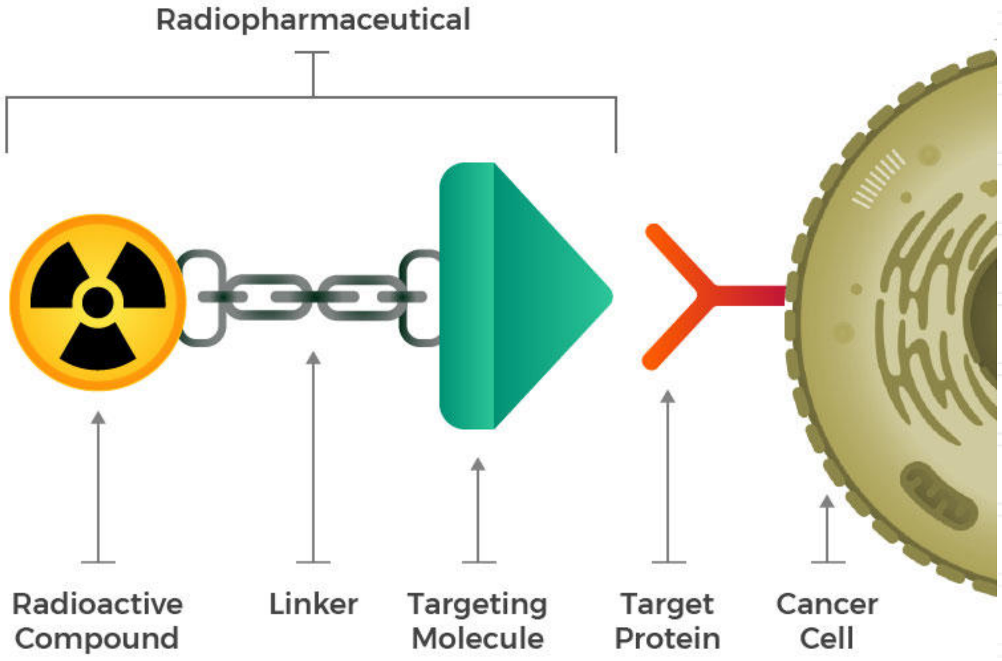
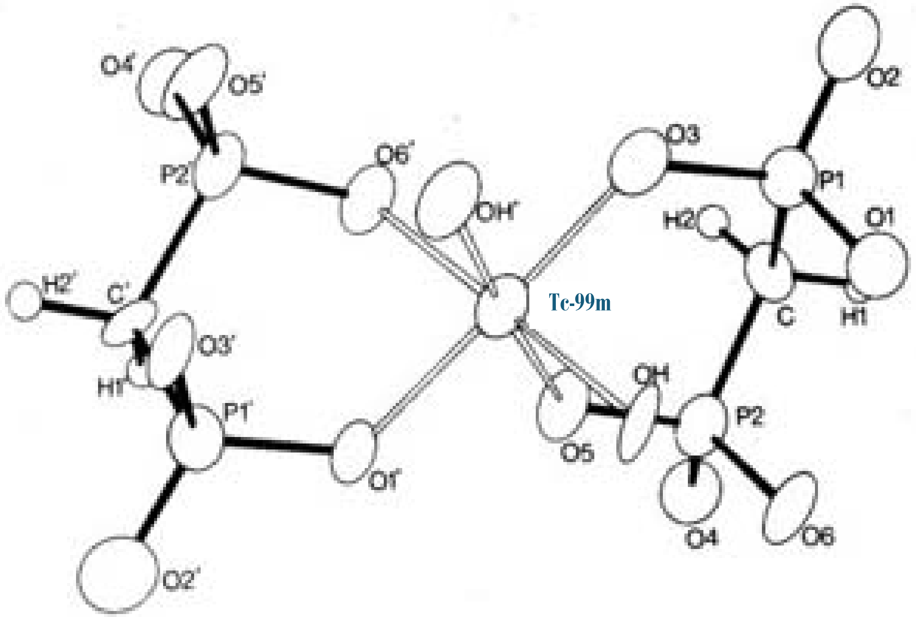
SHINE™

The future of medical isotope production

Safer, Cleaner, More reliable, More flexible, More cost effective

Medical Isotopes & Nuclear Medicine





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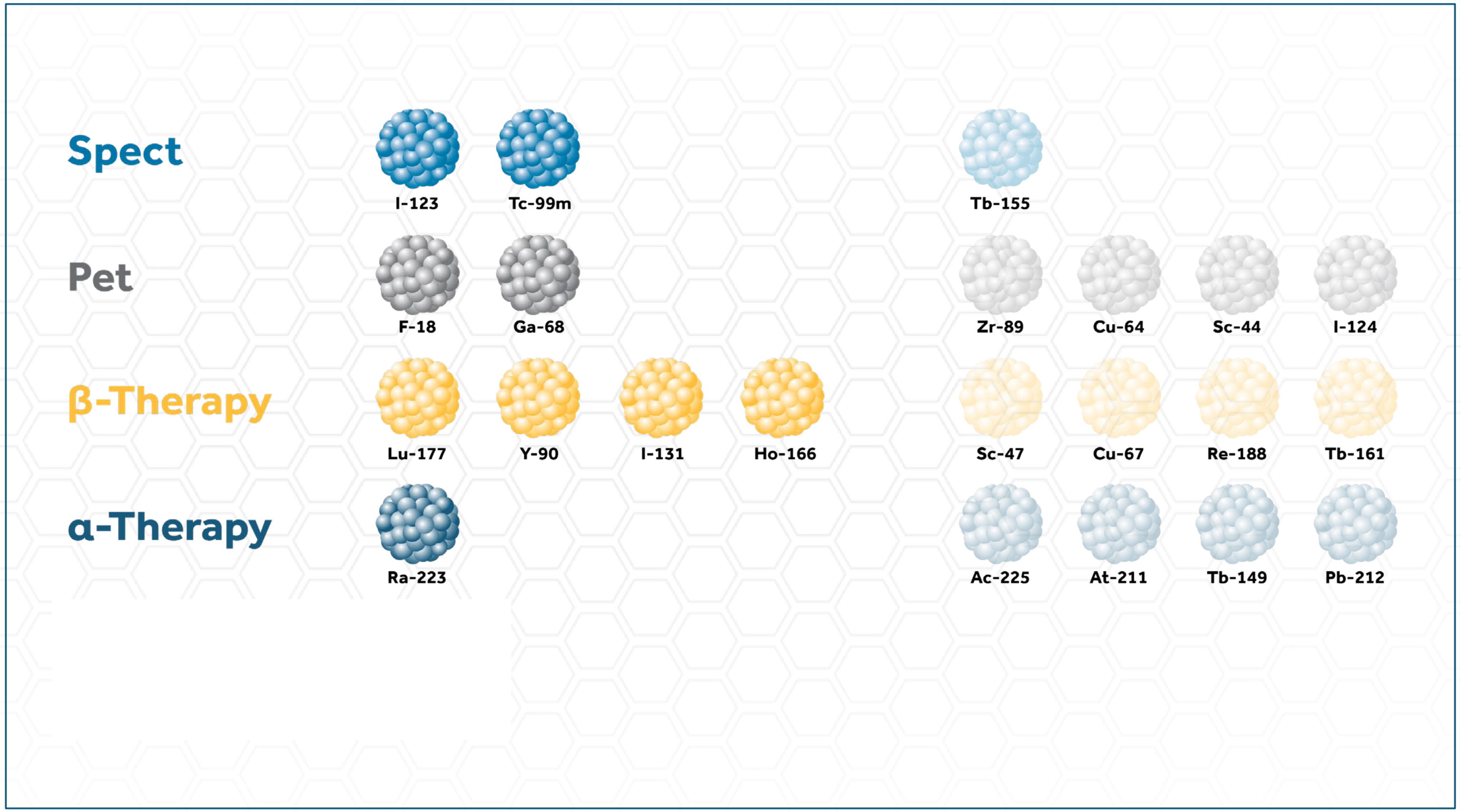
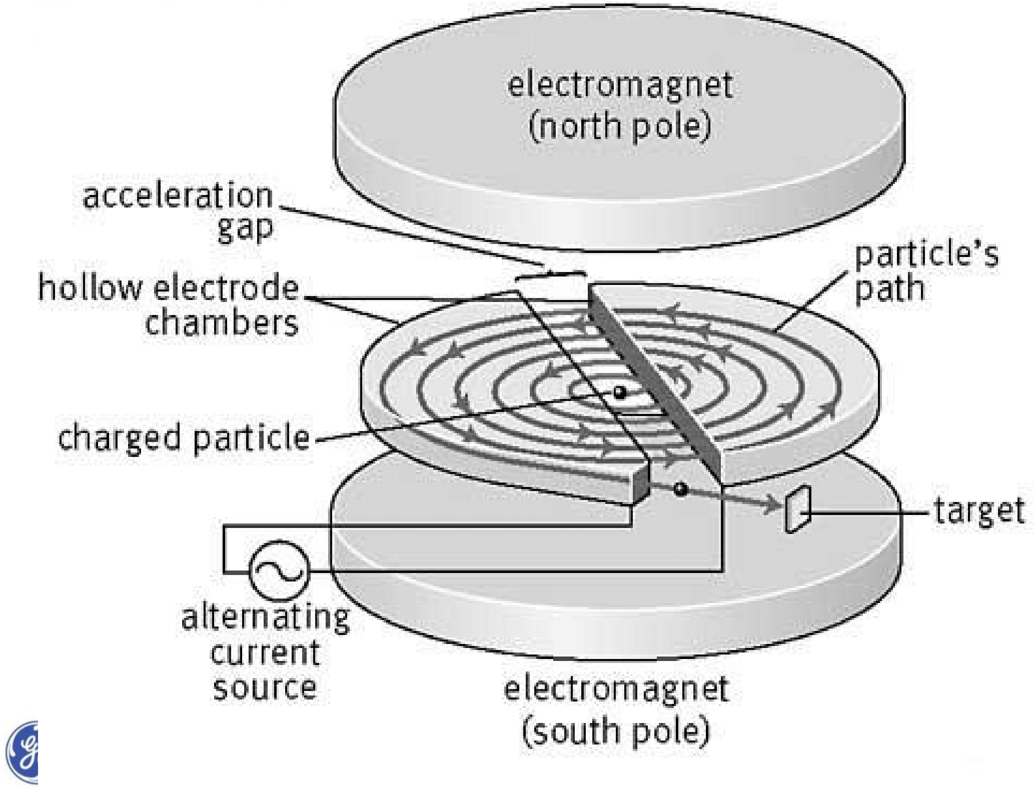
EU Medical Isotopes of Interest[1]



[1] European Commission August 2021
Co-ordinated Approach to the Development and Supply of Radionuclides in the EU (N°ENER/D3/2019-231)

EU Medical Isotopes: Cyclotron Production



ductie van radionucliden, dia 18
GE / Healthcare / Cygne Centre
22 april 2012

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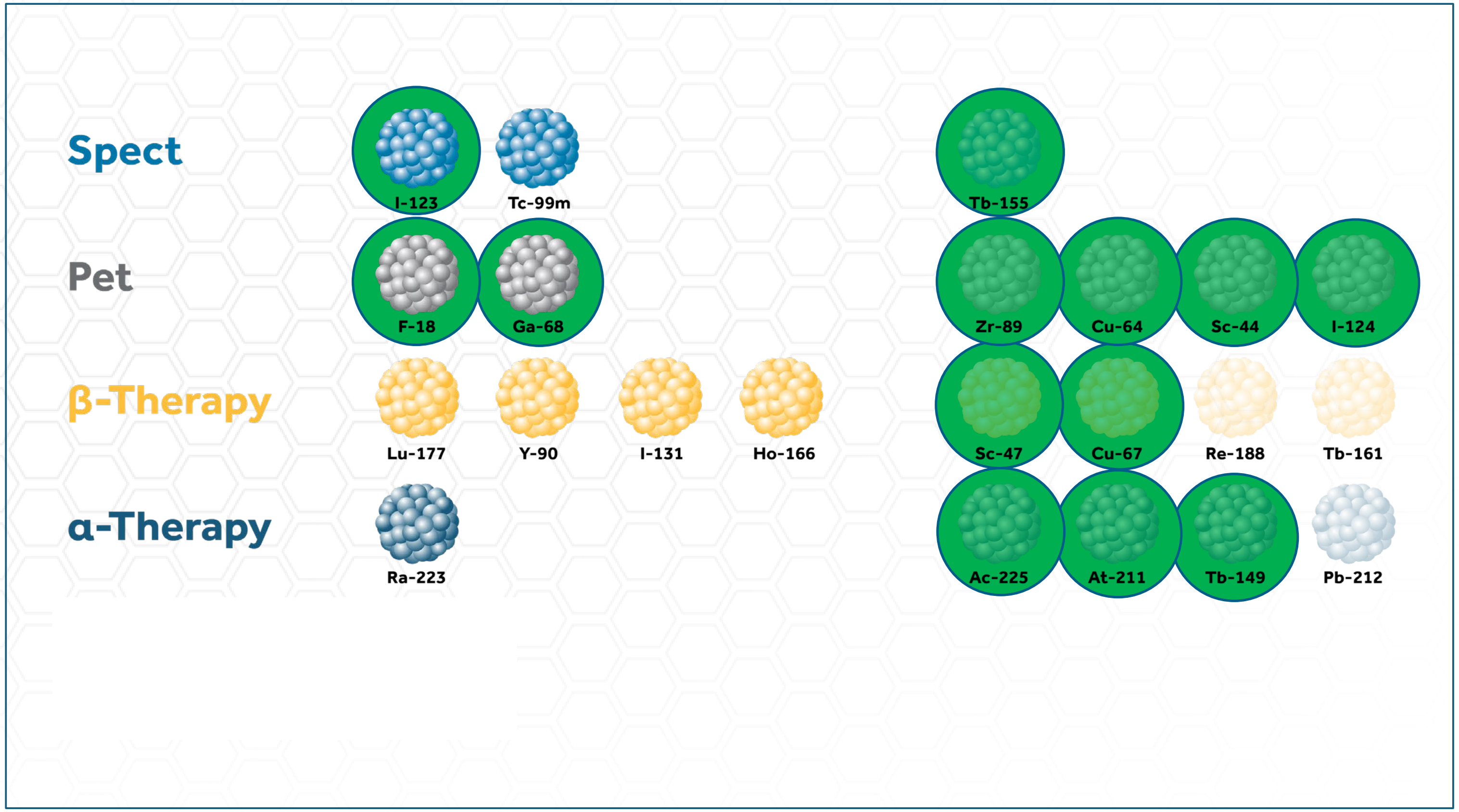
EU Medical Isotopes: Cyclotron Production

RN	Production	TRL
I-123	$^{124}Xe(p,2n)^{123}Cs \rightarrow {}^{123}Xe \rightarrow {}^{123}I$	9
Tb-155	$^{155}Gd(p,n)^{155}Tb$	9
F-18	$^{18}O(p,n)^{18}F$	9
Ga-68	$^{69}Ga(p,2n)^{68}Ge \rightarrow {}^{68}Ga$	9
Zr-89	$^{89}Y(p,n)^{89}Zr$	9
Cu-64	$^{64}Ni(p,n)^{64}Cu$	9
Sc-44	$^{44}Ca(p,n)^{44}Sc$	9
I-124	$^{124}Te(p,n)^{124}I$	9
Sc-47	$^{48}Ca(p,2n)^{47}Sc$	3
Cu-67	$^{67}Zn(p,n)^{67}Cu$	9
Ac-225	$^{226}Ra(p,2n)^{225}Ac$	4
At-211	$^{209}Bi(\alpha,2n)^{211}At$	6
Tb-149	$^{152}Gd(p,4n)^{149}Tb$	4



EU Medical Isotopes: Radiochemistry on Stockpiles

RN	Production	TRL
Pb-212	^{232}U stockpile: $^{228}Th \rightarrow ^{224}Ra \rightarrow ^{212}Pb$	9

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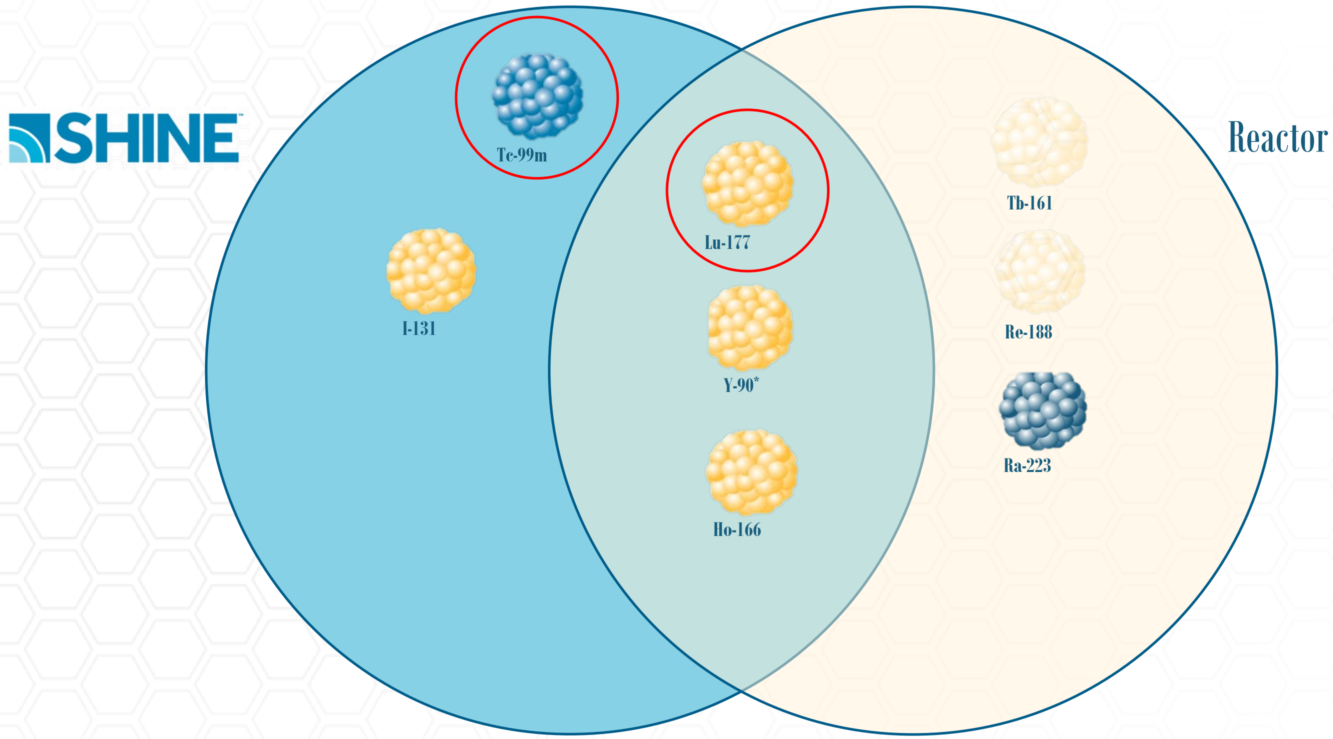
EU Medical Isotopes: Produced with neutrons

Preferred neutron source (SHINE claim)

RN	Current EU demand (# of procedures)	Future EU demand (# of procedures)
Tc-99m	± 10 M	± 11 M
Lu-177	± 5 – 10 K	Up to 100 K per RP
Y-90	± 10 – 50 K	± 10 – 50 K
I-131	± 10 – 50 K	± 10 – 50 K
Ho-166	R & C only	uncertain
Re-188	R & C only	uncertain
Tb-161	R & C only	uncertain
Ra-223	± 20 – 40 K	± 20 – 40 K

Quantification of future RN demand in 2040[1]



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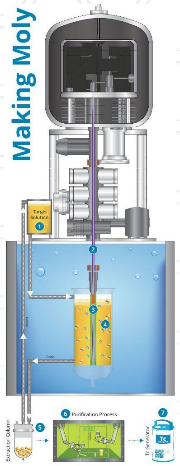
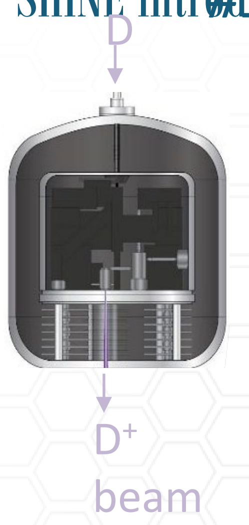
The innovative SHINE technology

Subcritical Hybrid Intense Neutron Emitter

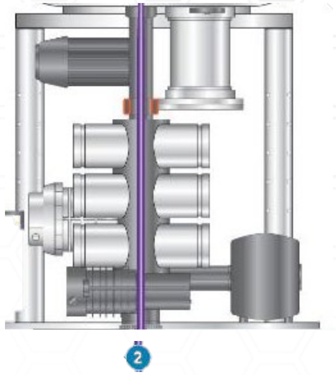


SHINE introduces two groundbreaking innovations

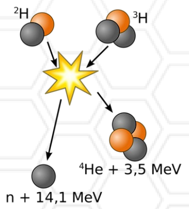
#1: The accelerator driven neutron source!

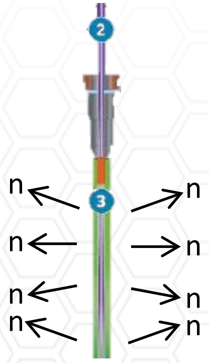


Ion source / accelerator
EMwave energy strips an electron from Deuterium (^2H ; symbol D); creating positively charged Deuterium ions. D^+ is accelerated to 10 million mph (16 million km per hour) .



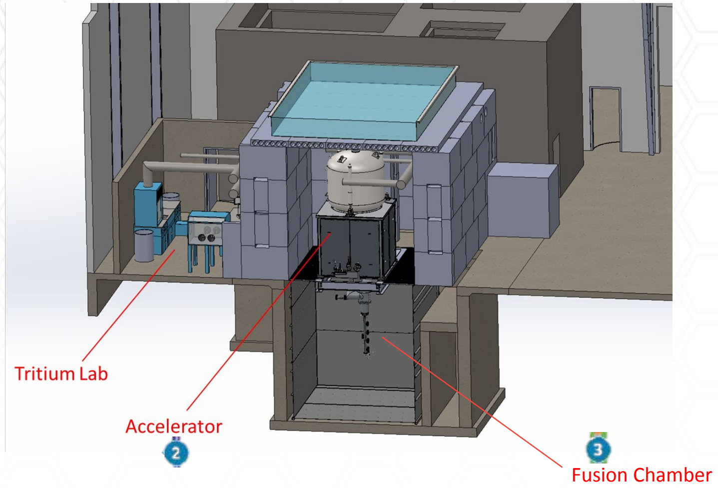
Differential pumping
The beam is focused, and a pressure difference is maintained to assure an on-going flow of D in the downward direction (2)





Fusion Chamber
Accelerated D+ (2) collides with Tritium gas (^3H) in the Fusion Chamber (3). This fusion reaction creates fusion neutrons.

The accelerator based neutron source



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#2: The closed uranium loop!

Target Solution Tank
Low Enriched Uranium (LEU) is dissolved by SHINE to form a uranium sulfate mixture. The mixture (1) is pumped into the target solution tank (4). This solution is irradiated with the (moderated fusion and fission) neutrons for app. 1 week. Uranium splits into multiple fission elements. Mo-99, I-131, Sr-90 and many other useful fission isotopes are created.

Mo-99 extraction column
The irradiated solution is drained and pumped through the extraction column. This column maintains Mo-99 and allows uranium to pass through. The uranium is pumped back and re-used.

Purification and Distribution of Mo-99
A separate solution is them pumped through the extraction column (5) to take the Mo-99 to purification (6). A proven chemistry process is used to purify Mo-99 to pharma standards. As Mo-99 decays 1% per hour it is quickly transported to our generator customers (7).

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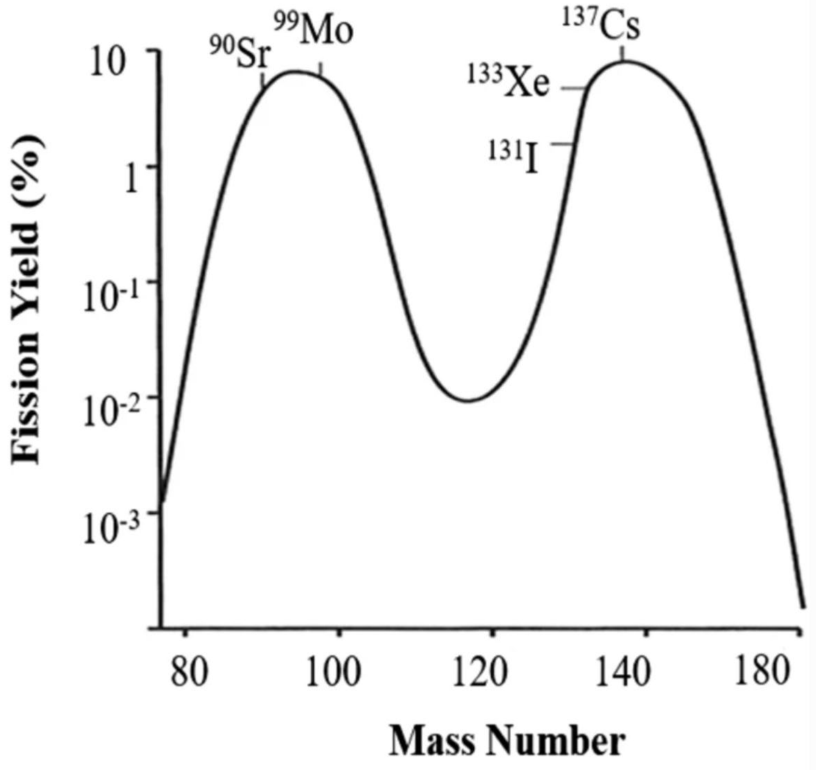

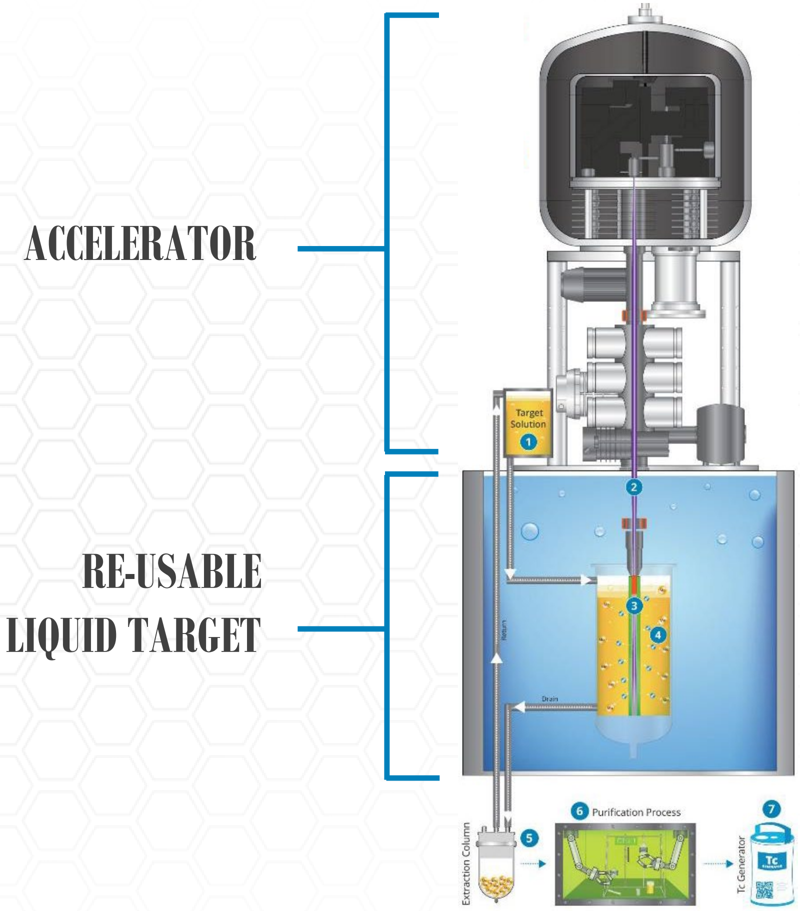

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SHINE is the preferred neutron source for all U-235 fission medical isotopes

- # ^{235}U fissions factor 100 lower (accelerator eliminates uranium fuel use)
  - Much Safer: subcritical system, no core melt down scenarios. Source term factor 100 lower
  - Much cleaner: factor 100 reduction of high active waste, no external cooling systems, factor 100 less activation of installation. Significant reduction of LEU use.
- Much more reliable and flexible
  - 365 days a year, modular system (8,3), Ful integration in one plant, one plant per continent.
- Much More cost effective
  - CAPEX factor 10+ lower ; OPEX factor 5+ lower (Lower Labour Costs, Lower Materials Usage, Lower Waste, etc)

SHINE ^{177}Lu production

$^{176}Yb(n,\gamma)^{177}Yb \rightarrow {}^{177}Lu$

$^{174}Yb(n,\gamma)^{175}Yb \rightarrow {}^{175}Lu$

Isotope	**Abundance**	***σ(b) (n,γ)***	***Activation RN***	***Daughter***
^{168}Yb	0.1%	2300	^{169}Yb	^{169}Tm
^{170}Yb	3.1%	10	^{171}Yb	stable
^{171}Yb	14.4%	53	^{172}Yb	stable
^{172}Yb	21.9%	1	^{173}Yb	stable
^{173}Yb	16.2%	17	^{174}Yb	stable
^{174}Yb	31.6%	69	^{175}Yb	^{175}Lu
^{176}Yb	12.6%	2.4	^{177}Yb	^{177}Lu

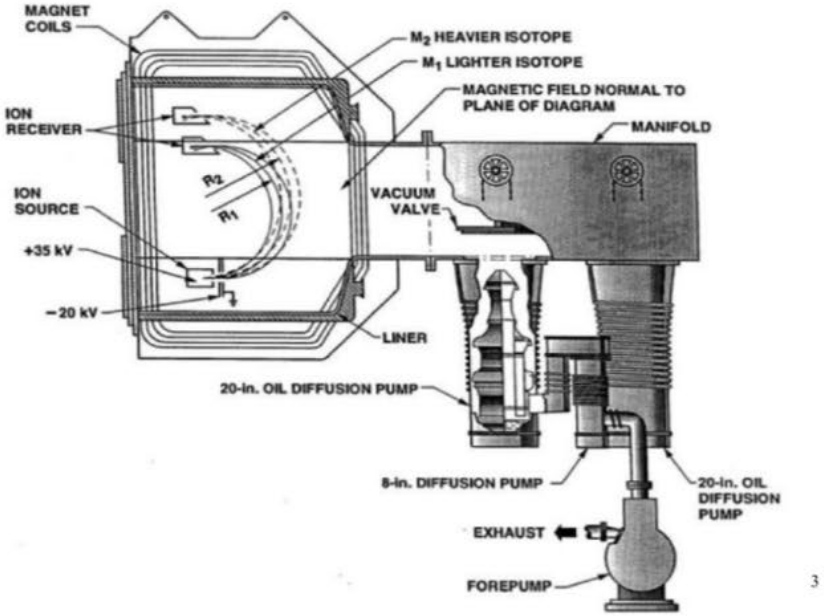
Calutrons at the Y-12 National Security Complex (Oak Ridge)

Manhattan Project – Electromagnetic project costs through 31 December 1946 [86]

Site	Cost (1946 USD)	Cost (2019 USD)	% of total
Construction	$304 million	$3.98 billion	53%
Operations	$240 million	$3.15 billion	41.9%
Research	$19.6 million	$258 million	3.4%
Design	$6.63 million	$86.9 million	1.2%
Silver Program	$2.48 million	$32.5 million	0.4%
Total	**$573 million**	**$7.51 billion**	

The Y-12 electromagnetic plant

Calutron

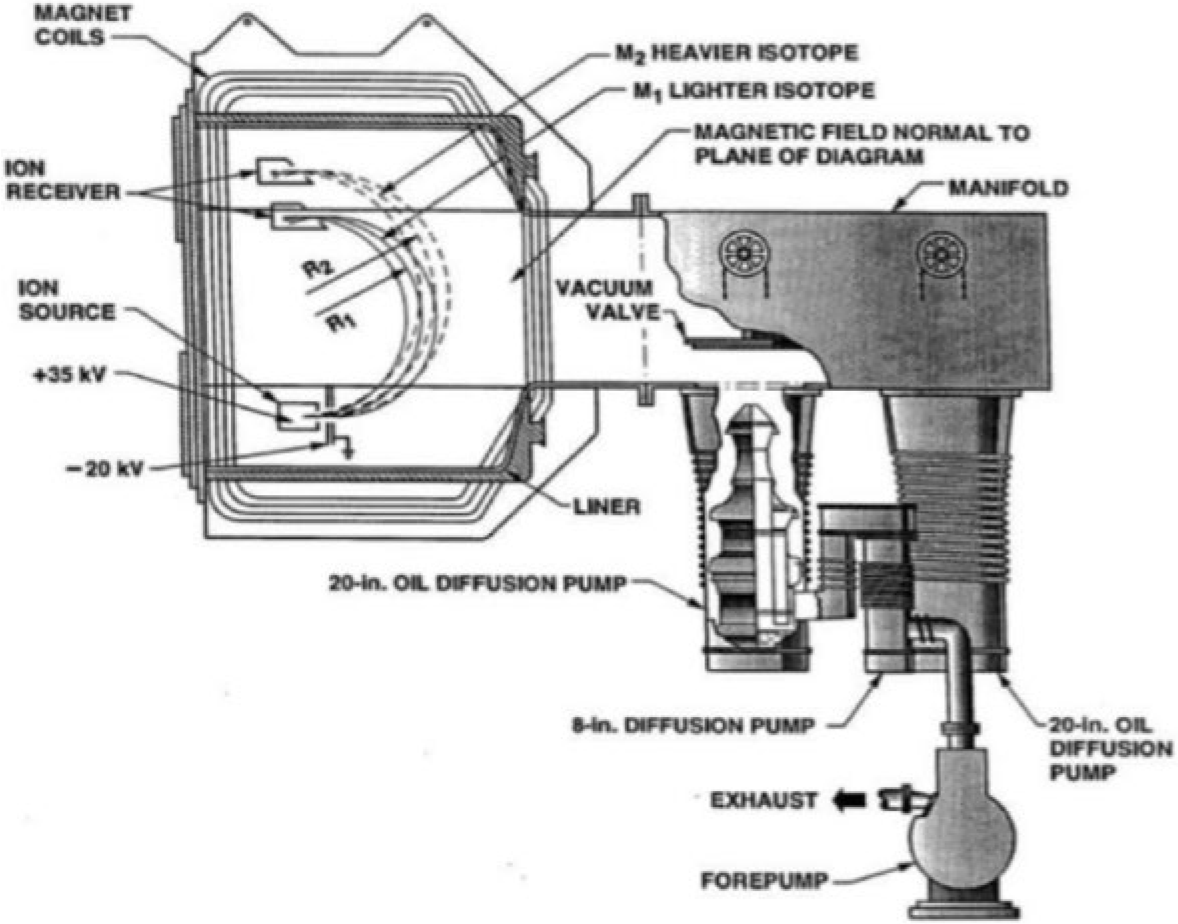


RAY SMITH

It's hard to imagine . . .. . . an entire city existing in secret.. . . 60,000 acres set aside for one, top-secret purpose. . . . a discovery so huge it could end a World War.

*It's hard to imagine – **but it's true**.*

Calutron


MAGNET COILS
M_2 HEAVIER ISOTOPE
M_1 LIGHTER ISOTOPE
MAGNETIC FIELD NORMAL TO PLANE OF DIAGRAM
MANIFOLD
ION RECEIVER
ION SOURCE
R2
R1
VACUUM VALVE
+35 kV
−20 kV
LINER
20-in. OIL DIFFUSION PUMP
8-in. DIFFUSION PUMP
20-in. OIL DIFFUSION PUMP
EXHAUST
FOREPUMP

3

SHINE ^{177}Lu Supply chain

1. Yb-176 Enrichment Capability
2. Flexibility for Irradiation
3. Exclusive Separation Technology
4. Logistics

3

CORE ADVANTAGES

High Performance Separation Technology

for uniquely scalable production of Lu-177

ADVANTAGES

Proprietary separation technology licensed from IOCB and further enhanced internally

Can accommodate low neutron systems

Ability to scale faster to meet surges in demand

No longer dependent on aging research reactors

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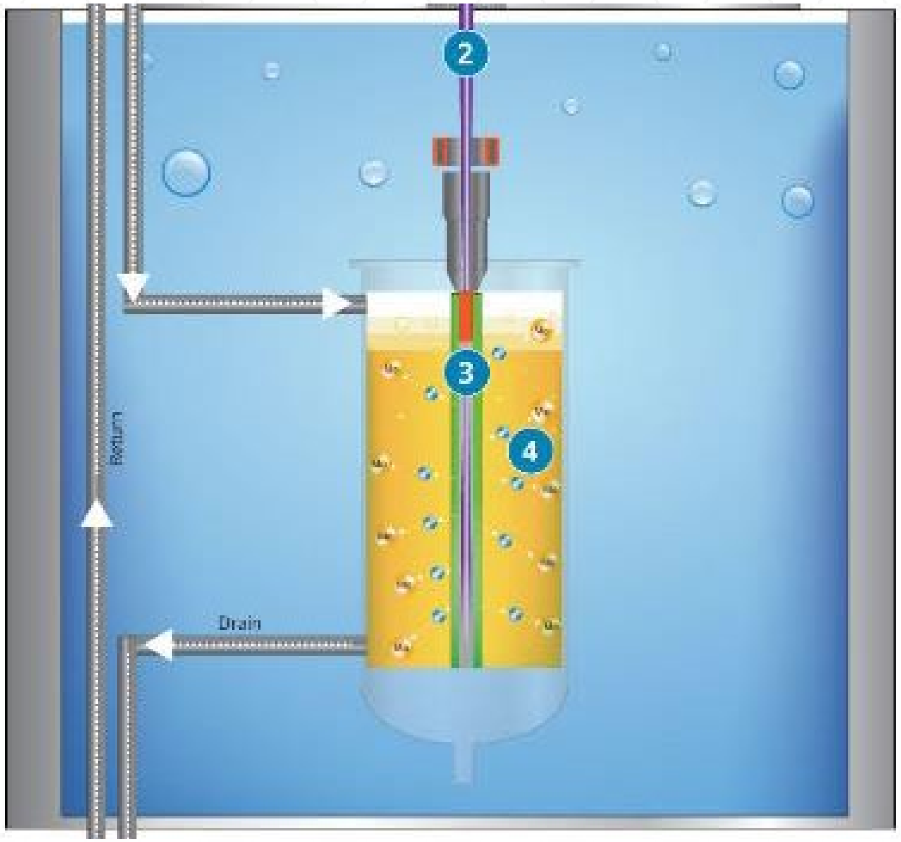
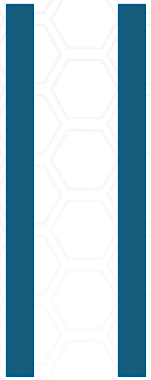
$^{176}Yb(n,\gamma)^{177}Yb \rightarrow ^{177}Lu$



2 vertical irradiation ports



SHINE™

VEENDAM!

DE LOCATIE

VEENDAM
SORGHVLIET
Van Stolbergweg
Boven Oosterdiep
Borgercompagnie
Nijverheidsstraat
Woortmanslaan
Dalweg 12
DALLEN II
N33
N366
N33
Poststraat
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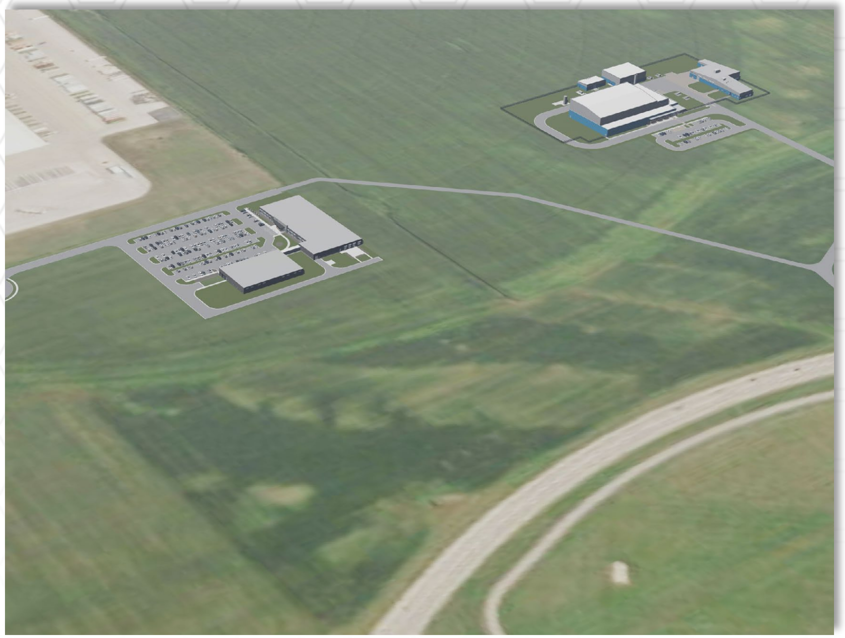
WILDERVANK

DE LOCATIE



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SHINE® ON