A High-Intensity, Low-Energy Heavy Ion Source for a Neutron Target Proof-of-Principle Experiment at LANSCE

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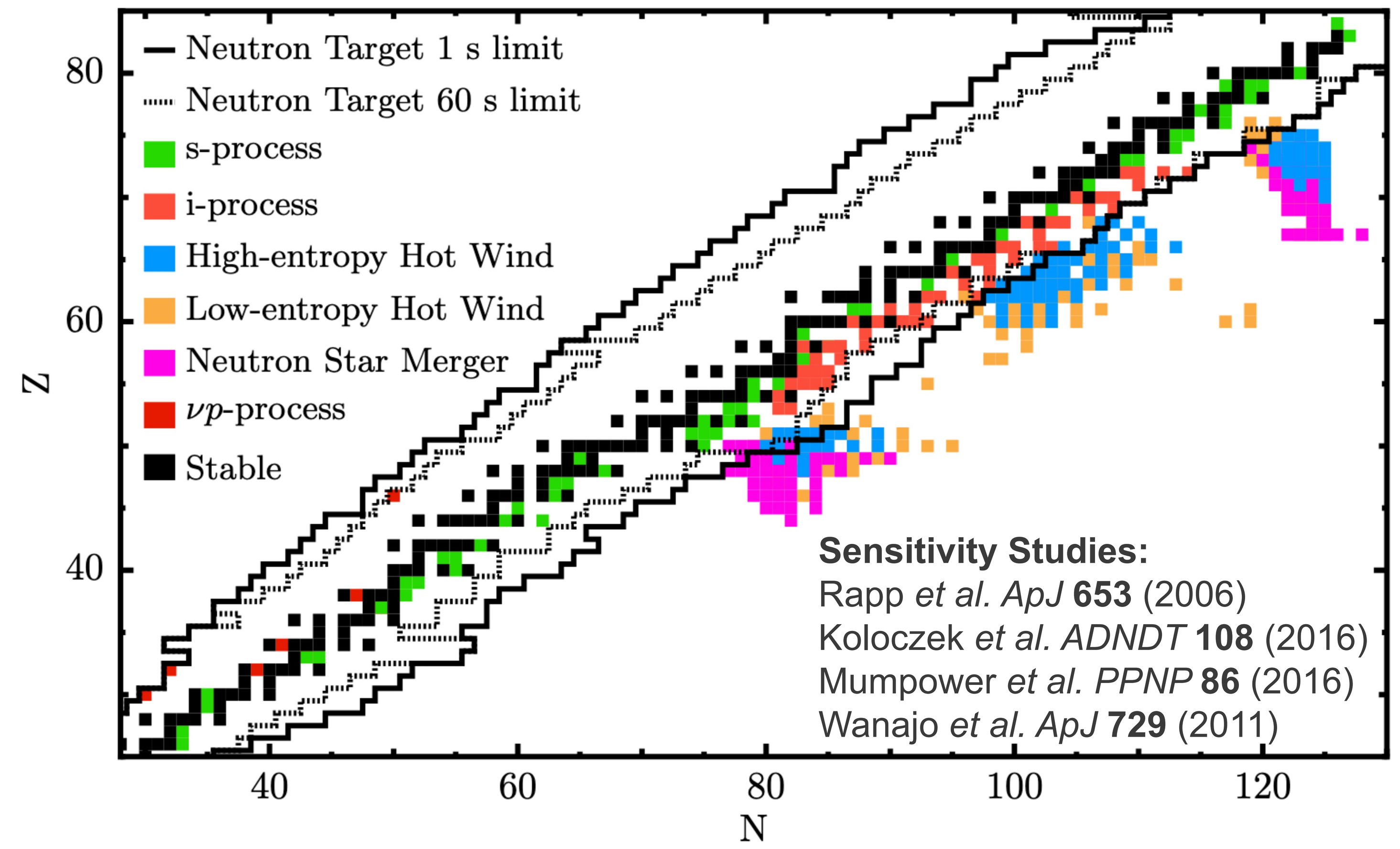
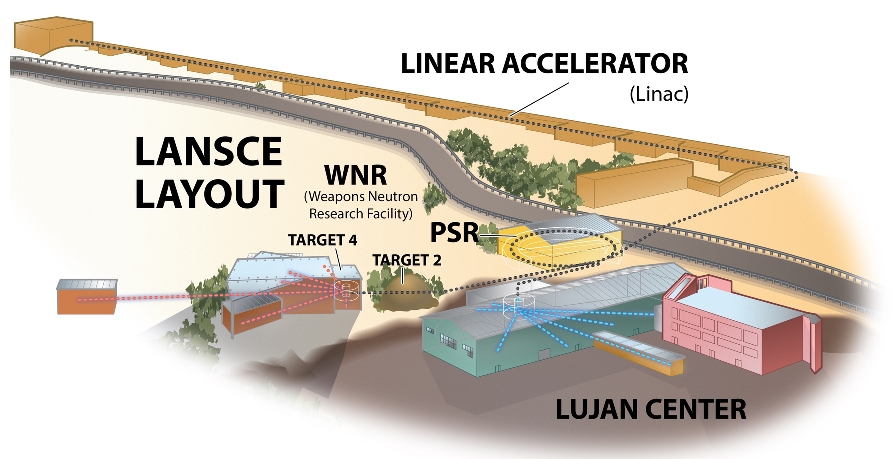
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT WHERE INNOVATION BEGINS

Why measure neutron reactions on unstable isotopes?



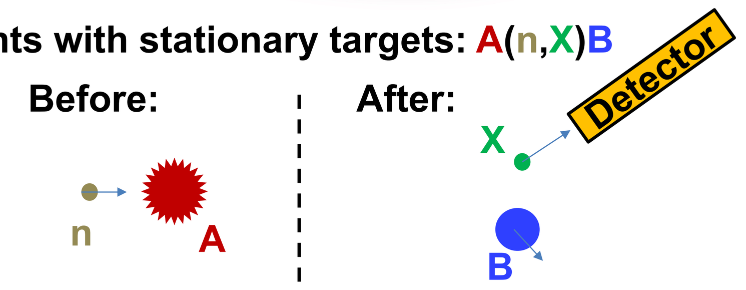
1. Heavy-element nucleosynthesis via neutron capture:
   - s-process (10^8-10^{11} n/cm^3, $t_{1/2}$ ~ yrs-days)
   - i-process (10^{12}-10^{15} n/cm^3, $t_{1/2}$ ~ hrs-sec)
   - r-process (10^{20}-10^{22} n/cm^3, $t_{1/2}$ ~ subsec)
2. Data for the weapons physics and radiochemical diagnostics communities on daughter nuclei from fission neutron reactions.

Current measurements on radionuclides at LANSCE



The Los Alamos Neutron Science Center (LANSCE) linac provides 800-MeV pulsed proton beams to produce spallation neutrons.

Experiments with stationary targets: A(n,X)B



Where X can be prompt gammas, neutrons, charged particles, or fission fragments, and B is the recoiling reactant nucleus.

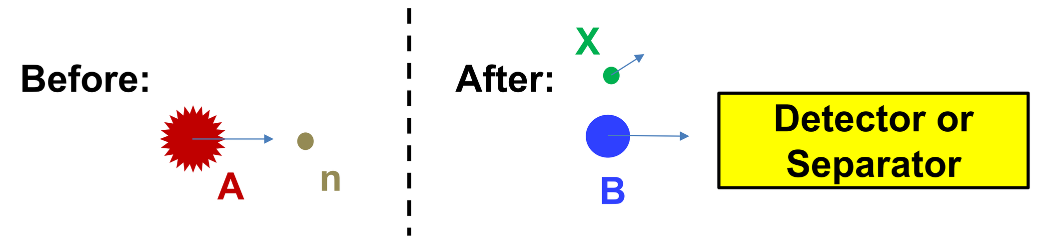
Experimental challenges with stationary targets:

- Detection system can be overwhelmed by the sample decay radiation field.
- Samples can be very small (and difficult to field).
- The sample may decay away quickly.

Sample half-life limit using forward kinematics: $t_{1/2}$ ~ days.

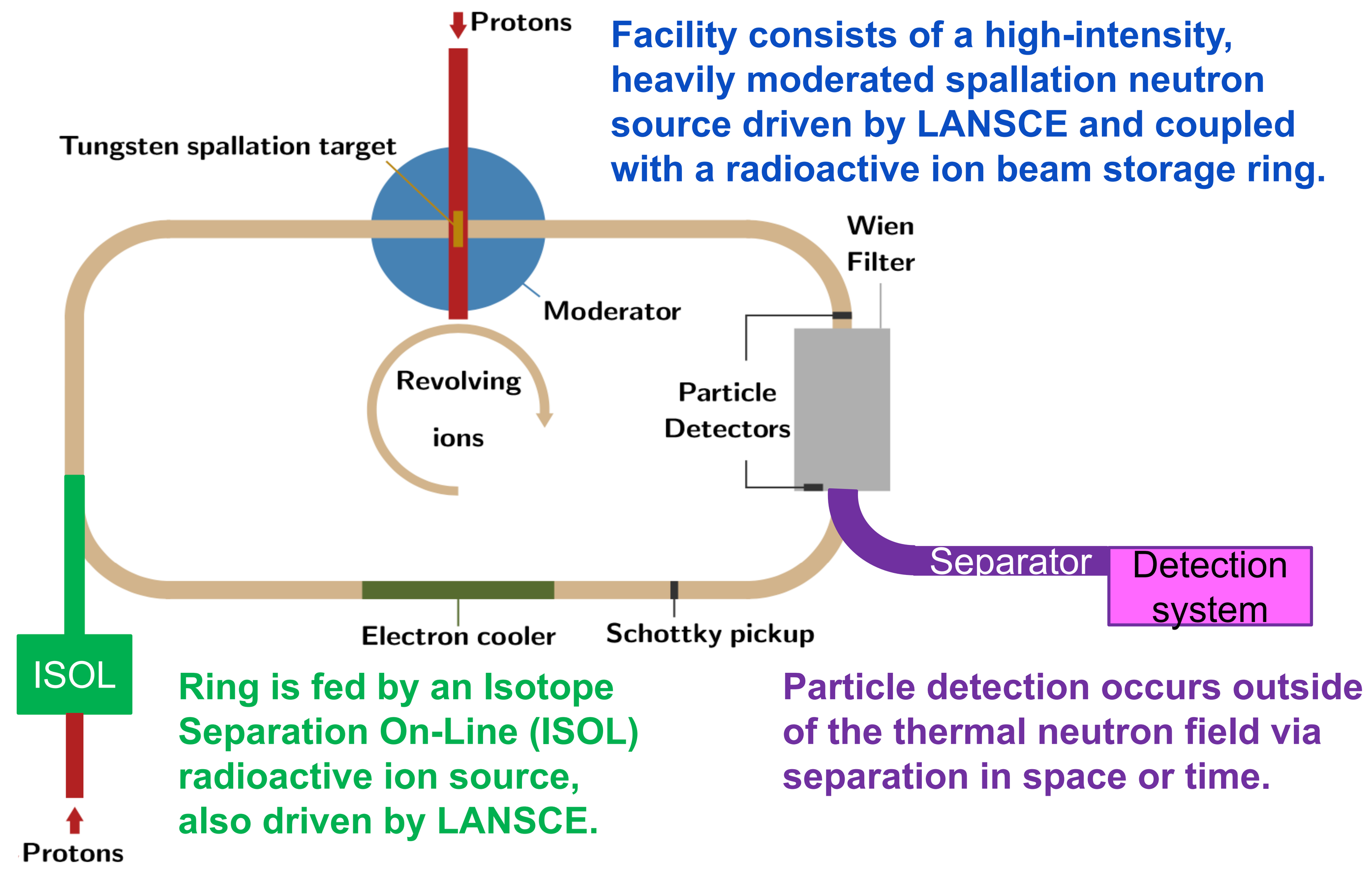
Neutron reactions in inverse kinematics

Inverting the roles of beam and target: n(A,X)B



Sample half-life limit using inverse kinematics: $t_{1/2}$ ~ minutes!

Neutron Target Facility concept [1,2]



Facility consists of a high-intensity, heavily moderated spallation neutron source driven by LANSCE and coupled with a radioactive ion beam storage ring.

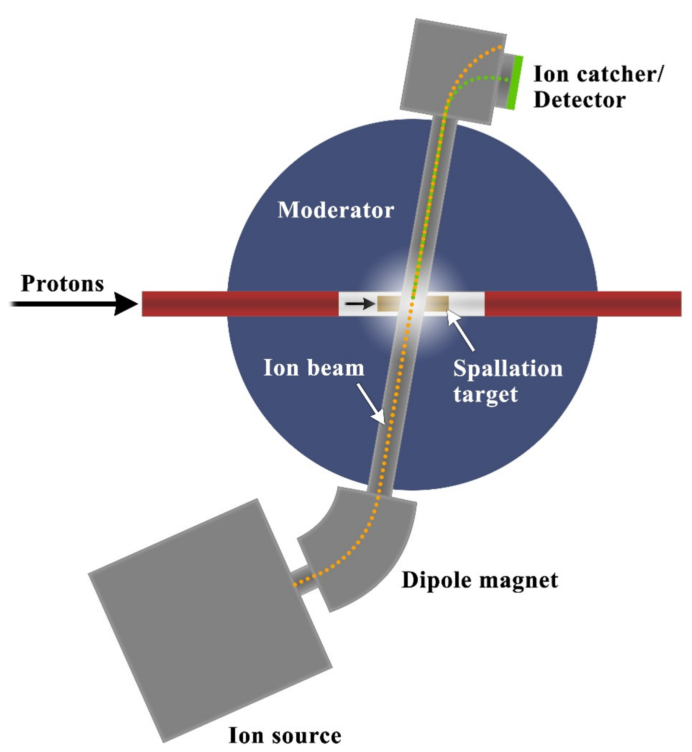
Ring is fed by an Isotope Separation On-Line (ISOL) radioactive ion source, also driven by LANSCE.

Particle detection occurs outside of the thermal neutron field via separation in space or time.

The Neutron Target Demonstrator (NTD) at LANSCE

A single-pass experiment at Target 2:

1. Construct a simple spallation target and moderator, and characterize ion pipe neutron field density with Au samples during operation with LANSCE proton beam.
2. Transport mA-level beams of stable heavy ions through the neutron target assembly to induce neutron captures in inverse kinematics using strong, well-known resonances at low energies and collect ions for offline analysis.
3. Measure the number of transmuted beam ions collected via decay gamma-ray counting setup to obtain the effective neutron density within the moderator.



Demonstrator science objectives:

- Tech. mat. ➡ Validate the neutron target concept and reveal future challenges.
- n density in moderator ➡ Validate design and simulation capability.

The NTD low-energy, high-intensity heavy ion source by D-Pace, Inc.

Ion species: $^{84}Kr^+$

Reaction	$\sigma(E_r)$ [b]	E^{LAB}_r [keV]	$T_{1/2}$
$^{69}Ga(n,\gamma)^{70}Ga$	439.333	23.032131	21.1 4 m
$^{69}Ga(n,\gamma)^{70}Ga$	966.705	7.645131	21.1 4 m
$^{71}Ga(n,\gamma)^{72}Ga$	224.908	50.0408	14.10 h
$^{71}Ga(n,\gamma)^{72}Ga$	1925.31	6.7946432	14.10 h
$^{79}Br(n,\gamma)^{80}Br$	422.341	14.9705	17.68 m
$^{79}Br(n,\gamma)^{80}Br$	944.678	4.242142	17.68 m
$^{79}Br(n,\gamma)^{80}Br$	3522.58	2.8281763	17.68 m
$^{81}Br(n,\gamma)^{82}Br$	308.482	46.8747	35.282 h
$^{81}Br(n,\gamma)^{82}Br$	1280.23	10.9836	35.282 h
$^{81}Br(n,\gamma)^{82}Br$	2238.58	8.197038	35.282 h
$^{78}Kr(n,\gamma)^{79}Kr$	581.563	35.1702	35.04 h
$^{78}Kr(n,\gamma)^{79}Kr$	1613.8	8.455122	35.04 h
$^{84}Kr(n,\gamma)^{85m}Kr$	362.594	43.596	4.480 h
$^{108}Cd(n,\gamma)^{109}Cd$	881.106	33.658848	461.4 d
$^{108}Cd(n,\gamma)^{109}Cd$	1364.05	25.2288	461.4 d
$^{114}Cd(n,\gamma)^{115}Cd$	1365.53	13.69482	53.46 h
$^{127}I(n,\gamma)^{128}I$	1017.8	9.9733862	24.99 m
$^{127}I(n,\gamma)^{128}I$	1683.76	5.7651142	24.99 m
$^{127}I(n,\gamma)^{128}I$	3389.91	4.7929292	24.99 m
$^{127}I(n,\gamma)^{128}I$	2940.08	3.9680388	24.99 m
$^{127}I(n,\gamma)^{128}I$	386.326	2.5944322	24.99 m
$^{124}Xe(n,\gamma)^{125}Xe$	925.311	31.192572	16.9 h
$^{124}Xe(n,\gamma)^{125}Xe$	42255.1	1.2548304	16.9 h
$^{124}Xe(n,\gamma)^{125}Xe$	39581.9	0.6311352	16.9 h
$^{126}Xe(n,\gamma)^{127}Xe$	437.868	31.437	36.346 d
$^{126}Xe(n,\gamma)^{127}Xe$	2125.46	1.24475526	36.346 d
$^{132}Xe(n,\gamma)^{133}Xe$	102.45	84.9156	5.2475 d
$^{132}Xe(n,\gamma)^{133}Xe$	743.81	15.17076	5.2475 d

Ion species experimental requirements:

- Strong (n,g) resonances: $\sigma(Er)$ > 100 b
- Daughter half-life: Hours < $T_{1/2}$ < days

Benefits of $^{84}Kr(n,\gamma)^{85m}Kr$:

- Abundant isotope and inert gas
- ^{85m}Kr has a simple decay structure
- E^{CM}_r = 519 eV resonance energy should permit efficient transport

NTD Heavy Ion Source Design: 2.45 GHz ECR ion source

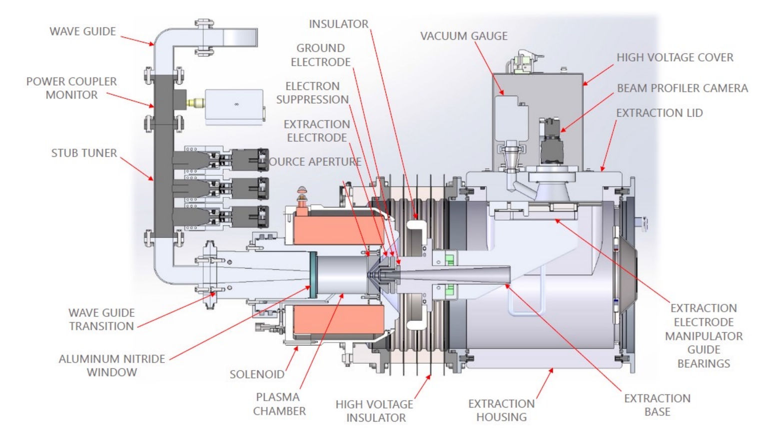
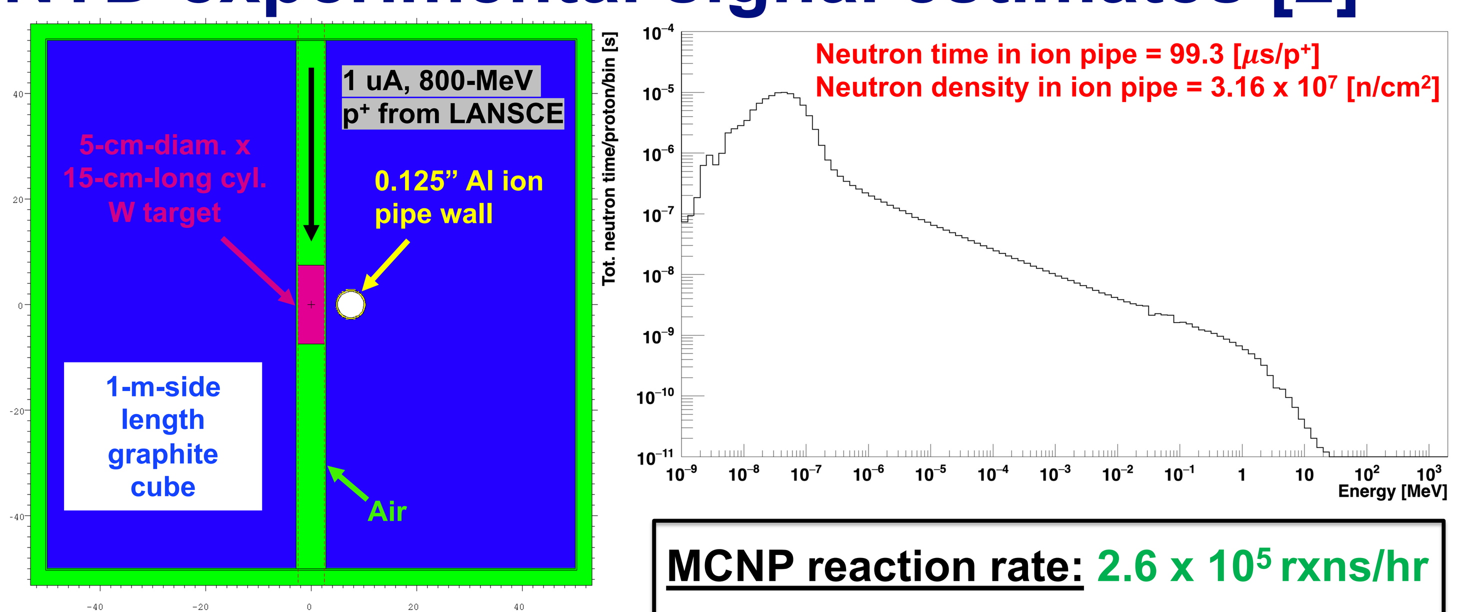


Fig. credit: D-Pace, Inc.

Performance requirements:

- Beam energy range: 0-50 keV
- Peak output beam current: 10 mA
- Beam pulse structure: 1-100 Hz pulse rate, 100-10% duty cycle
- Mass resolution: M/ΔM = 100 where ΔM = 1 [m/q unit] at 50% mass peak max.
- Absolute beam energy calibration uncertainty and resolution: < 10 eV
- Why an ECR source?: Low maintenance, robust design with flexible tunability
- Must operate in a gamma and neutron radiation environment, at 7000 ft above sea level.

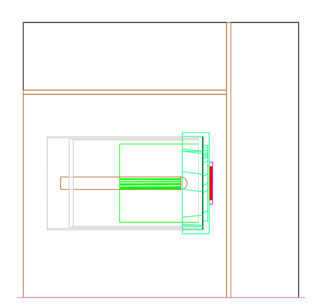
NTD experimental signal estimates [2]



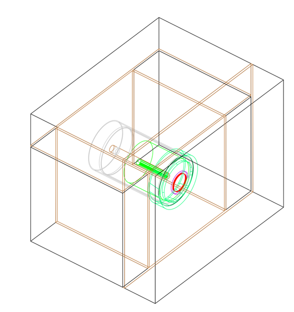
MCNP reaction rate: 2.6 x 10^5 rxns/hr

➢ using 1-mA-average $^{84}Kr^+$ beam input

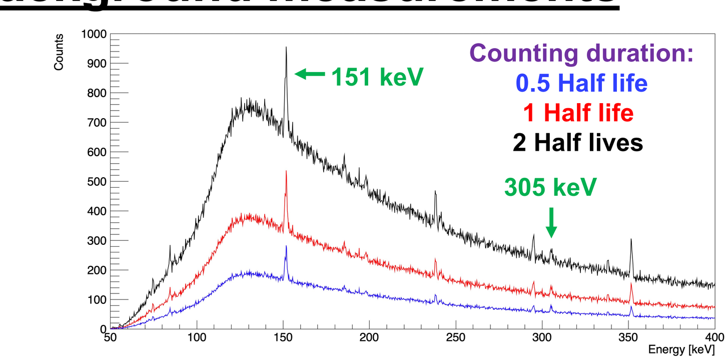
Signal estimates via GEANT4 decay gamma detector simulations convolved with background measurements



Side view



3D view



Decay gamma counting 5 targets after a 2 half-life delay

References:
[1] R. Reifarth et al., Phys. Rev. Acc. Beams 20, 044701 (2017)
[2] S. Mosby et al., LA-UR-21-30261 (2021)

U.S. DOE Funding Sources:
Contract No. 89233218CNA000001
Contract No. DE-NA0003624