Measurement of Secondary Neutron Yield by Copper Activation

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The measurement of secondary deuterium–tritium (DT) neutrons from pure-deuterium inertial confinement fusion (ICF) targets can be used to diagnose the fuel areal density. Copper activation diagnostics have been used for many years to measure primary neutron yield in DT implosions. In recent years, progress in ICF implosions on the 30-kJ, 60-beam OMEGA laser system has made it possible to apply the existing copper activation diagnostic for secondary DT neutron yield measurements in pure-DD implosions. Single-hit detectors can measure yield and energy spectrum of secondary neutrons, but they saturate at high neutron yields. The copper activation diagnostic can measure very high secondary yield, but its accuracy is limited by the uncertainty in the energy spectrum of the secondary neutrons. The copper activation diagnostic on OMEGA, its operation, and the limitations of this diagnostic for secondary neutron measurements will be presented. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460.

Abstract

The measurement of secondary deuterium–tritium (DT) neutrons from pure-deuterium inertial confinement fusion (ICF) targets can be used to diagnose the fuel areal density. Copper activation diagnostics have been used for many years to measure primary neutron yield in DT implosions. In recent years, progress in ICF implosions on the 30-kJ, 60-beam OMEGA laser system has made it possible to apply the existing copper activation diagnostic for secondary DT neutron yield measurements in pure-DD implosions. Single-hit detectors can measure yield and energy spectrum of secondary neutrons, but they saturate at high neutron yields. The copper activation diagnostic can measure very high secondary yield, but its accuracy is limited by the uncertainty in the energy spectrum of the secondary neutrons. The copper activation diagnostic on OMEGA, its operation, and the limitations of this diagnostic for secondary neutron measurements will be presented.

The secondary neutron yield can be used to diagnose the fuel areal density in pure-DD implosions

- **Primary fusion reaction:**

  $D + D \rightarrow {}^{3}He$ (0.82 MeV) + n (2.45 MeV)

  $D + D \rightarrow p$ (3.02 MeV) + T (1.01 MeV)

- **Secondary, "in-flight" fusion reaction:**

  T (1.01 MeV) + D $\rightarrow \alpha$ + n (11.8 MeV to 17.1 MeV)

- **For small ρR, the probability that a triton undergoes a secondary in-flight reaction is proportional to the fuel ρR. In this case, ρR is proportional to the ratio of DT to DD neutrons.**

- **Secondary neutron yield can be measured by**
  - single-hit detectors (LaNSA, MEDUSA, MANDALA)
  - current-mode detectors, i.e., single scintillator and PMT
  - copper activation

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Copper activation is a standard diagnostic to measure primary neutron yield in DT implosions

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- Copper nuclei are activated by the reaction

  $n + {}^{63}Cu \rightarrow {}^{62}Cu + 2n$

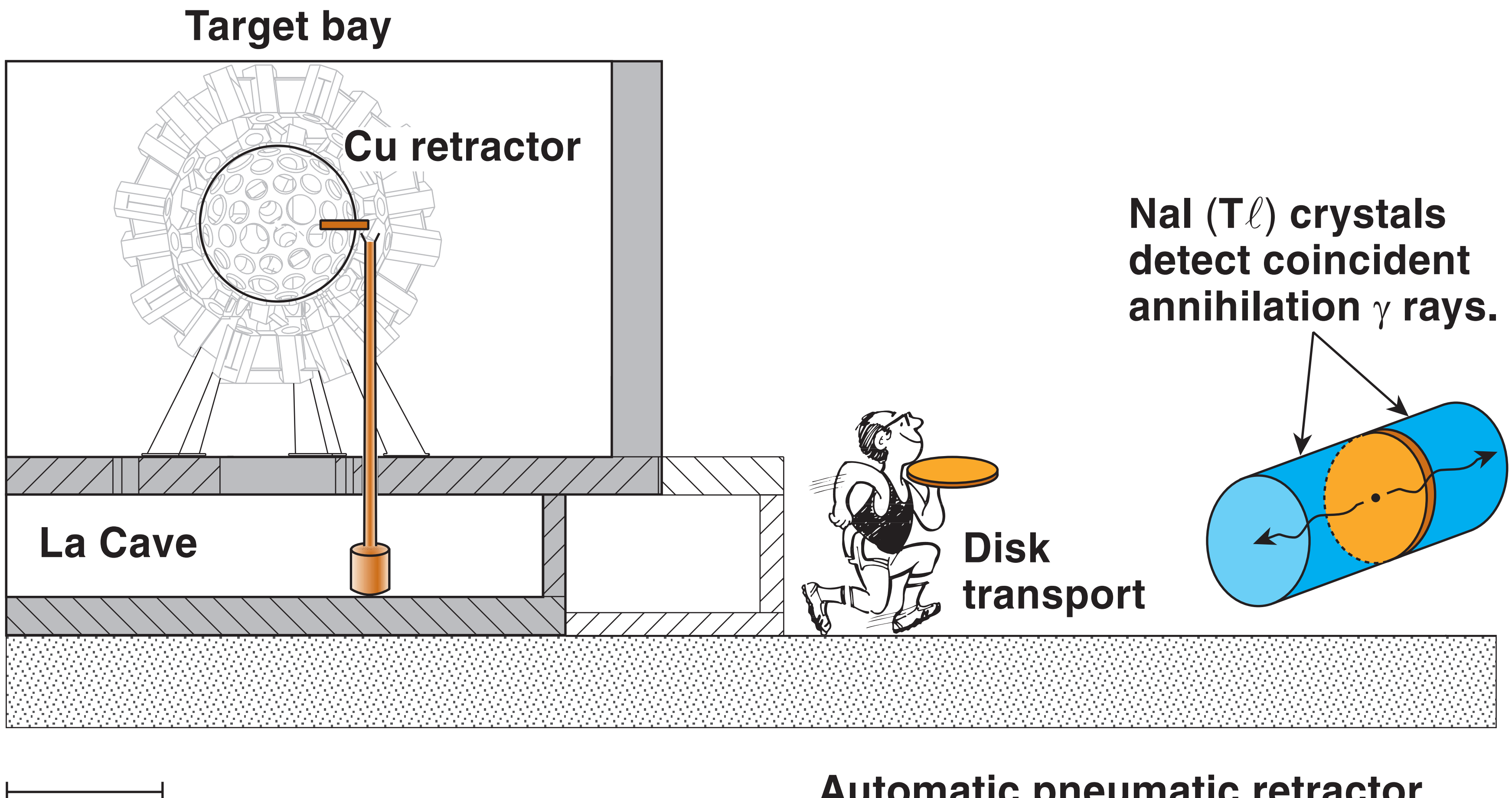
- Reaction threshold = 10.9 MeV, cross section = 0.5 b at 14.1 MeV
- ${}^{62}Cu$ emits a positron that produces two gamma rays:

  ${}^{62}Cu \rightarrow {}^{62}Ni + e^{+}$ ($\tau_{1/2}$ = 9.8 min.)

  $e^{+} + e^{-} \rightarrow 2\gamma$ (0.511 MeV)

- The coincidence of two gamma rays is detected by two NaI detectors.

The OMEGA copper activation system was designed for primary DT yield measurements



Automatic pneumatic retractor
Cu disk: 76-mm diam × 9.5 mm
Disk-to-target distance: 40 cm
Detector threshold: ~10^7 neutrons

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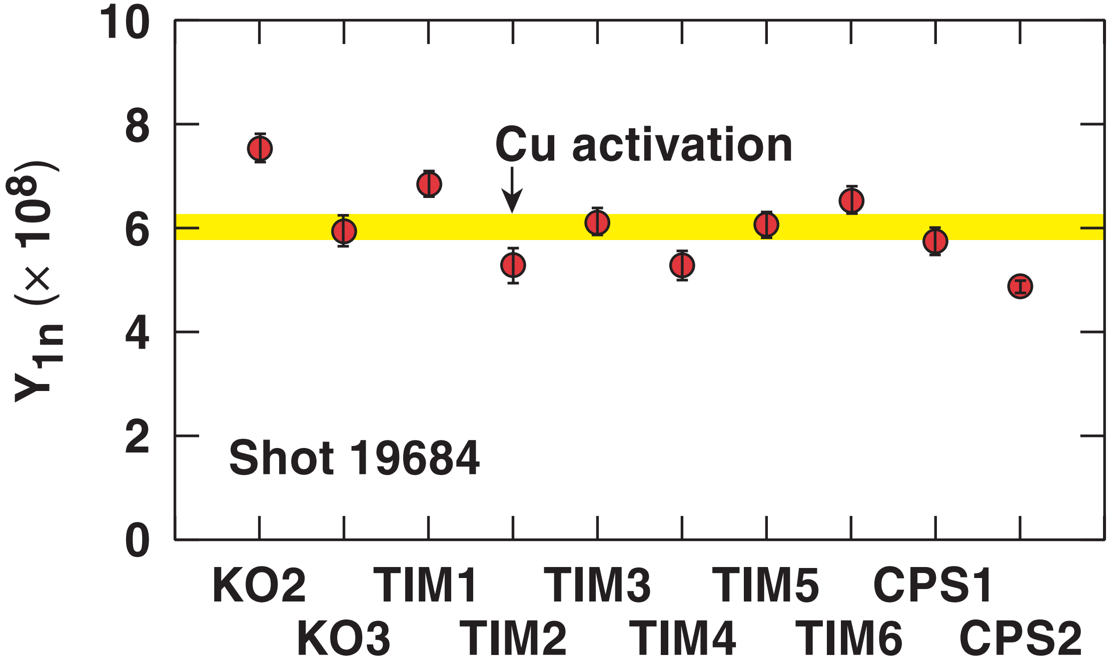
The absolute calibration of the OMEGA copper activation system is better than 10%

- Copper activation was calibrated by several methods in 1996.
- Copper calibration was checked in April 2000 by measuring DT neutrons and associated alpha particles by CR-39 range filters and CPS.

$$D + T \rightarrow {}^4He\ (3.5\ MeV) + n\ (14.1\ MeV)$$

$Y_n = (6.02 \pm 0.23)10^8$ $\qquad$ $\langle Y\alpha \rangle = (6.0 \pm 0.2)10^8$



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The ^{63}Cu (n,2n) ^{62}Cu reaction cross section depends on the neutron energy

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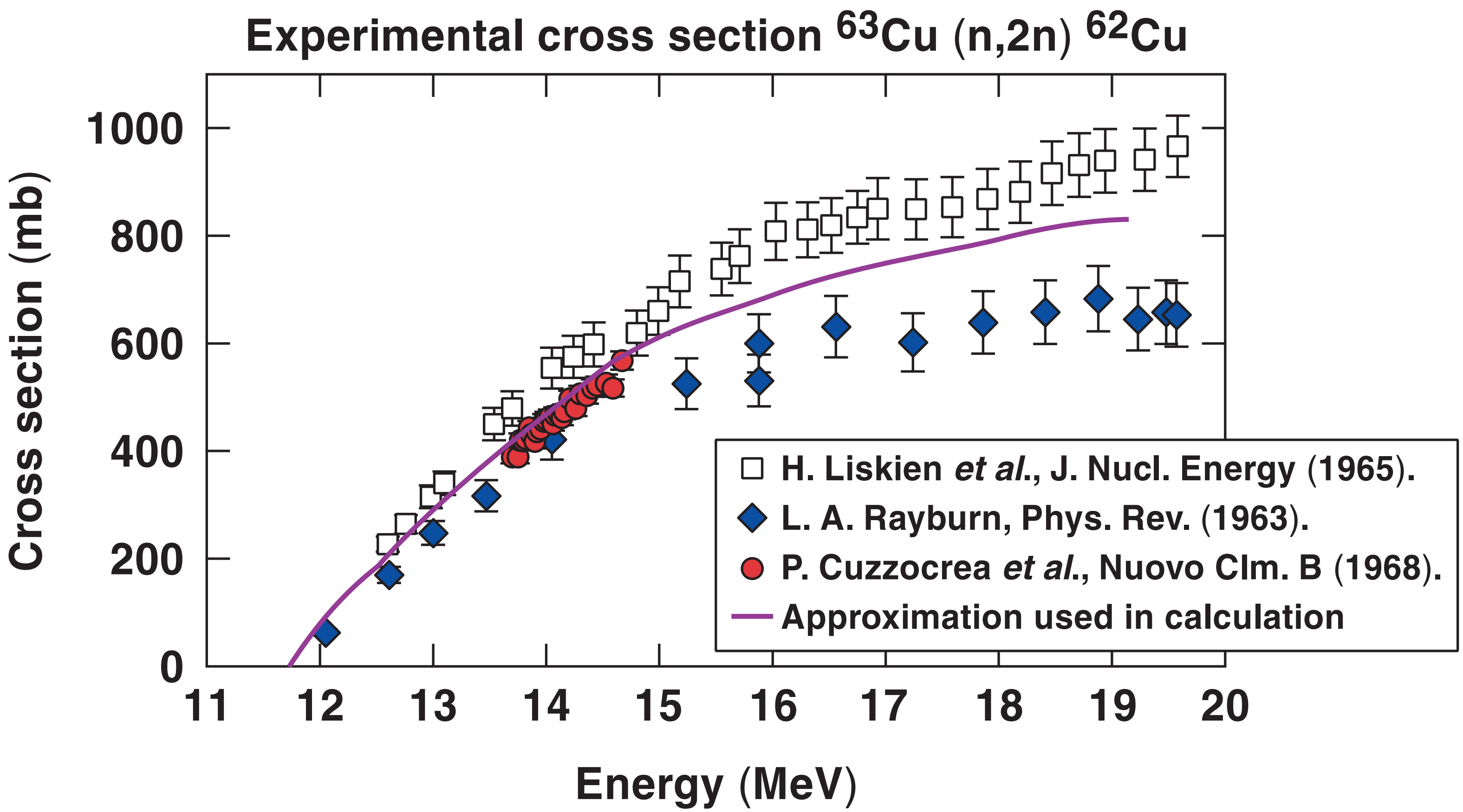
- In the case of secondary DT neutrons, we have a broad energy spectrum (11.8 MeV to 17.1 MeV) instead of the 14.1-MeV line of primary DT neutrons.



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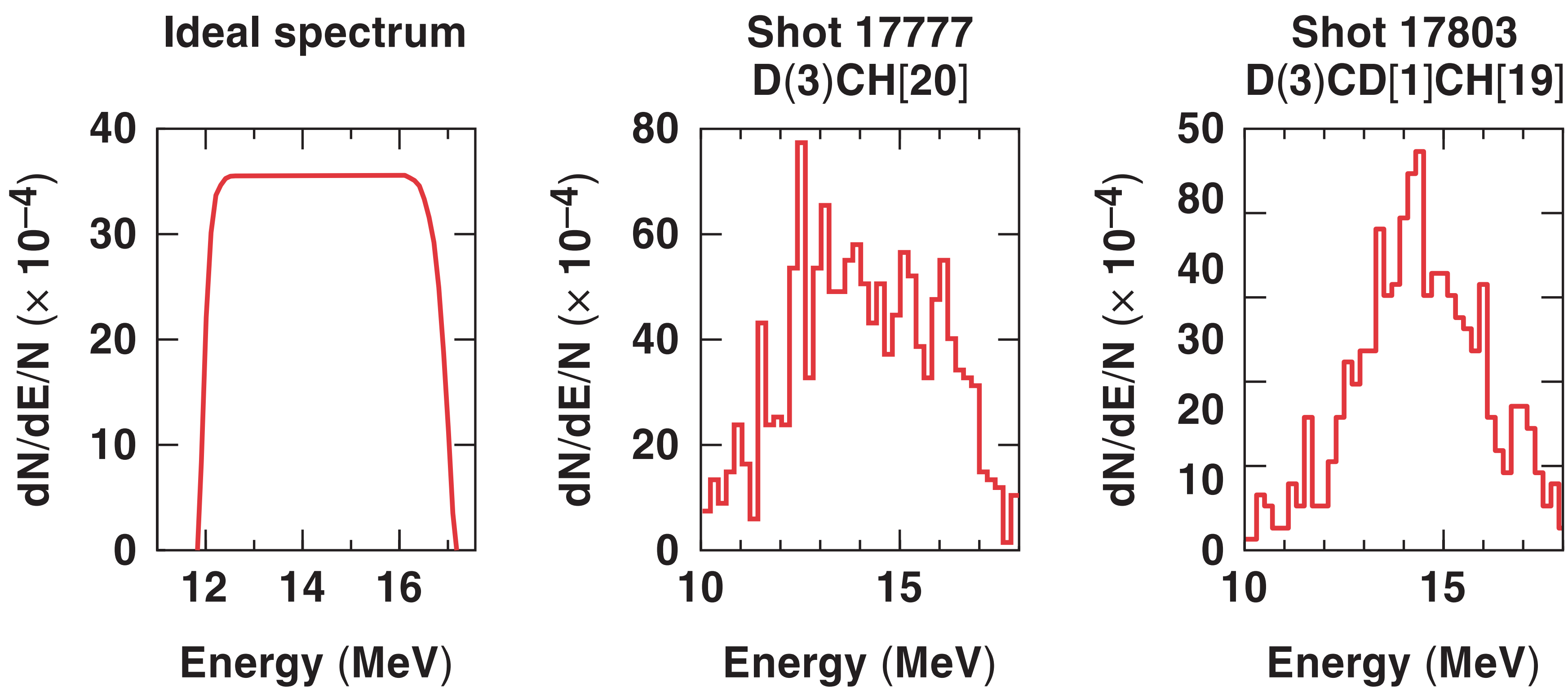
Uncertainty in the secondary DT neutron energy spectrum creates an error in the secondary yield Cu measurement



2.9% 6.7% 1.7%

Calculated DT yield error with 14.1-MeV cross section

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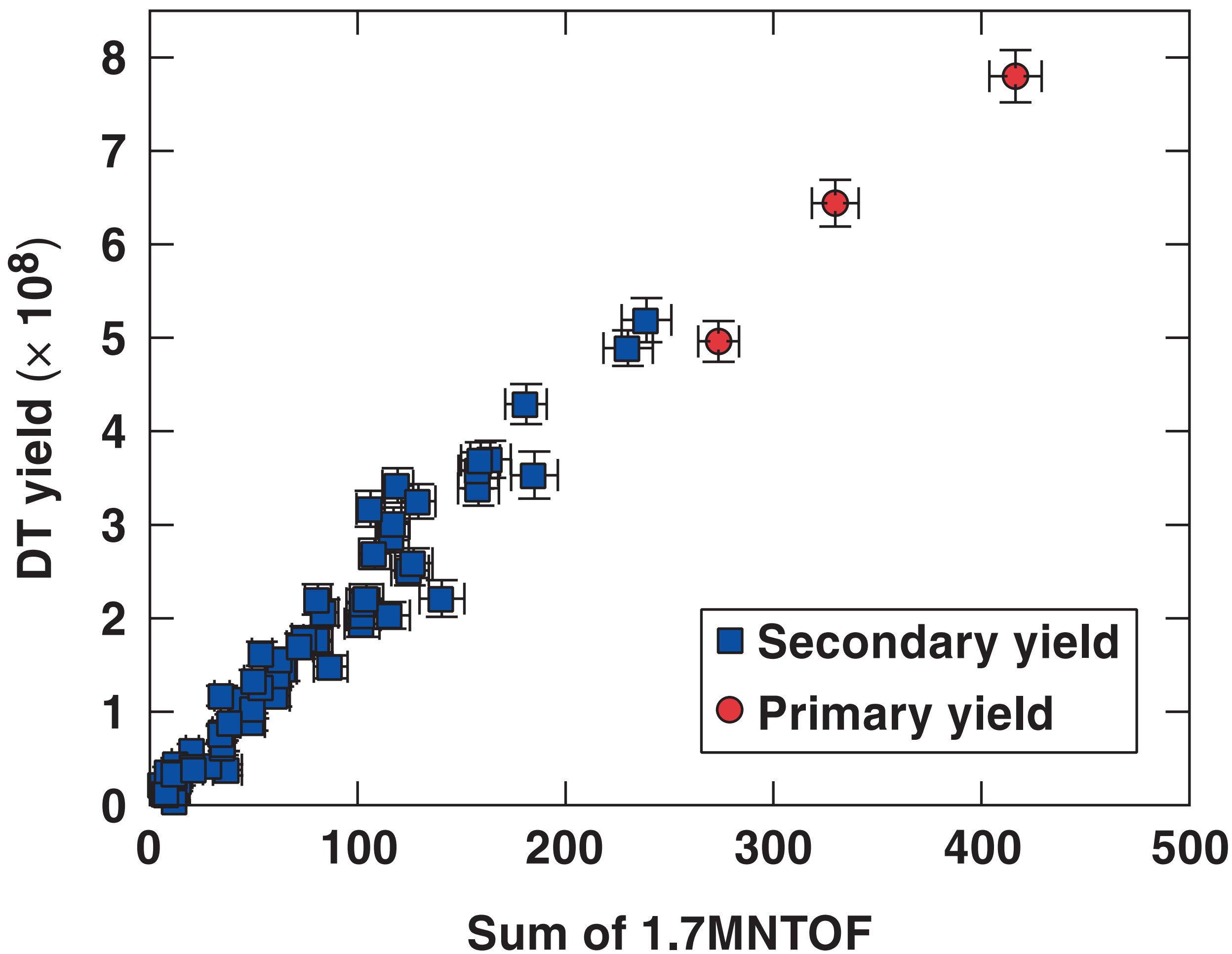
The copper activation diagnostic has advantages and disadvantages

- Advantages
  - low cost and simplicity
  - large dynamic range (10^7 to 10^{12} on OMEGA)
  - excellent stability (based on radioactivity)
- Disadvantages
  - no secondary neutron spectra
  - precision limited to 10%
  - requires manual operation

The primary and secondary DT yields measured by Cu activation and the scintillator counter agree well



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Summary/Conclusions

We use the existing copper activation system for secondary neutron measurements for high-yield experiments.

- Single-hit detectors like LaNSA or MEDUSA are expensive and have a limited dynamic range.
- Copper activation is an alternative to current-mode detectors to measure secondary neutrons in a wide range of yields with an accuracy of 10%.
- Copper activation was used to calibration of the current-mode detectors on OMEGA.
- We are using copper activation as a second measurement to the current-mode detectors in direct-drive implosion experiments on OMEGA.