



# ON THE ABSOLUTE CALIBRATION OF A DT FUSION<sub>SAND2011-7090C</sub>

## NEUTRON YIELD DIAGNOSTIC\*

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## ABSTRACT

Recent advances in inertial confinement fusion (ICF) experiments at Lawrence Livermore National Laboratory's National Ignition Facility (NIF) have underscored the need for accurate total yield measurements of DT neutrons. Future gas-puff DT experiments at Sandia National Laboratory's Z facility will also require similar measurements. Accurate yield measurements provide an essential measure of the calculated performance of the experiments.

The standard technique for measuring the DT neutron (14.1 MeV) yield is by counting the activity (counts/minute) of irradiated copper samples.<sup>1</sup> The activity is induced by the  $^{63}\text{Cu}$  (n, 2n)  $^{62}\text{Cu}$  reaction where  $^{62}\text{Cu}$  decays by  $\beta^+$  with a half-life of 9.74 minutes. This necessary measurement requires that the counting system (detector efficiencies, self-attenuation corrections due to volumetric copper samples, neutron scattering effects, etc.) is calibrated with sufficient accuracy (< 5%). Briefly, for this absolute calibration, will employ the associated-particle technique where of the alpha ( $^4\text{He}$ ) particle from the T (d, n)  $^4\text{He}$  reaction is measured. This technique infers accurately the neutron flux on a copper sample and the subsequent induced  $^{62}\text{Cu}$  activity. A complete description of the calibration procedure to achieve the prescribed accuracy will be presented.

<sup>1</sup> R. J. Leeper et al, this conference

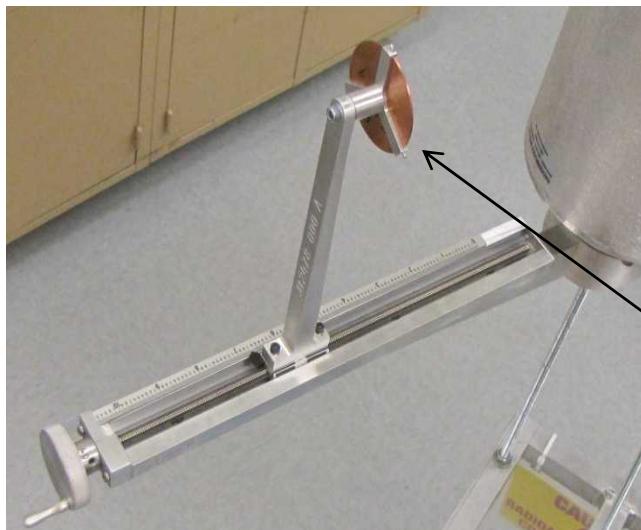
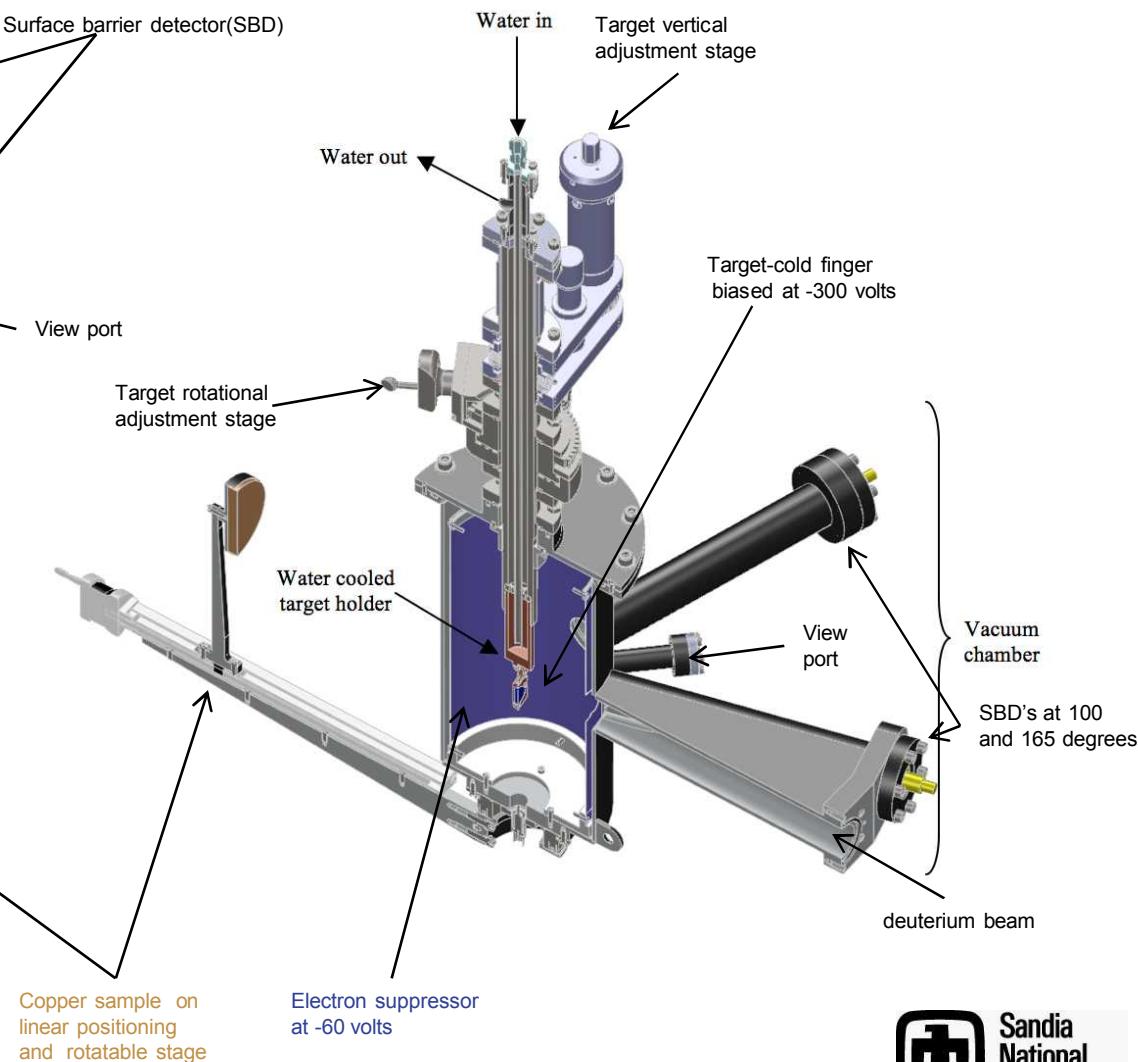
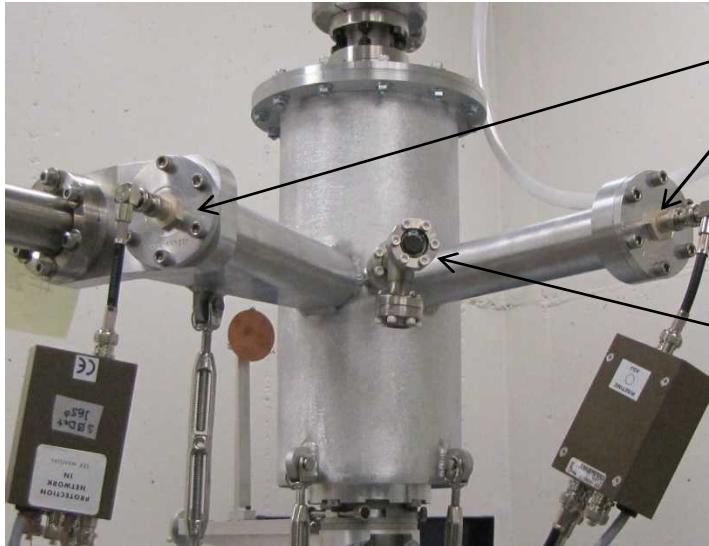


# objective

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- Use a steady state source of 14.1 MeV DT neutrons to activate a copper sample by the  
$$^{63}\text{Cu} (\text{n} , 2\text{n}) ^{62}\text{Cu} \ (\beta^+ , 9.74 \text{ min half-life})$$
- Employ the associated-particle technique and minimize experimental uncertainties and employ the reaction  
$$\text{T} (\text{d} , \text{n}) ^4\text{He}$$
- Measure the copper activity in a well-characterized  $\beta^+$  decay copper coincidence counting system.
- Calibrate the copper-coincidence system to give a measure of counts/neutrons-mass of copper/cm<sup>2</sup> which is called the F-factor
- Use this F-factor as a measure of the yield of a short duration ( sub ns) source of DT 14.1 MeV fusion neutrons

# Associated – particle vacuum chamber with water- cooled $\text{ErT}_2$ target, two surface barrier detectors, and adjustable copper sample holder

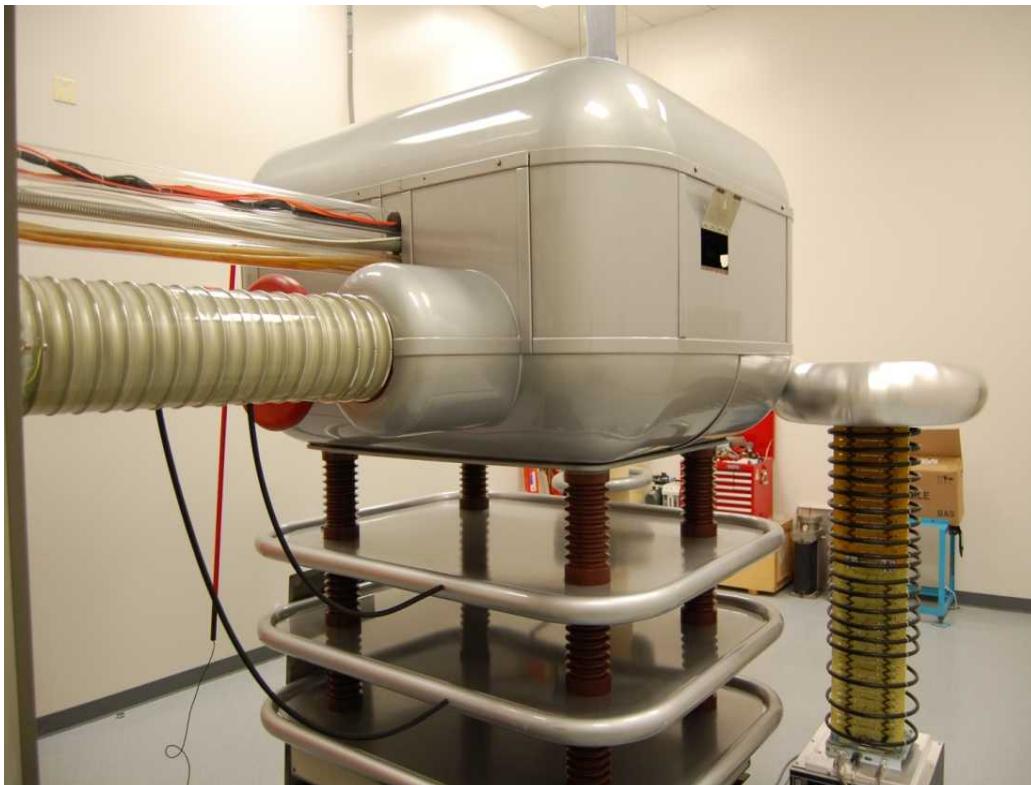




# Accelerator-based steady-state source of 14.1 MeV dT neutrons

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## 300 keV Cockcroft-Walton



Source of neutrons are from the  $T(d, n)^4\text{He}$  reaction. A thick  $\text{ErT}_2$  target, fully stopping the incident energetic deuteron beam, is generated by Sandia's Ion Beam Laboratory's 300 keV Cockcroft-Walton accelerator. The kinetic energies of the deuterium beam in these experiments were conducted at 100.0 and 175.0 keV and the targets were nominally 2 – 3 microns thick with a 5.0 mm diameter. Typical currents on water-cooled target were 1.0 to 10.0 microamperes. Targets were biased with +300 volts to prevent emission of secondary electrons and allowing accurate current monitoring. An electron suppressor at -60 volts was also utilized.



## thick target differential yield of neutrons or alphas per mstr per $\mu$ coul

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$$\frac{d Y}{d \Omega} = \int_{E_d^{\max}}^0 n \frac{d \sigma (E) / d \Omega}{d E / d x} d E$$

where,

$E_d^{\max}$  is the bombarding energy of the deuteron, n is the loading ratio of tritium in Erbium, typically 1.96.  $d\sigma/d\Omega$  is the differential cross-section<sup>1</sup> in the lab, and the stopping power<sup>2</sup>  $dE/dx$  is a modified Bragg rule of additive for metal hydride

ErT<sub>1.96</sub> written as

$$dE/dx = dE/dx_{Er} + (B)(n)dE/dx_T$$

and where B = .723 is a reduction factor.<sup>3</sup>

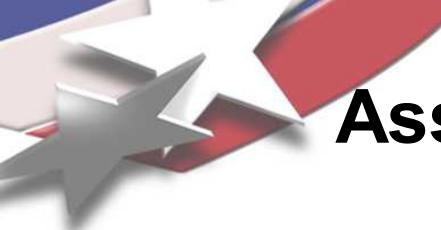
Place target  
picture here

The tritium loading throughout the depth of the target is assumed to be uniform. Past data suggest this to be a valid assumption.

<sup>1</sup> H. Liskien and A. Paulsen, Nuclear Data Tables **11** (1973), 569.

<sup>2</sup> H.H. Anderson and J.F. Ziegler, Hydrogen Stopping Powers and Ranges in All Elements (Pergamon Press, New York, 1977)

<sup>3</sup> Malbrough et al, **NIM**, B28 (1987) 459-469.

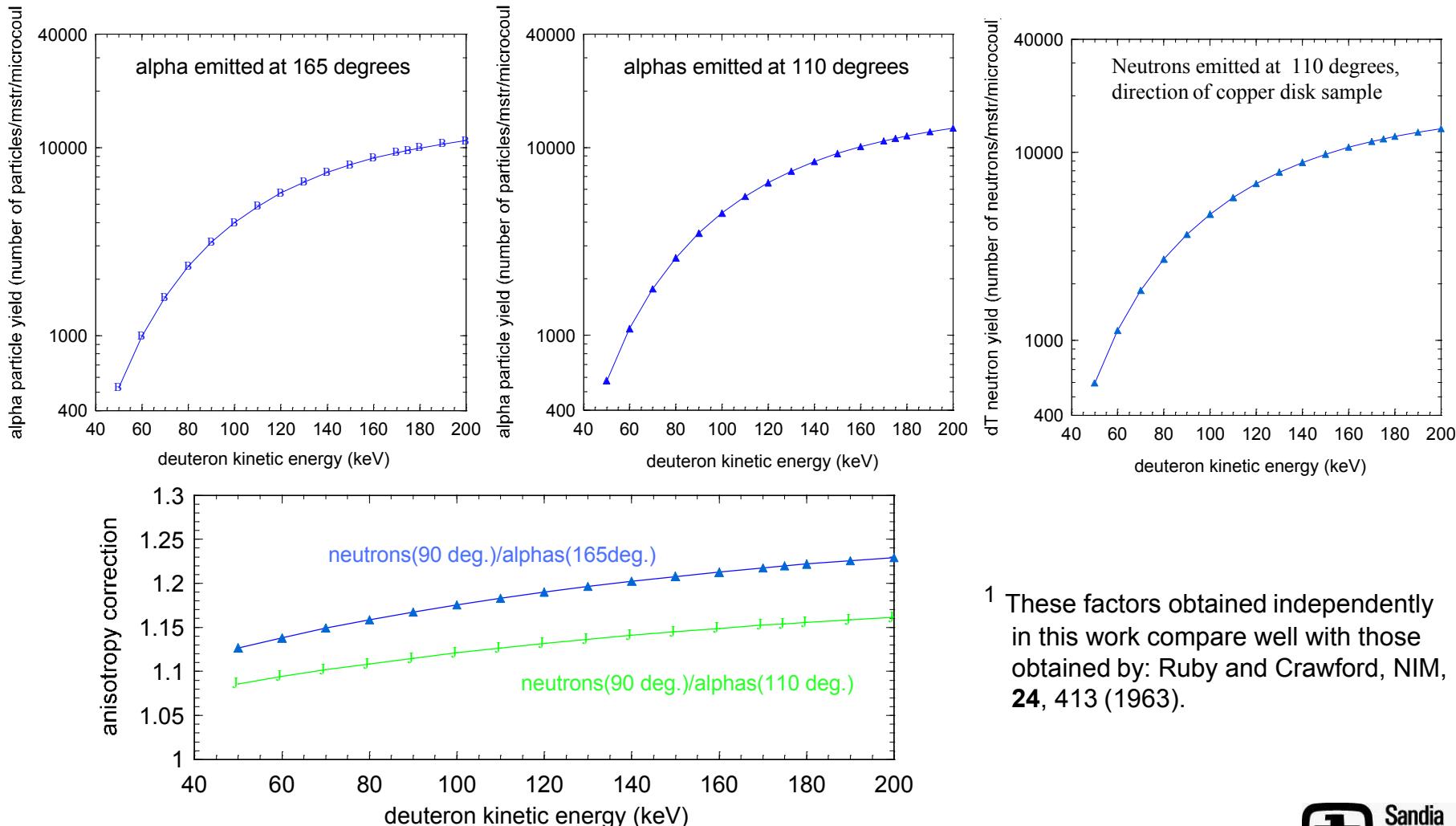


# Associated-particle yield as it relates to the neutron emission

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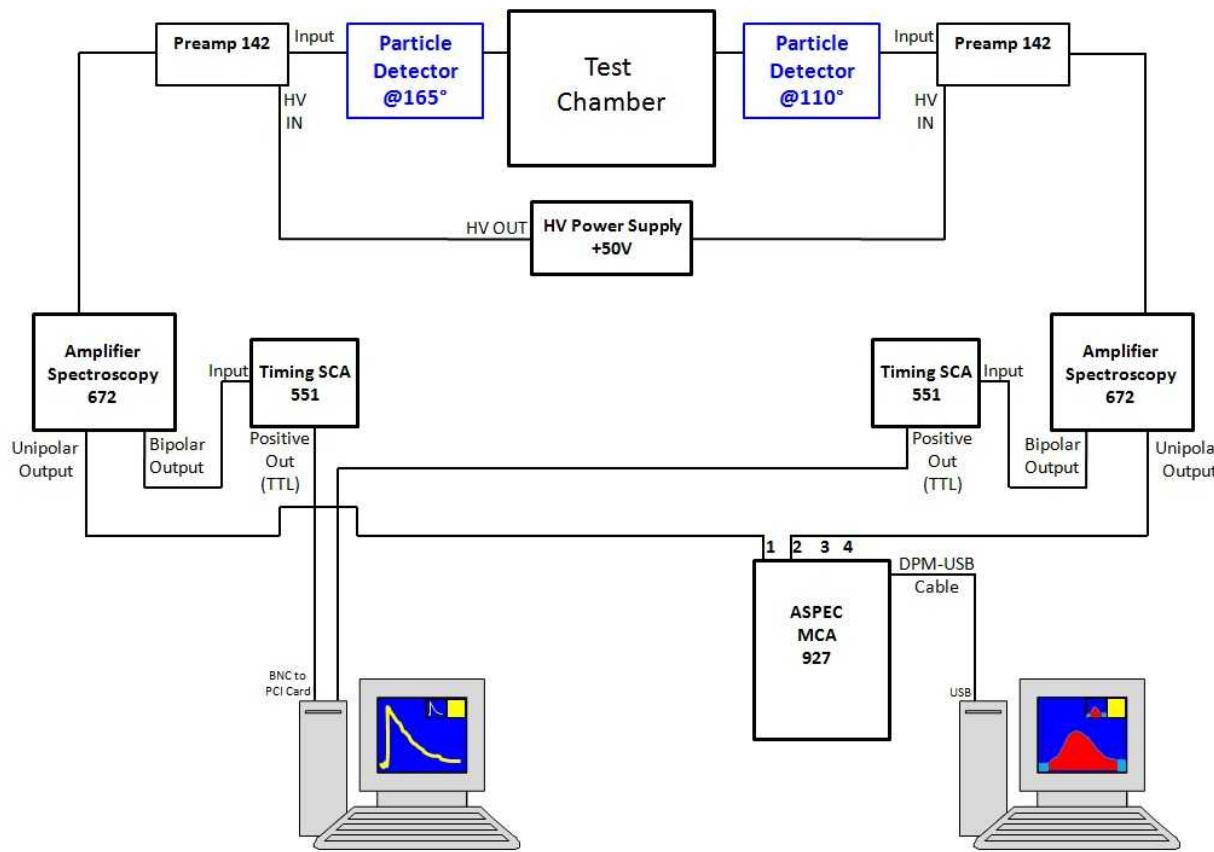
- **$^4\text{He}$  and neutrons emitted from the  $\text{T}(\text{d},\text{n})^4\text{He}$  reaction, being isotropic in the center-of-mass, require a kinematic and differential-cross-section transformations of the thick target differential yields to the lab at the angles which they are measured and calculated from the maximum kinetic energy of deuterons.**
  - The ratio of calculated neutron yield at nominally 90 degrees to calculated  $^4\text{He}$  yields at 110 and 165 degrees allows for the conversion of two differentially measured  $^4\text{He}$  yields to determine neutron yield.
  - The solid angles subtended by the alpha particle detectors and the irradiated copper sample must be taken into account.

# Thick target alpha yields calculated at 110 and 165 degrees and neutron yields at 90 degrees plus anisotropy correction factors<sup>1</sup> as a function of deuteron kinetic energy



<sup>1</sup> These factors obtained independently in this work compare well with those obtained by: Ruby and Crawford, NIM, **24**, 413 (1963).

# Diagram of electronics setup



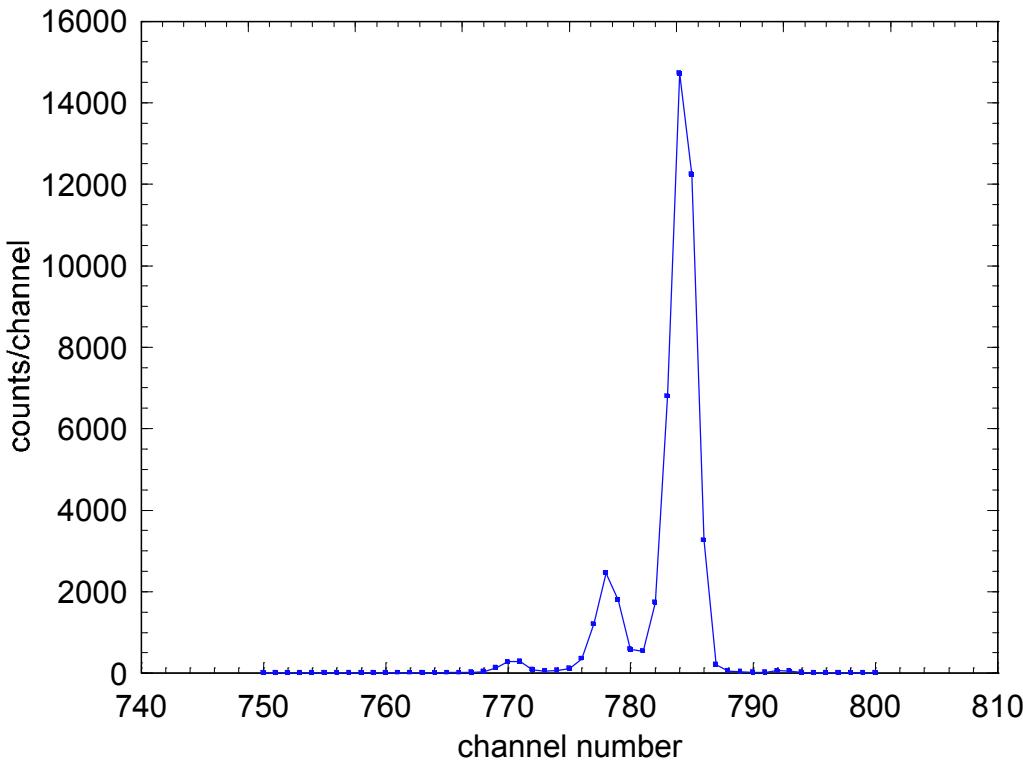
The SCA's are adjusted with a lower and upper level discriminator setting over the alpha particle signals to monitor the rate production (multi-channel scaling) for constancy and indications of target deterioration



# Associated-particle alpha particle detector measurements from $^{241}\text{Am}$ source

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Alpha particle spectrum from an Am-141 source. Main peaks are at 5.486 and 5.443 MeV indicating an energy resolution of 15.5 keV



Two surface barrier detectors are situated at 12 inches from the target beam spot at 110 and 165 degrees relative to the beam. Surface barrier detectors (ion implanted ORTEC type) have an active area of  $50\text{ mm}^2$  and are 200 microns thick. The detectors have a nominal energy resolution of 14.5 keV determined with an Am-241 source. Distances and collimators have very tight tolerances leading an estimated solid angle subtended by both detectors to be  $(2.177 +/- .022) \text{ e-4 str}$ . This has been compared by measuring the fractional alpha particle measured activity of a 3% calibrated 5 mm diameter Am-241 located at the target surface to be  $(2.258 +/- .068) \text{ e-4 str}$ .



# Copper activation formalism

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$$(C - B) = \phi \cdot \varepsilon_A \cdot \varepsilon_D \cdot \varepsilon_S \cdot \varepsilon_B \cdot M \cdot N_A \cdot \sigma(E) \cdot [(1 - e^{-\lambda t_0})(e^{-\lambda t_1} - e^{-\lambda t_2})] / \lambda A_W$$

The coincident counts minus background measured by the coincidence system between  $t_1$  and  $t_2$  for an irradiation time of  $t_0$  is given by the equation above given a associated-particle Inferred neutron flux  $\phi$ .<sup>1</sup>

where:

C = counts

B = background counts

$\varepsilon_A$  : natural abundance of Cu-63 =

$\varepsilon_D$  : coincidence detection efficiency =

$\varepsilon_B$  : branching ratio for  $\beta^+$  decay =

$\varepsilon_S$  : self-absorbtion for 511 keV  
annihilation gammas

M : mass of copper sample

$N_A$  : Avogadro's number

$\sigma(E)$  : energy dependent cross-section

$A_W$ : atomic weight of copper

$\lambda$  :  $.693/\tau_{1/2}$  where  $\tau_{1/2}$  is 9.74 min half-life

$t_0$  : time of neutron irradiation of copper

$t_1$  : starting counting time after  $t_0$

$t_2$  : ending counting time after  $t_0$

<sup>1</sup> G. W. Cooper and C. L. Ruiz, RSI, vol. 72, No. 1, Jan. 2001



# The F-factor concept

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The previous equation can be re-written to give a calibration factor F in terms of experimental quantities:

$$F = \frac{(C - B)}{Y \cdot M \cdot (1 - e^{-\lambda t_0})(e^{-\lambda t_1} - e^{-\lambda t_2})} \cdot (4\pi d^2) t_0 \cdot \lambda$$

or, alternatively, in terms of fundamental units:

$$F = \epsilon_A \cdot \epsilon_D \cdot \epsilon_S \cdot \epsilon_B \cdot \sigma(E) N_A / A_W$$

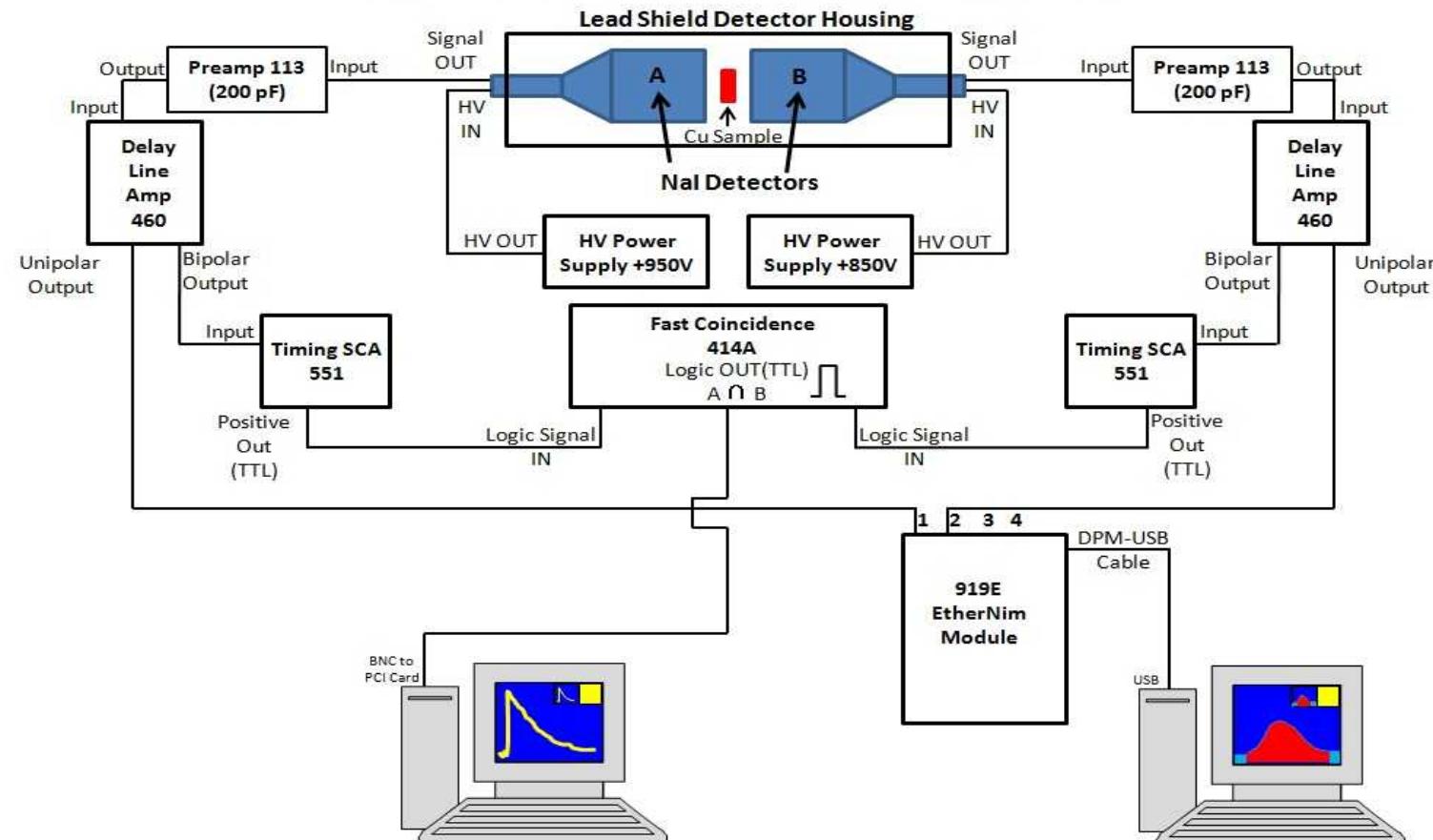
flux  $\phi$  has been re-defined as

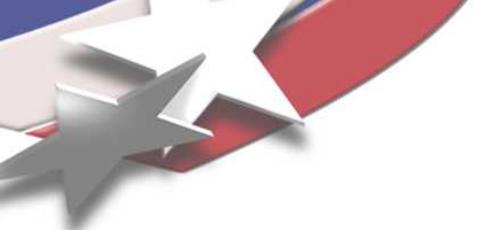
$$Y / (4\pi d^2 t_0)$$

where d is the distance from the neutron source to the face of the copper sample and Y is the total neutron yield into  $4\pi$ . In the alternative F-factor equation, explicit knowledge of the quantities,  $\sigma(E)$ ,  $\epsilon_D$ ,  $\epsilon_S$  is not required. Rather, F is measured by the experimental quantities given in the first equation.

# Electronic setup for the counting of an activated copper sample

Diagram of Copper Coincidence Counting System





## Copper coincidence counting hardware

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3 inch by 6 inch diameter NaI detectors spaced 2 inches apart inside 1 inch thick Pd shields



Pre-calibration of the coincidence system is very important. A 0.5 cm diameter by .005 inch thick Ge-68 beta decay source with about 20 to 40 nCi is used to adjust the amplifier gains and fix the centroids of the 511 keV annihilation gamma-rays detected by two 5 inch by 3 inch thick NaI detectors. For each detector the centroids are adjusted as close as necessary to a specified channel for a chosen conversion gain on the Multi-channel analyzer. The measured coincidence rate from the source is compared to the corrected rate due to the decay of the 270 day half-life of Ge-68.



## Summary

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- **At this writing we have not received permission to use tritiated targets until a formal review.**
- **Results are pending but should be available in time for the submission of the manuscript associated with this poster presentation.**