Radiochemistry at the National Ignition Facility:

The first doped capsule cross-section

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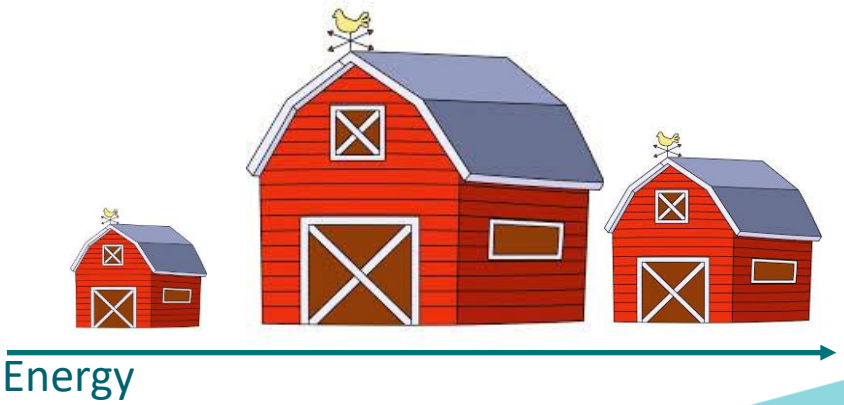


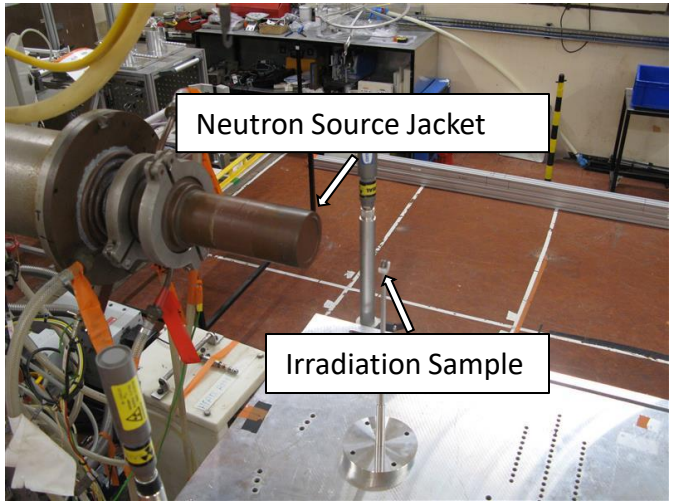
The first doped capsule cross-section

$^{89}Y(n,2n)^{88}Y$

A well-known case to prove the method.

Methods

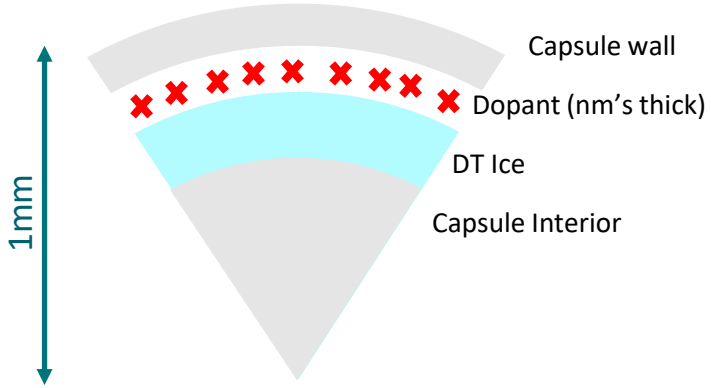
- **Accelerator Approach**
  - D beam is accelerated.
  - Impacts upon T target.
  - T(D, n)^{4}He reaction occurs releasing 14.1 MeV neutrons.
  - Irradiation samples are ≈ 0.5-2g of material and ϕ: 12mm, ||: 1mm



ASP: AWE capability for neutron irradiation

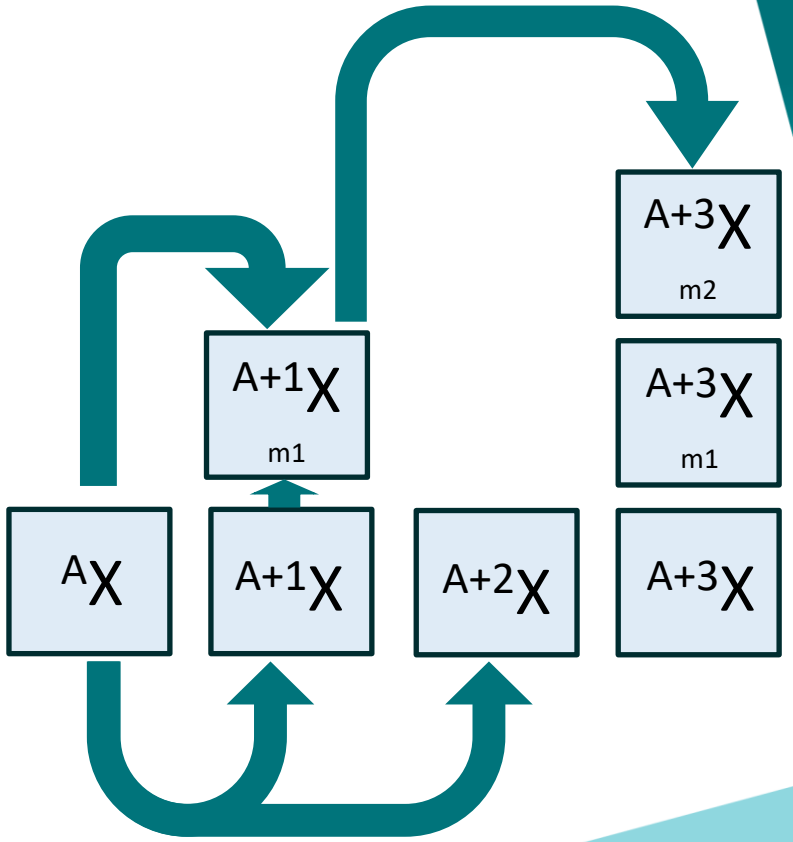
Methods

- **Laser Driven Approach**
  - Doped target capsule.
  - DT ice fuel inside the capsule.
  - Capsule isotropically compressed.
  - Dopant areal density ≈2.5E^{16} atoms/cm^{2}.
  - 0.2 ns pulse of up to1E^{17} 14.1 MeV n^{0}.



Methods

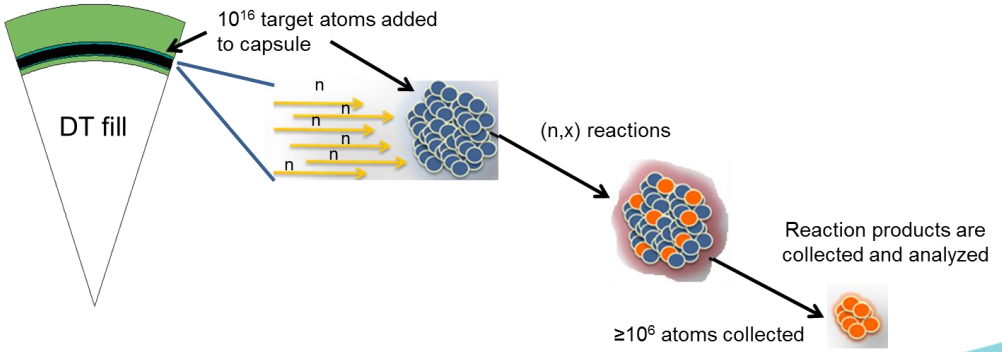
- **Laser Driven Advantages**
  - Smaller sample quantity.
  - Potential for 2nd order reaction studies.
  - Potential for isomeric studies.
  - Opportunities to use an ignition platform.



Reaction Product Detection

- **SRC Collectors**
  - Vanadium discs ϕ=2”
  - 12 can be deployed simultaneously.
  - 0.768% solid angle coverage.

- **HPGe Detectors**
  - P-Type Coaxial detectors
  - Varying sample heights



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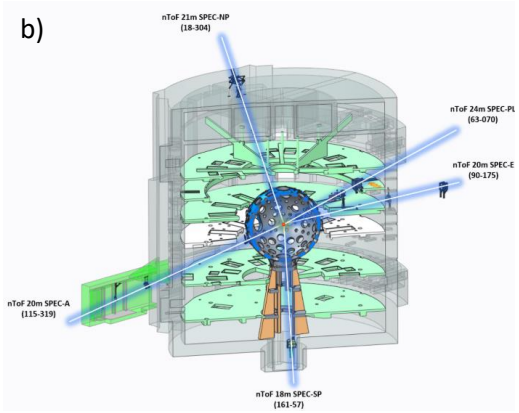
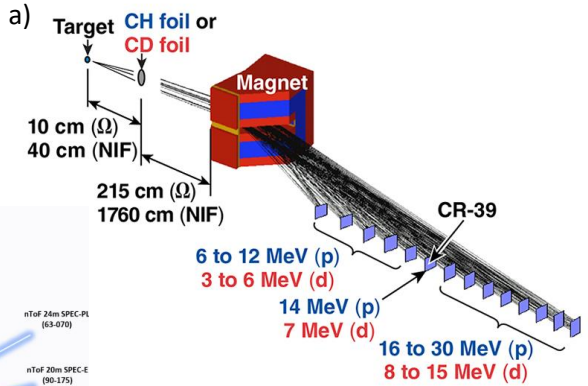
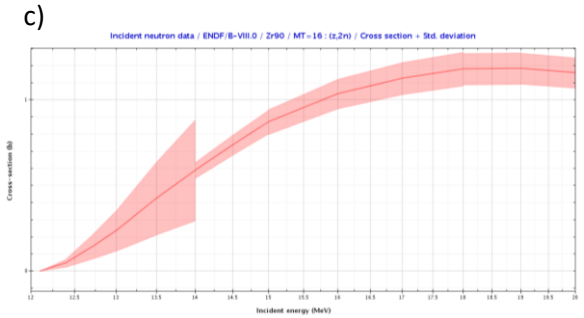
Neutron Detection

- **Magnetic Recoil Spectrometer**
  - Absolute yield.
- **Scintillator nToF**
  - Spectral shape.
  - 5 lines of sight.
  - 18-24m long.
- **WELL-NAD**
  - Zr activation foils using DT peak threshold reaction $^{90}Zr(n,2n)^{89}Zr$.



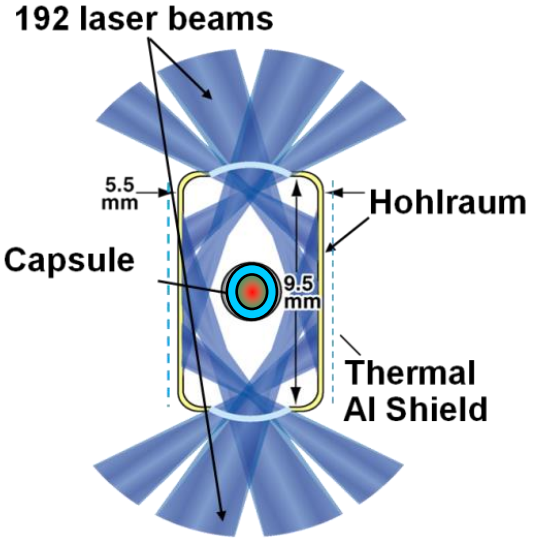




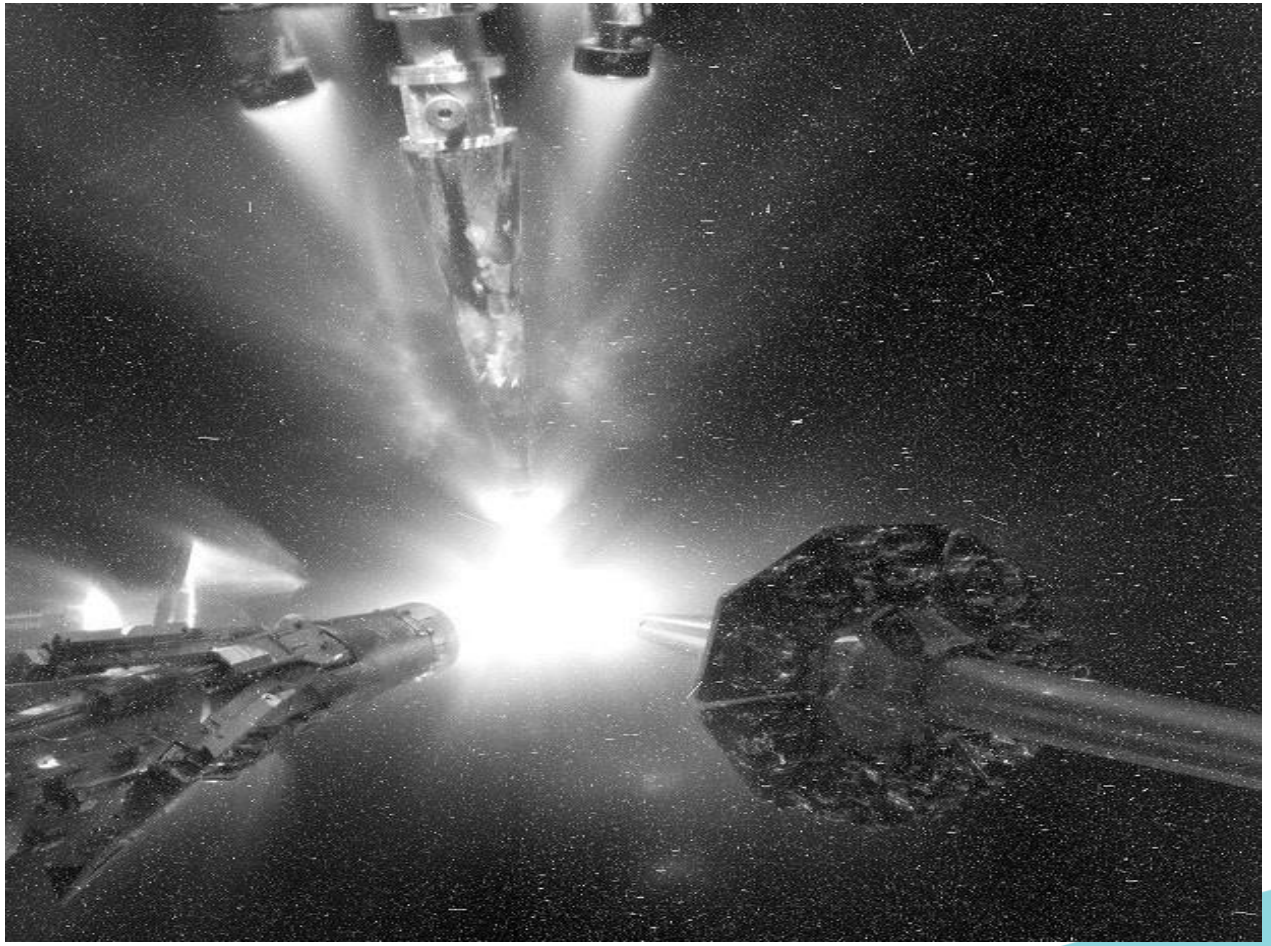
a, b) D Shaughnessy, Private Communication, 06/2024
c) 90Zr(n,2n)89Zr cross-section from ENDF/B-VIII.0 accessed via JANIS on 10/06/2024.

$^{89}Y(n,2n)^{88}Y$

- **Experiments**
  - Two shots were fired
    - July 2023 (2.8×10^{14})
    - January 2024 (6.1×10^{14})
  - Doped capsules (^{169}Tm, ^{89}Y, ^{152}Eu).
  - Cryo-cycled DT fuel.
  - 192 beam indirect compression.
  - Debris collected with SRCs.
  - γ spectra taken with P-type HPGe detectors using Ortec DSPec MCAs.
  - Spectra pre-processed by GAMANAL.



K. J. Moody *et al.,* Fractionation of copper activation products in debris samples from the National Ignition Facility, Applied Radiation and Isotopes, 143 (2019) 163-175.



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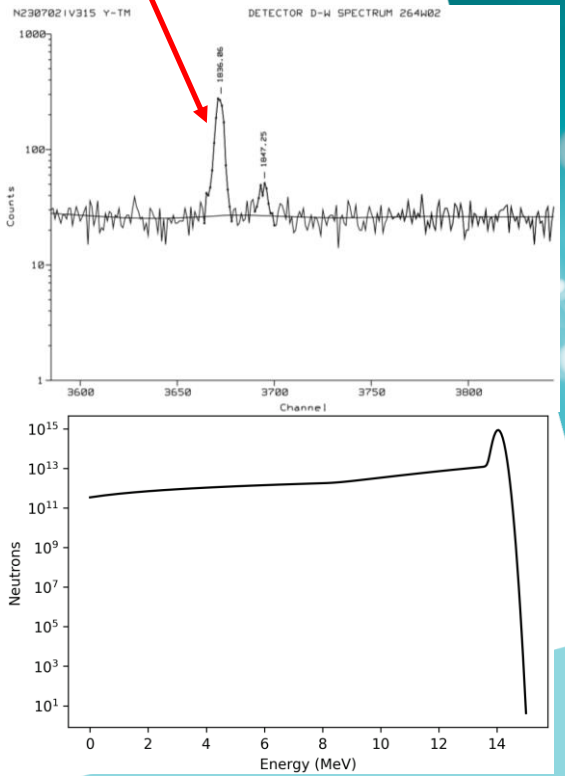
$^{89}Y(n,2n)^{88}Y$

^{88}Y (1836 keV) from $(2.3\pm0.3)\times10^{7}$ atoms over a 10-day count period

- **Analysis**
  - Reaction products ^{88}Y and ^{168}Tm, and collection tracer ^{152}Eu quantified γ–ray spectrometry.
  - Corrected by collection efficiency to get total production, N(^{88}Y) and N(^{168}Tm).

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Reaction Product: TM 168
Atoms calculated:
SRC V315: 4.432E+07
SRC V324: 1.512E+07
SRC V286: 5.437E+06
SRC V325: 3.563E+07

Summed TM 168 atoms: 1.005E+08 ± 7.826E+02

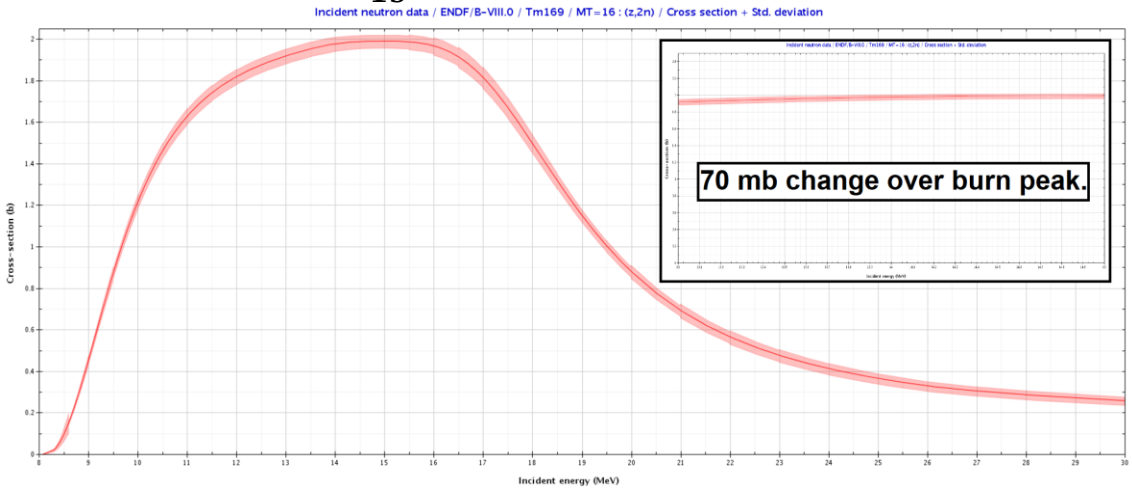
EU 152 atoms calculated:
SRC V315: 3.814E+10
SRC V324: 1.957E+10
SRC V286: 6.932E+09
SRC V325: 3.213E+10
Summed collection tracer atoms: 9.676E+10 ± 1.5e+03
Collection Efficiency over the above SRCs: (2.88 ± 4.5e-08) %

Efficiency Corrected Reaction Product Atoms inc systematic errors: 3.50E+09 ± 1.05E+08
```

$^{89}Y(n,2n)^{88}Y$

- **Analysis**
  - Evaluated σ's of ^{89}Y and ^{160}Tm, 50 keV intervals.
  - Average reference σ,

$$\overline{\sigma_{^{169}Tm}} = \frac{\int_{13}^{15} \sigma_{^{169}Tm}(E)\varphi(E)dE}{\int_{15}^{13} \varphi(E)dE}$$



$^{89}Y(n,2n)^{88}Y$

- **Analysis**
  - Activation fractions,

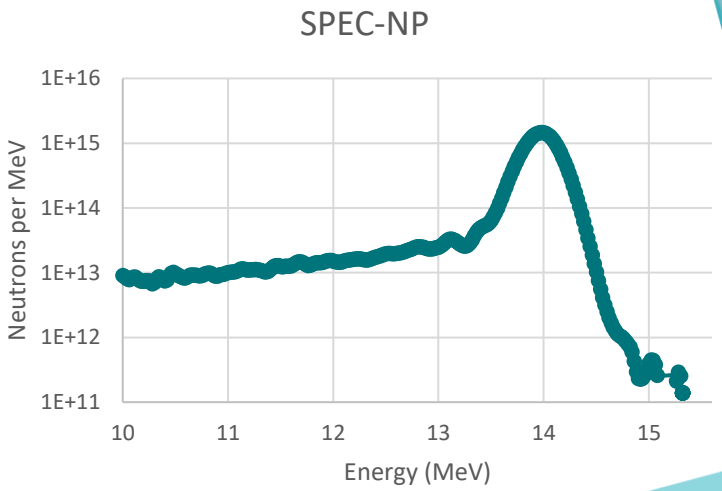
$$F_x = \frac{\int_{13}^{15} \sigma_x(E)\varphi(E)dE}{\int_0^{\infty} \sigma_x(E)\varphi(E)dE}$$

  - Cross–section Scaling,

Reactions in burn peak

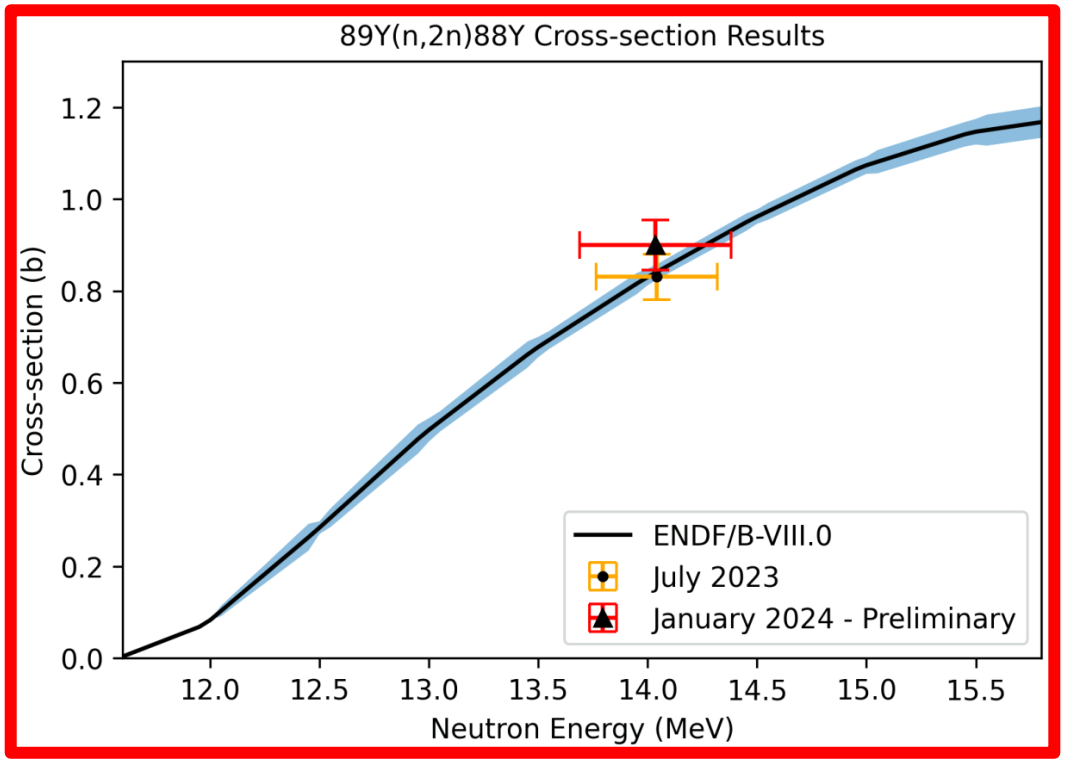
$$\overline{\sigma_{^{89}Y}} = \overline{\sigma_{^{169}Tm}} \left(\frac{F_{^{89}Y} N_{^{89}Y}}{F_{^{169}Tm} N_{^{169}Tm}} \right)$$

Reaction ratio



$^{89}Y(n,2n)^{88}Y$

- **Result**



Upcoming Measurements

Reaction	$T_{1/2}$	Notes
^{173}Lu(n,2n)	8.24 hrs	Shot Awarded
^{88}Y(n,2n)	106.6 days	Repeat Measurement (Sept 2025)

Summary

- Two ^{89}Y doped capsule shots took place on the NIF.
- (n,2n) reaction products were observed in both shots.
- Cross–section results for both shots agree with the ENDF/B-VIII.0 evaluation.
- Future work is planned to apply this method to poorly constrained cross–sections.

Thanks to Collaborators

LLNL
- D. Shaughnessy
- J. Despotopulos
- K. Kmak
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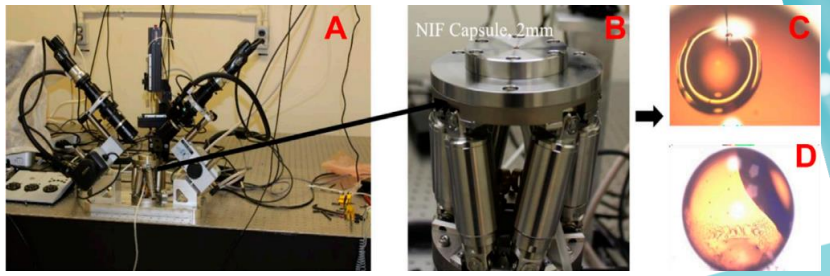
- J. Escher
- C. Yeamans
- K. Thomas
- E. Monzon
- C. Cerjan

AWE
- J. Benstead
- J. Read
- M. Cornock
- T. Gaines
- A. Stott

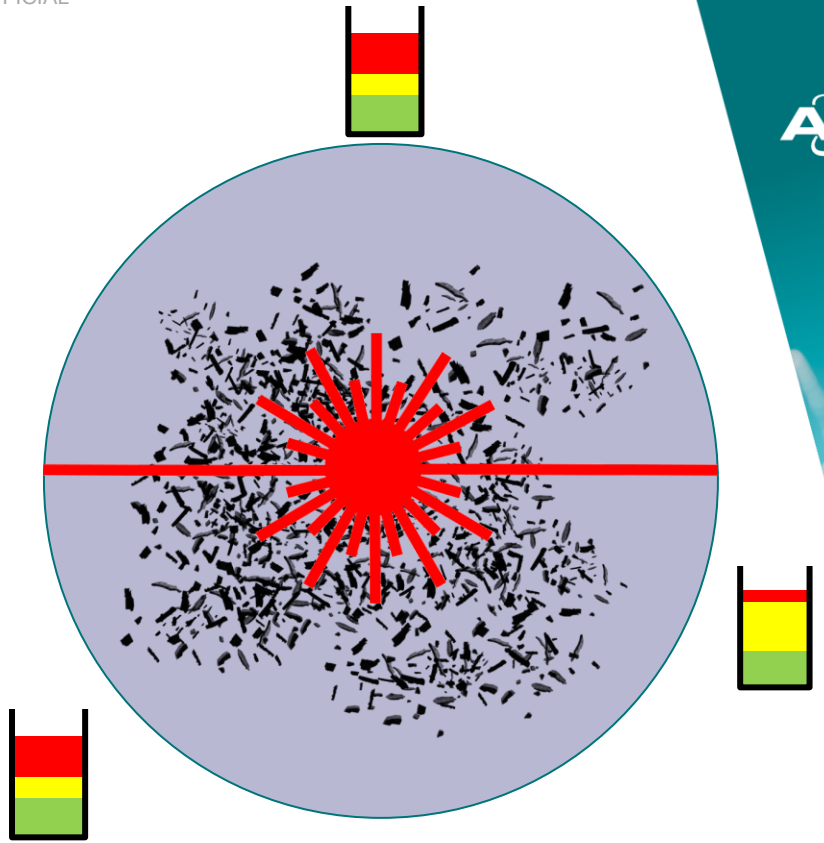
Capsule Doping

- **VORCAN**
  - Vacuum based system.
  - Simple and fast to use.
  - ~10-30% of solution doped into capsule.
  - 3-10 µL of solution can be injected.
- **ANDARIST**
  - Direct injection into capsule.
  - 100% of solution doped into capsule.
  - < 1 µL of solution can be injected.
  - Clean solution, injection capillary is easily clogged.

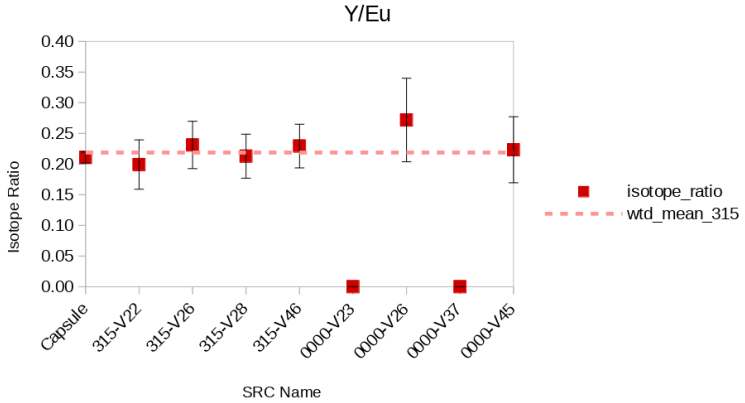


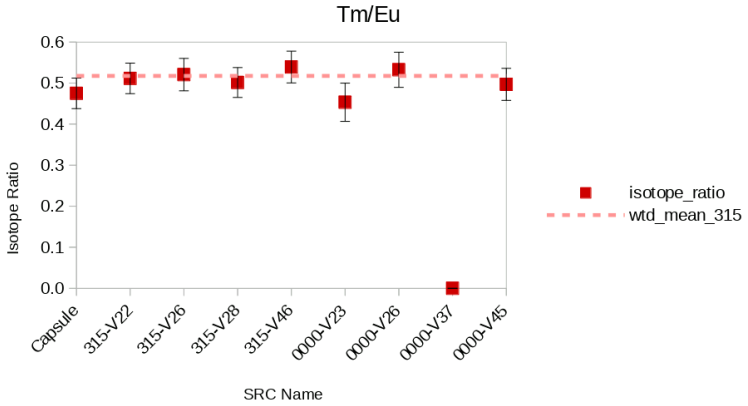
NIF Shot Debris

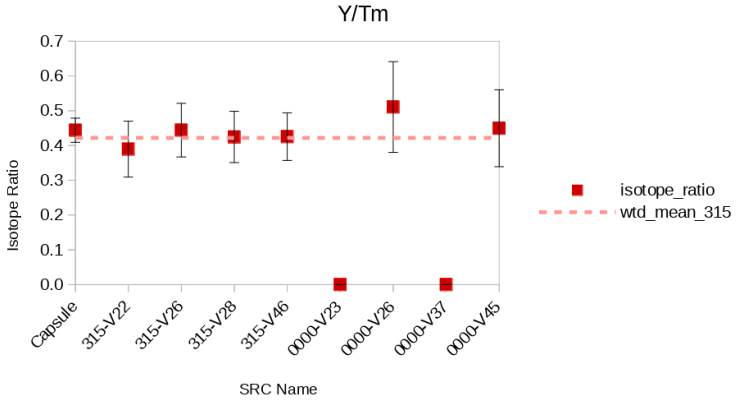
- **Chamber Considerations**
  - Fusion reaction emits isotopically.
  - Lasers are highly directional.
    - $P \approx 0.006$ kg m s^{-1} into target.
  - Debris directionality.
- **Target Considerations**
  - Phase change.
  - Fractionation of dopants
  - Unrepresentative data.



Fractionation Study

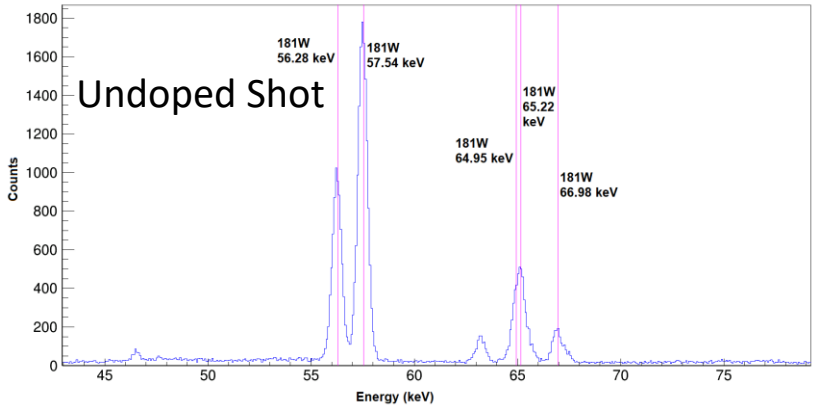






Chamber Contamination

23-111701_SRC-N230329_315-V16.SPE_cal



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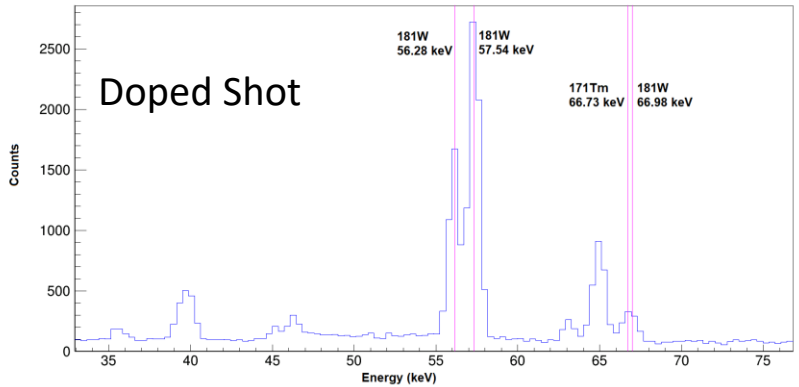

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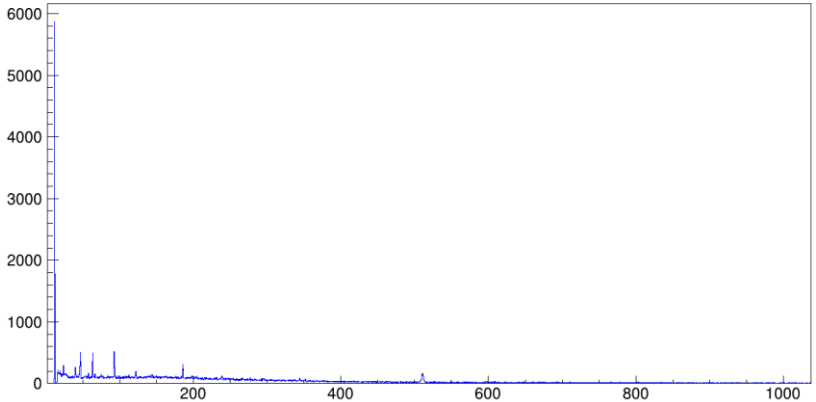
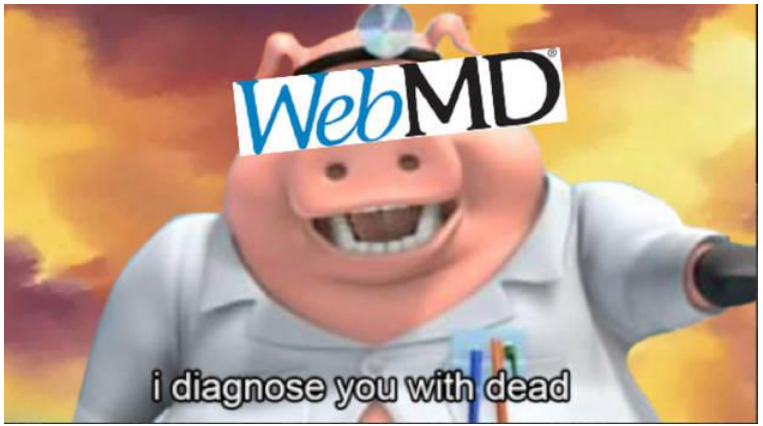


Diagnostic opportunities

- **Solid RadChem**
  - Alternative types of collector.
- **Gaseous RadChem**
  - RAGS System
- **Sample Activations**
  - Tree-Frog
  - TOAD
  - H-TOAD
  - Bullfrog

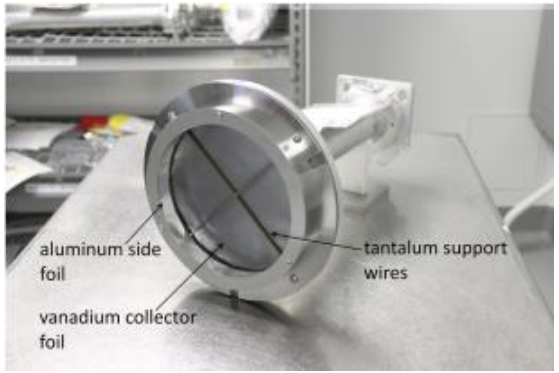


Imageresizer.com accessed on 11/06/2024

Diagnostic opportunities

Solid RadChem

- **VADER**
  - Vanadium trapezoids or ϕ=2” discs
  - Up to 1.74% solid angle coverage.
  - Compatible with x-ray camera.
- **LASR**
  - Vanadium discs ϕ=20 cm
  - Up to 2% solid angle coverage.
  - Compatible with x-ray camera.



Diagnostic opportunities

Solid RadChem

- Collectors can be directly measured with standard HPGe's or low-background detectors.
- α and β counting also available.
- Foils can be leached, and reaction products chemically separated.

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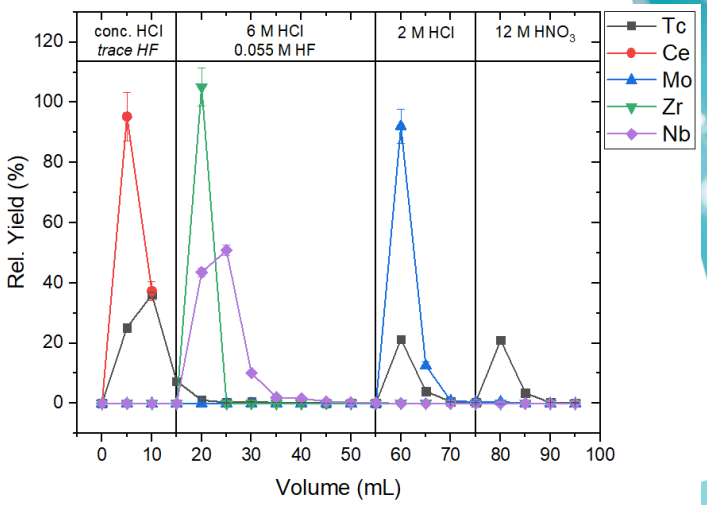

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Radiochemical Analysis of Gaseous Species (RAGS)

With shielding and detectors in place

The Collector Cart:
Xe/Kr Trap and Sample Collection Bottle

HPGe Detector
Quadrupole Mass Spectrometer

The Filter Cart:
Water Trap and Getters

3 $LaBr_3$ Detectors

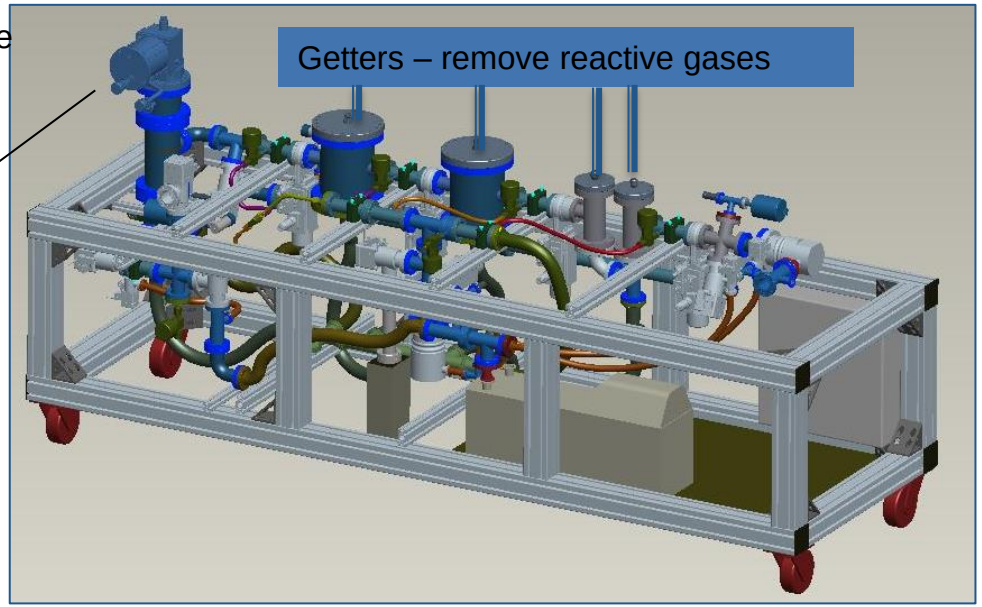
RAGS has a very high collection efficiency - >95% of target chamber gases are pumped

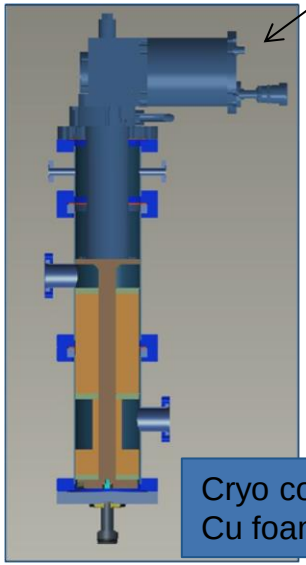
* *This presentation is being recorded*

Gas from the NIF chamber will first go through a pre-cleaner to remove water and reactive gases

From NIF chamber turbo pumps (~170' run)
10-100 millitorr Pressure

To Xenon collection cart





Cryo collector for water vapor removal – contains Cu foam to maximize surface area

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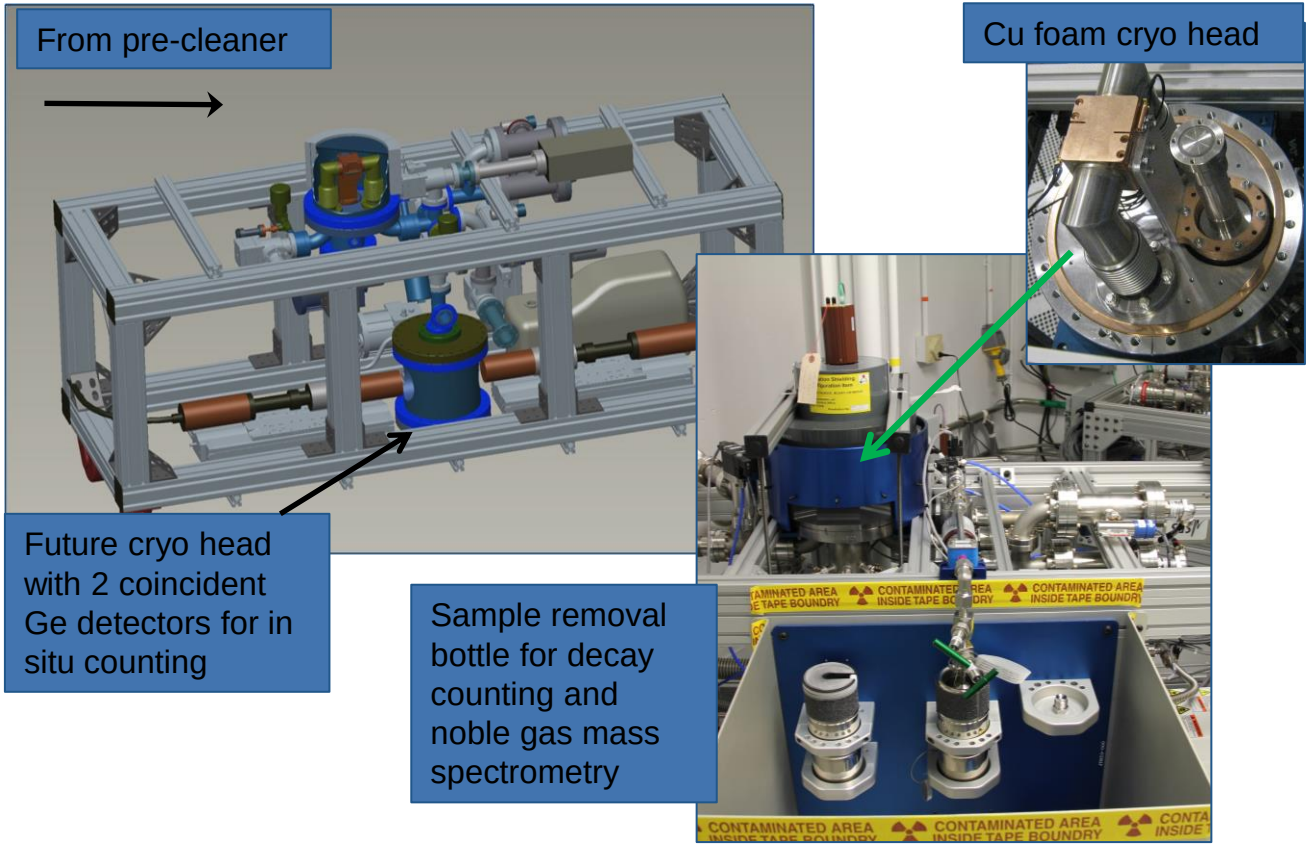
Xenon collection and detection cart



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