - Turnkey Accel normal conducting 50MeV linac $5M ("much higher" cost for superconducting CW machine)
  - Kazimi (TJNAF) FEL-based linac estimated at $7M + cryogenics
  - SPIRAL II e-beam option linac $7.2M
  - Advanced Energy Systems (Alan Todd) turnkey FEL linac design not priced

Energy distribution of photoneutrons in the targets.
(a) The target with 0.1 cm thickness and (b) the target with 6 cm thickness



(a)



(b)