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Title: Measuring Neutron Capture with DANCE

Author(s): A. Couture

Intended for: Capture Gamma Symposium XIV, Guelph, Canada

Los Alamos
NATIONAL LABORATORY
EST. 1943

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The Detector for Advanced Neutron Capture Experiments (DANCE) is a 4-pi BaF2 calorimeter composed of 160 independent crystals. The array located is at the Los Alamos Neutron Science Center (LANSCE). With high efficiency and segmentation coupled to the intense epithermal neutron flux, it is an ideal instrument for study properties of neutron capture, including cross sections, gamma-ray multiplicity distributions, gamma-ray energy distributions, gamma-ray strength functions, and capture:fission ratios on both stable and moderately long-lived isotopes. I will discuss the capabilities for measurements with DANCE, recent results, as well as future additional capabilities.

Measuring Neutron Capture with DANCE

A. Couture

Capture Gamma Symposium XIV
Guelph, Ontario
29 August 2011

Outline

- The Science of Neutron Capture
- DANCE: The Instrument
- Recent Measurements and Efforts at DANCE
- Where Do We Go from Here?

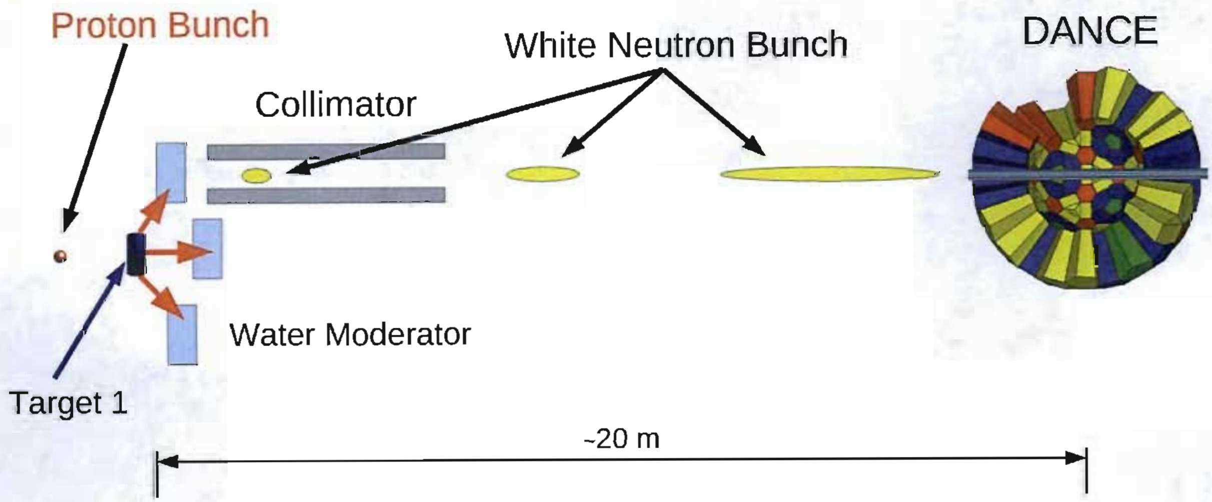
Why Neutron Capture?

- DANCE was built to measure cross sections
  - Important for multiple fields
    - Nuclear Astrophysics (Synthesis of the Heavy Elements)
    - Nuclear Enery
    - Stockpile Stewardship
  - All programs need cross sections from 500 eV < E_n < 500 keV
- Neutron capture is a probe of other properties of nuclei
  - Statistical properties of nuclei
    - Spins, level densities, etc.
  - Gamma-ray Strength Function

The 800 MeV linac at LANSCE produces neutrons via spallation on Tungsten

Lujan Center

Time of Flight with DANCE at the Lujan Center



$E_p = 800$ MeV $\nu_p = 20$ Hz $10\ \text{meV} < E_n < 500\ \text{keV}$

$\varphi_n = 3 \cdot 10^5$ n/s/cm^2/decade

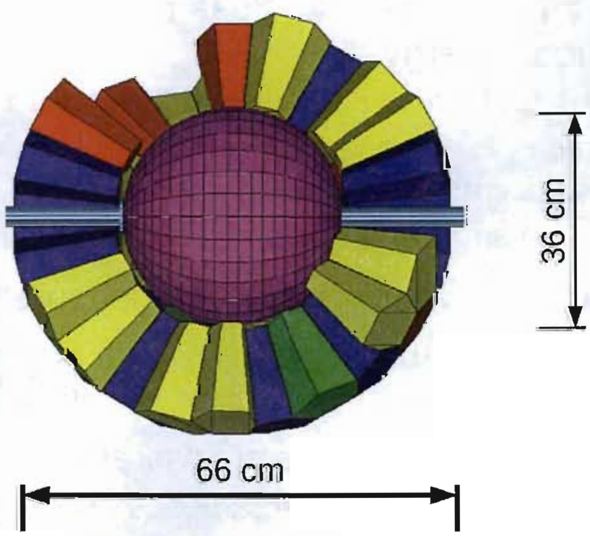
The Detector for Advanced Neutron Capture Experiments (DANCE)

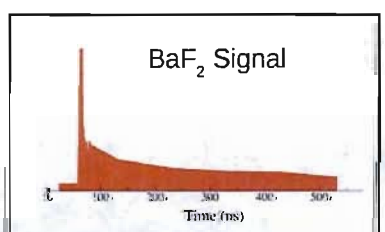
160 BaF_2 Scintillators

4 Detector Shapes each covering the same solid angle

$P_{FL} \approx 90$ %

$P_{casc} \approx 98$ %

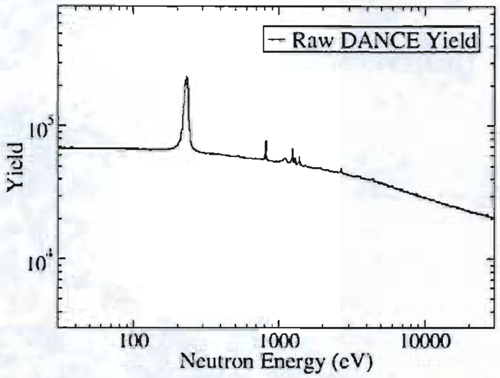




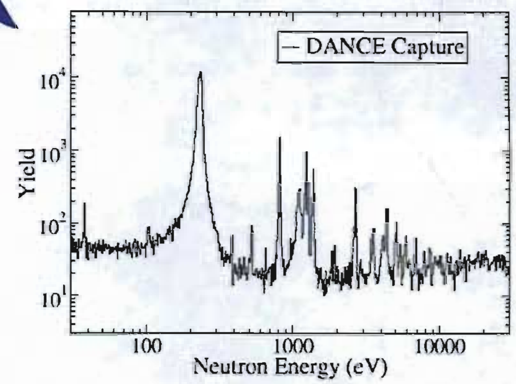
^6LiH Shell Surrounds Sample (6 cm)

For details see: Heil *et al*, NIM A 459 (2001) 229-246

Effect of DANCE Selection on Q-Value and Multiplicity



Mult and Q Cuts



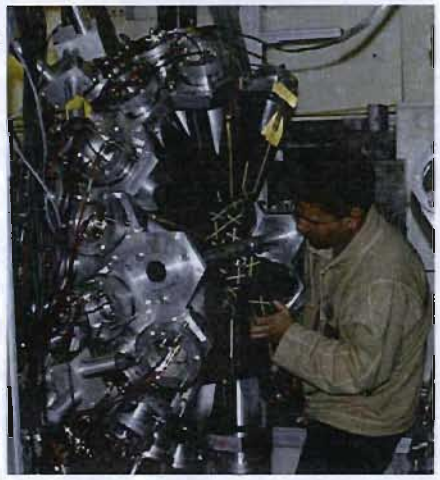
- All measurements are from a 50 mg sample of ^{203}Tl.
- No subtraction of elastic background has been done.
- While the losses in efficiency are large, the enhanced S/N is worth it.

Why are Calorimetric Detectors "Needed" for Radioactive Samples?

- Calorimetric detectors can distinguish capture from decay based on total energy.
  - High efficiency allows small samples.
  - Isotopically mixed samples can be used if the isotopes have sufficiently different Q-value
  - High segmentation limits individual crystal count rates.
- Traditional neutron capture measurements were done with C_6D_6 liquid scintillators.
  - C_6D_6 has very low neutron sensitivity, but no energy information.
  - High purity samples are typically required.
  - Gamma rays from a radioactive sample could not be distinguished from neutron capture.
  - C_6D_6 has very low efficiency, typically requiring gram samples.

Recent Measurements at DANCE

- Cross section measurements on actinides
  - Serves nuclear energy and stockpile stewardship programs
  - PPAC allows capture:fission measurements
- Studies for the weak *s*-process
- Resonance spin determinations
- Gamma-ray strength function studies
- Fission gamma ray spectrum on actinides



DANCE PPAC

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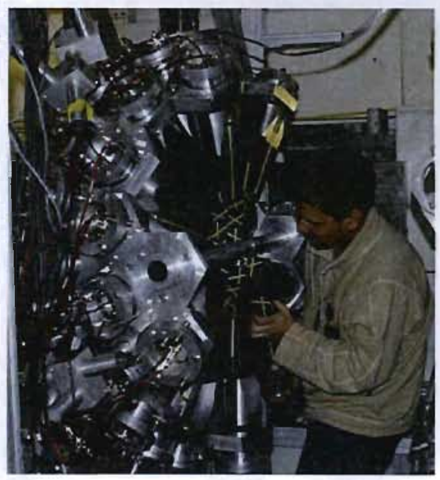
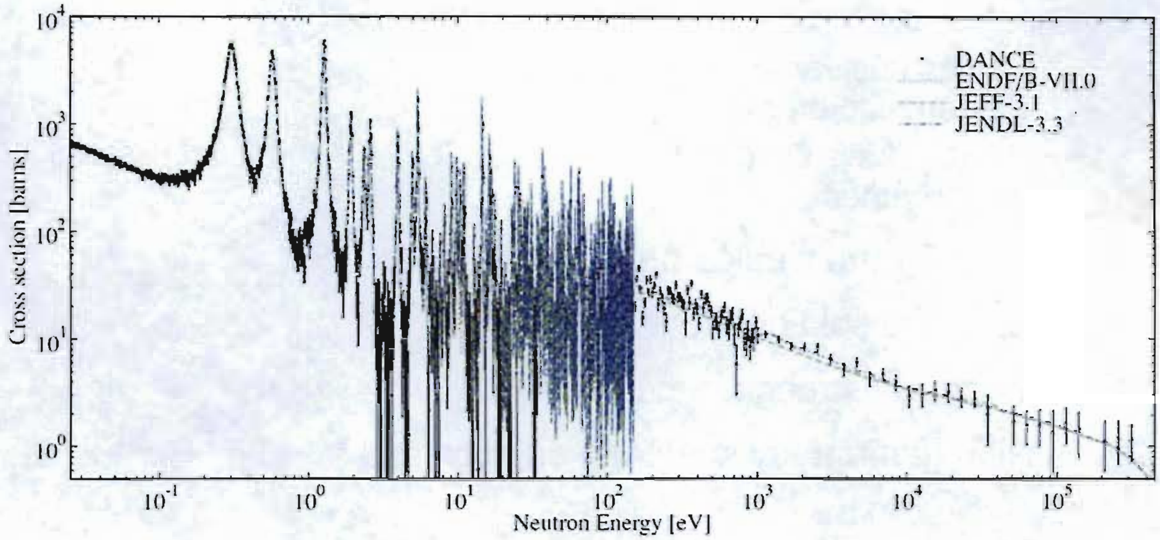
See Talk by A. Chyzh (Next)

See Talk by J. Ullmann (Thursday)



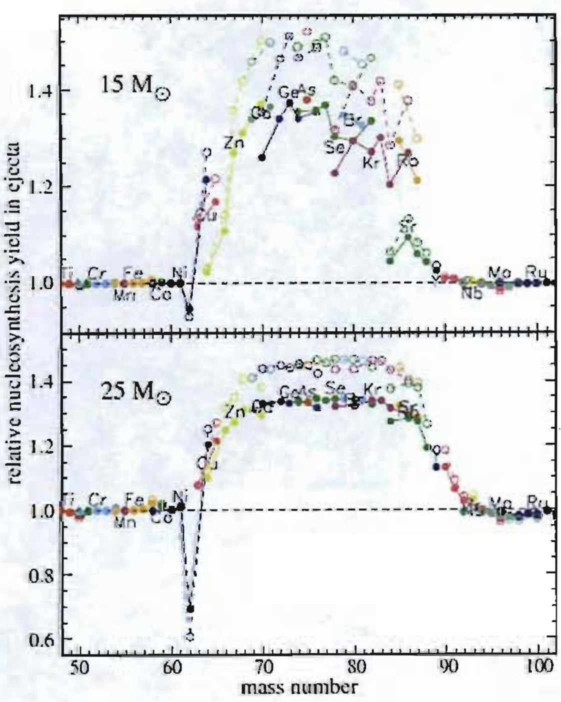
DANCE PPAC

Cross Section Measurement of $^{241}Am(n,\gamma)$



Jandel *et al. Phys. Rev. C* **78** 034609 (2008)

Measurements for the weak *s* process



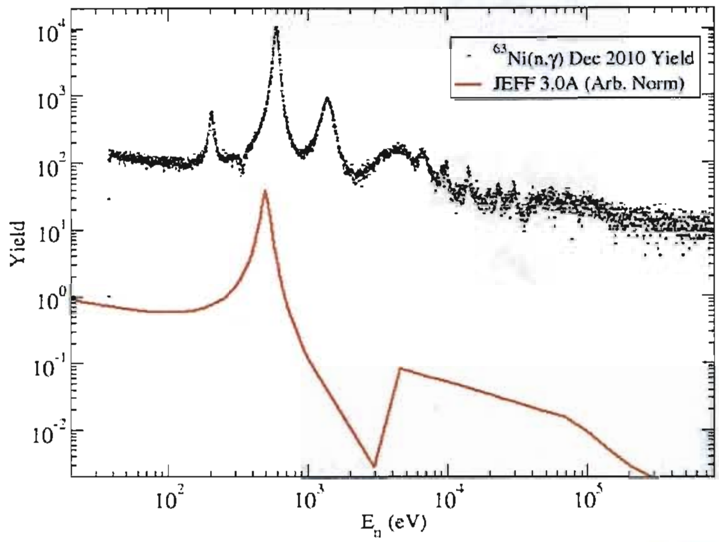
- New activation measurement on ^{62}Ni adjusted abundances 30 mass units down-stream
- Cross sections for the weak *s* process are
  - small
  - difficult to calculate
  - likely non-statistical
  - Individual resonances and DC likely play a role
  - Impact propogates
- Multiple measurement techniques may be needed to understand the weak *s* process

Nassar *et al.* PRL 2005

December 2010 DANCE Measurement on ^{63}Ni

- ^{63}Ni controls the abundance of ^{63}Cu, setting the local production scale
- Resonances sit in the regime of astrophysical interest
- This first measurement was performed with a sample 11% enriched in ^{63}Ni

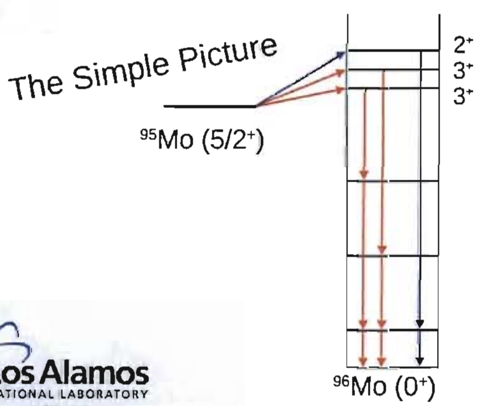
PRELIMINARY Yield Data

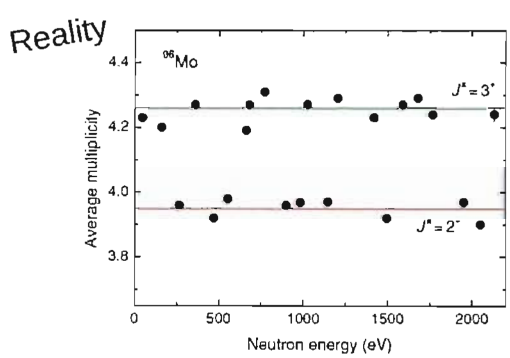


Ph. D. project of M. Weigand, Univ. of Frankfurt

Using DANCE for Spin Assignments

- Neutron capture typically proceeds via s-wave (*l=0*) capture
  - This allows capture states of $J^{\pi} \pm 1/2$
  - ΔL from capture state to ground state is typically 2-3
- Typical Q-values are 5-8 MeV
  - In a simple picture, the number of gamma rays is just the difference in spin between the populate state and the ground state

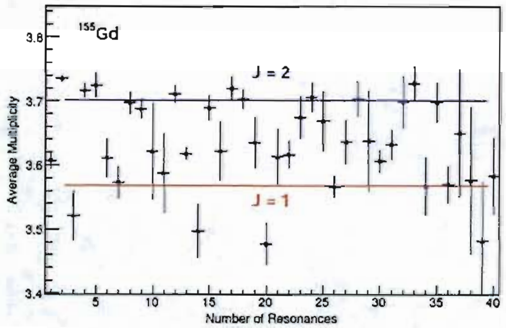


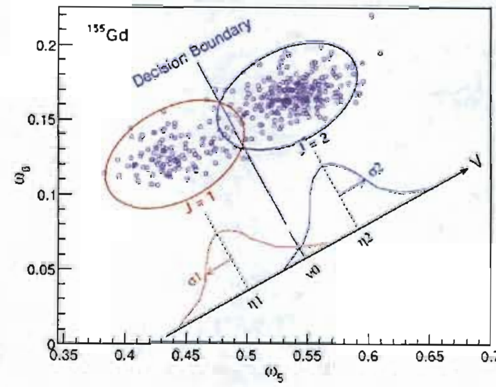


Sheets *et al. Phys. Rev. C* **76** 064317 (2007)

And then Life Gets More Complicated

- Average multiplicity techniques work for nuclei with relatively low level densities (like ^{96}Mo)





B. Baramsai, Ph. D. Thesis 2010 (NC State)

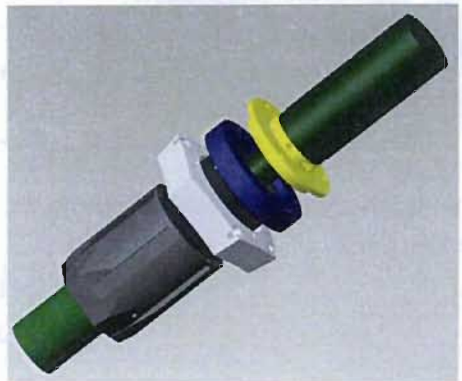
- Even when *average* multiplicity is insufficient, detailed information can still be extracted from the complete multiplicity distribution
  - Pattern Recognition Methods even give confidence levels of spin assignments

Future Developments for DANCE

- Upgrading DAQ hardware and software
  - Slight improvements to speed
  - Mainly maintenance
- Continued development of PPAC for measurements on fissile isotopes
  - Includes possibility of multi-foil PPAC for larger sample masses
- High resolution gamma detectors
  - HPGe and $LaBr_3$

Adding HPGe Detectors to DANCE

- Two HPGe have been purchased to replace DANCE crystals
- This should have minimal impact on DANCE efficiency
- Significantly enhanced resolution (with low efficiency) for identifying low-lying transitions
- May enhance measurements with large scattering background
- Should be installed and tested this winter



Conclusions

- TOF+Calorimetry are powerful tools for studying capture
- DANCE is actively pursuing cross section measurements on stable and unstable isotopes
- DANCE has proven very successful in measuring spin and multiplicity distributions for isolated resonances
- Upgrades are in the works which should enhance the capabilities and science studied with DANCE
- Proposals are evaluated annually by a PAC
  - Outside proposals and science are welcome

Collaborators

Los Alamos National Lab
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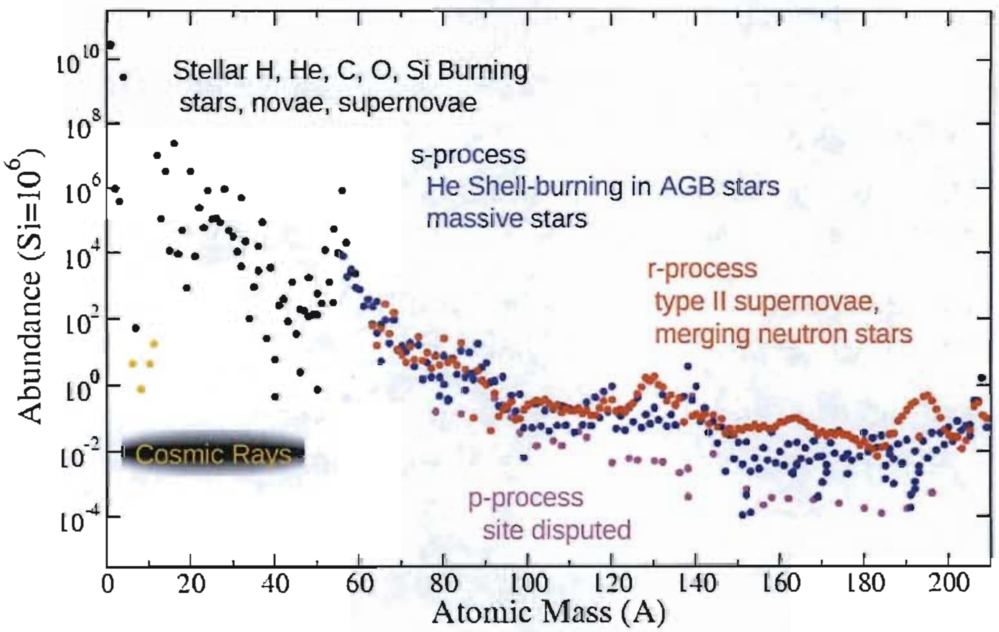
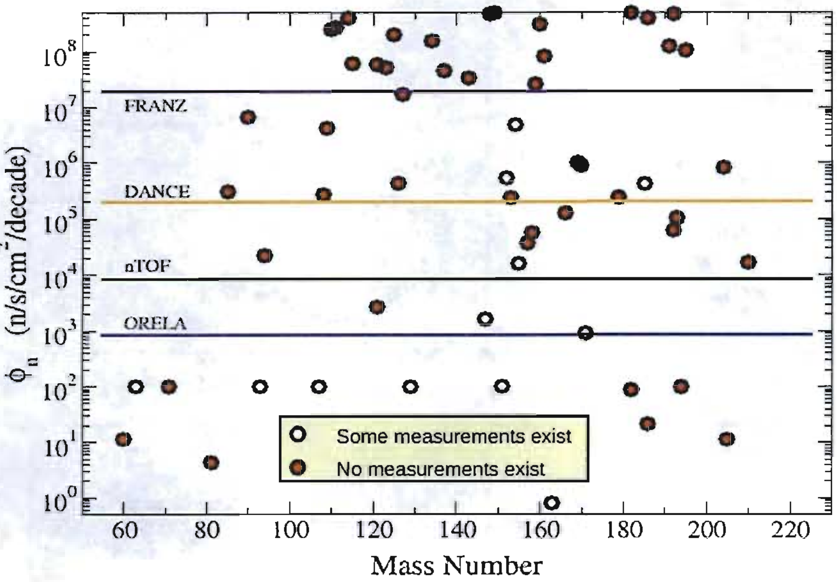
Isotopic Abundances Allow the Identification of Astrophysical Sites and Processes



Abundances and Attribution from Anders & Grevesse, 1989
and Käppeler, Beer, and Wisshak, 1989

Estimated Neutron Fluxes Required for TOF Measurements on Branch Point Isotopes



Each branch-point illustrates how the s-process operates in stars of different mass, age and metallicity

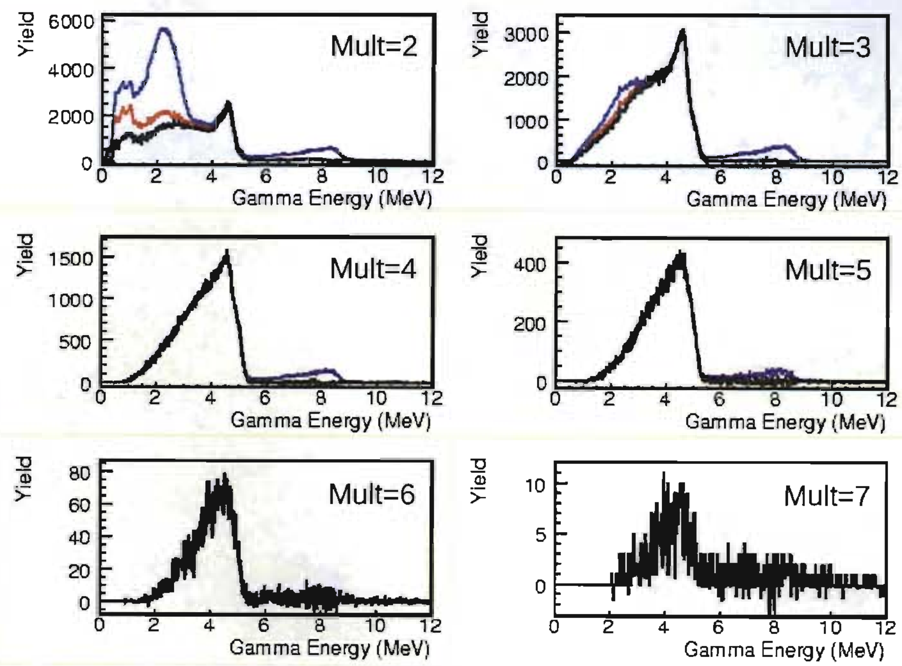
Only with measurements on many isotopes will we understand the temperature and densities in the many different s-process scenarios

A. Couture and R. Reifarth, "Direct Measurements of Neutron Capture on Radioactive Isotopes", At. Data and Nucl. Data Tables, **93** (2007) 803.

Total Gamma Energy vs. Multiplicity
(E_n = 1-10 eV)

^{242}Pu Raw
^{242}Pu less Ambient
^{242}Pu Final

Multiplicities used in cross-section determination



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