# FNAL Activation Analysis

- Performed by Vernon Cupps, ES&H radiation physicist.
- Analyzed three samples of 1.5 mil natural copper foil irradiated 3/25/03 in KSU JRML to beam-recorded fluence of $9.96\times10^{13}$ 10 MeV p/cm$^2$.
- Technique: look for 244d ½-life Zn-65→Cu-65 $\beta^+$ decay.
  - Detect high intensity 1.115 MeV $\gamma$-ray.
  - Used high purity intrinsic Ge detector, 1.6%×4$\pi$.
  - Similar to check done with higher acceptance well counter by KSU Nuclear Engineering on same foil.
- Vernon is a busy professional: thanks to him and Bill Freeman for doing this.

# Dosimetry with Copper foil

- Basic idea: both stable isotopes of Cu can be excited to long-lived Zn isotopes that decay via positron emission or electron capture with accompanying gamma rays back to copper.

$$N(t_1,t_2,t_3) = [\Phi a t_1]\sigma(p,n)\frac{N_A \rho f \delta}{A} g\epsilon \frac{(1-\exp(-t_1/\tau))}{(t_1/\tau)}(\exp(-(t_2-t_1)/\tau) - \exp(-(t_3-t_1)/\tau))$$

- Protons on target (what we want) = $[\Phi a t_1]$
- Production cross section (biggest external uncertainty) $\sigma(p,n)$
  - ~420 mb for Cu-63
  - ~700 mb for Cu-65
  - Uncertainty ~ 10-20%
- Target thickness (1.5 mil) $\frac{N_A \rho f \delta}{A}$
  - *f=0.69* for Cu-63
  - *f=0.31* for Cu-65

# Cu dosimetry, cont'd

- Gamma ray intensity $g$
  - 8.2% for 669 KeV Zn-63
  - 6.5% for 961 KeV Zn-63
  - 50.8% for 1115 KeV Zn-65
  - 511 KeV from positron not used.
- Detection efficiency $\epsilon$
  - ~1% for Ge detector from KSU Nuclear Engineering.
  - ~5% for NaI(Tl) detector at KSU physics (still underway).
- Production factor $\frac{(1-\exp(-t_1/\tau))}{(t_1/\tau)}$
- Sampling factor
  - $t_1$=irradiation time
  - $t_2$,$t_3$=start,stop of sampling time $\exp(-(t_2-t_1)/\tau)-\exp(-(t_3-t_1)/\tau)$
  - $\tau$ = 38 min/ln(2) for Zn-63
  - $\tau$ = 244 days/ln(2) for Zn-65

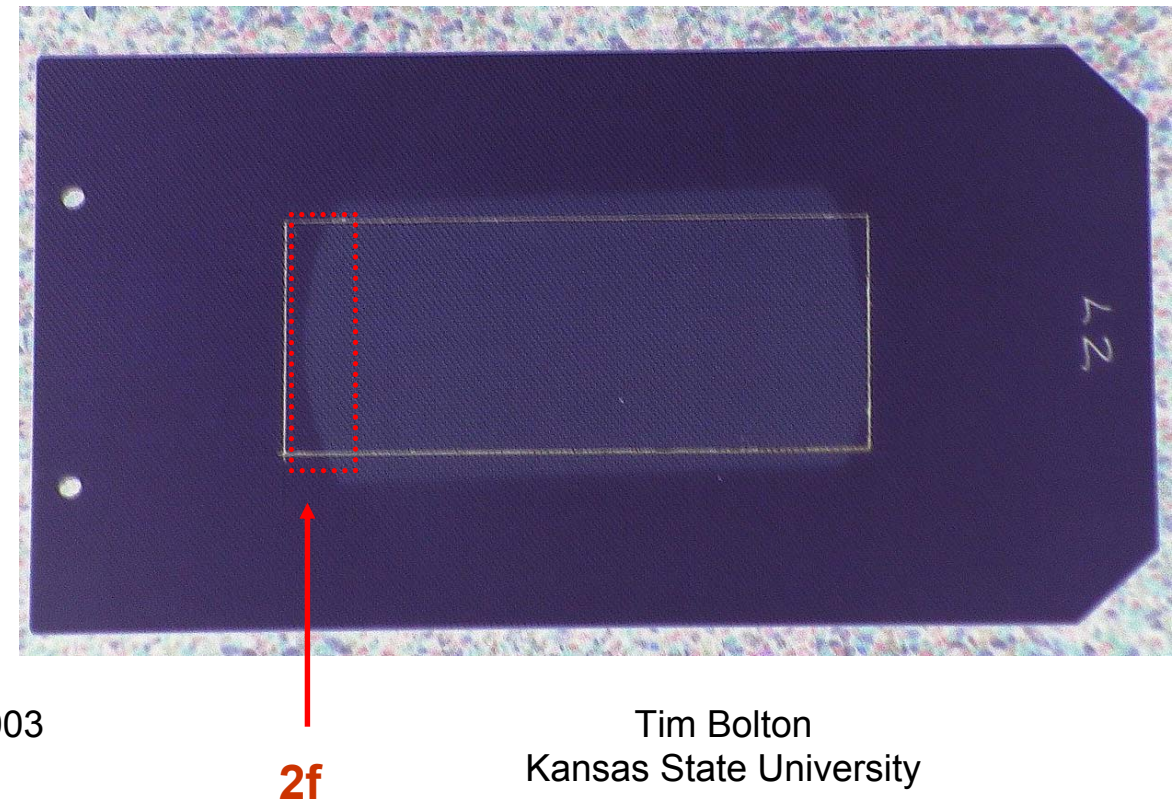
# Results

- After resolving some simple transmission/transcription errors (Cu-65 fraction, irradiation date, target thickness):

| | | activation fluence /direct beam fluence | | | | | |
|---|---|---|---|---|---|---|---|
| foil | sample | 669+961 keV | error | 1115 keV | error | isotope | detector |
| 1 | a | 0.92 | 0.05 | | | Zn-63 | Ge-KSU |
| | b | 1.00 | 0.05 | | | Zn-63 | Ge-KSU |
| | c | 1.04 | 0.04 | | | Zn-63 | Ge-KSU |
| | d | 0.98 | 0.03 | | | Zn-63 | Ge-KSU |
| | e | 1.02 | 0.04 | | | Zn-63 | Ge-KSU |
| | f | 1.01 | 0.05 | | | Zn-63 | Ge-KSU |
| | g | 1.07 | 0.04 | | | Zn-63 | Ge-KSU |
| | h | 1.04 | 0.04 | | | Zn-63 | Ge-KSU |
| 2 | a | | | 1.19 | 0.03 | Zn-65 | Ge-KSU |
| | b | | | 0.86 | 0.02 | Zn-65 | Ge-KSU |
| | c | | | 1.14 | 0.02 | Zn-65 | Ge-KSU |
| | d | | | 1.03 | 0.02 | Zn-65 | Ge-KSU |
| | e | | | 1.06 | 0.02 | Zn-65 | NaI(Tl)-KSU |
| | f | | | 0.53 | 0.02 | Zn-65 | Ge-FNAL |
| | g | | | 0.85 | 0.04 | Zn-65 | Ge-FNAL |
| | h | | | 0.82 | 0.04 | Zn-65 | Ge-FNAL |

# What's wrong with sample 2-f?

- Poor choice:  thin strip cut from near edge of beam sweep (used up much of rest of foil at KSU).
- Test with G10 dummy showed aperature effect.
- Propose to drop it.



# Bottom Line

- Totally independent FNAL check agrees to within <20% of direct flux and KSU activation checks.
- Resolving any remaining discrepancy would take a lot of work.
- No evidence that direct flux is wrong (KSU Lab has been measuring cross sections for longer than FNAL has existed!)
- L2 PRR flux issues resolution
  - Some dumb plotting errors, now fixed.
  - Physics: can't use NIEL scaling to go from 1 MeV neutrons to 10 MeV protons.
  - Consistent with two other groups' observations.