Prospects for neutron capture measurements on key unstable isotopes of astrophysical relevance at the CERN n_TOF facility

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Introduction and motivation

Neutron capture cross-sections are key in the study of astrophysical phenomena:

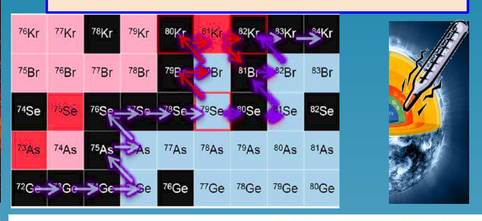
- Slow neutron capture **(s-) process [1]**
  - ~½ abundances A>56
  - AGB & Massive stars
- Intermediate neutron capture **(i)-process [2]**
  - Explains composition CEMP stars
  - Higher neutron densities →+ exotic nuclei

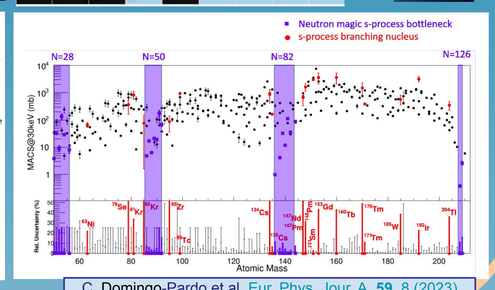
R. Reifarth et al., *EPJ WOC*, **146**,01003 (2017)

Our goal: measure (n,) of nuclei involved in the s-process (& i-process)

I. Dillmann et al., *Eur. Phys. J. A* **59**, 105 (2023).

Key cases: branching points [3]
^{A}Z(n,γ) competes with β decay
(n,γ) cross sections + isotopic ratios→
conditions stellar environment



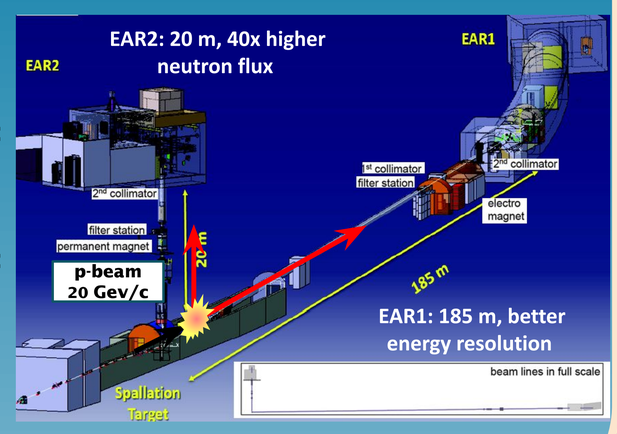


C. Domingo-Pardo et al. Eur. Phys. Jour. A, **59**, 8 (2023)

The n_TOF facility @ CERN

- Neutrons generated by spallation in Pb with a 7ns pulsed beam of 20 GeV/c protons
- Neutron flux from thermal to GeV.

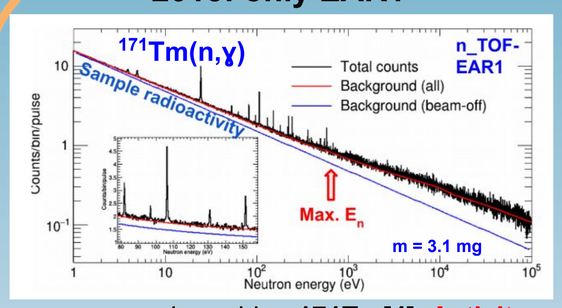
- **Experimental Area 1:**
  - TOF @ 185m forward
  - Very high E_n-resolution
- **Experimental Area 2:**
  - TOF @ 20m upwards
  - Higher neutron flux
- **NEAR**
  - **NEW** activation station more details below!)



NEAR: 3m, activation

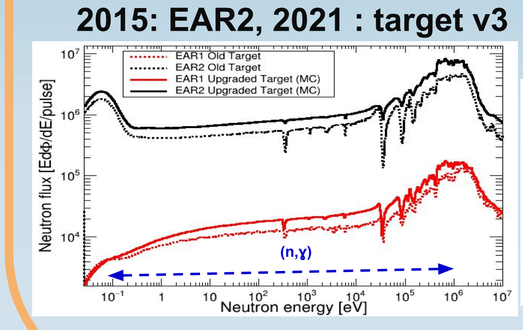
Recent progresses & challenges

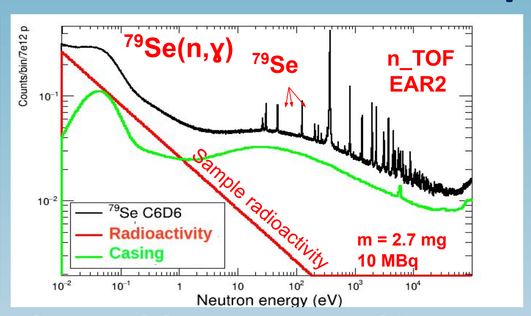
<2015: only EAR1



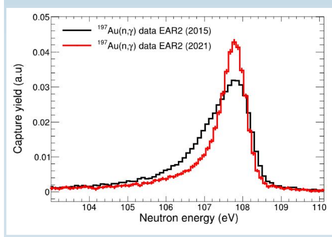
s-process branching **171Tm[4]**: **Activity background** was the main limiting factor

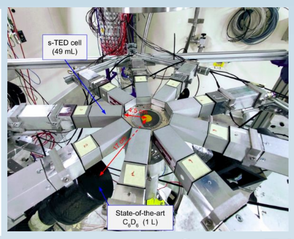
2015: EAR2, 2021 : target v3





Successful measurement of 2 more unstable s-process isotopes: **79Se[8], 94Nb[9]**





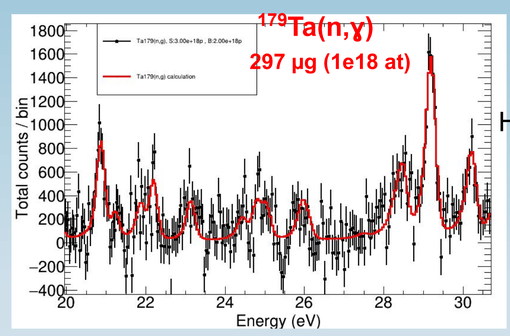
Upgraded EAR2 400x instantaneous n-flux vs EAR1,
Improved energy resolution **[5]**, new segmented (s-)TED detectors for high count rates **[6,7]**

Towards more unstable s-process branching points: → challenges

1. TOF requires mass >= 5e17-1e18 atoms (EAR2)
2. Mass/Activity limited by **radiation hazard**
3. **Low SBR & high activity background**

→ Many cases not accessible via TOF or not in the range of astrophysical interest

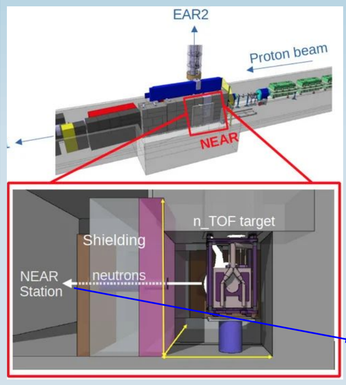
Possible solution: Activation

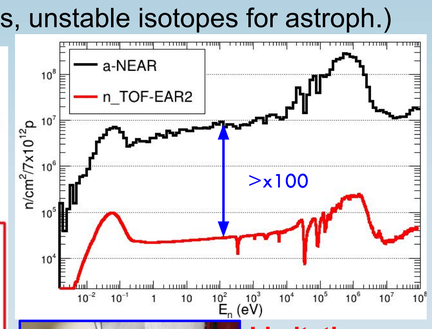


Sensitivity study [10] on s-process branchings:
Most cases: 5e17-1e18 atoms needed

2021: n_TOF NEAR[11]

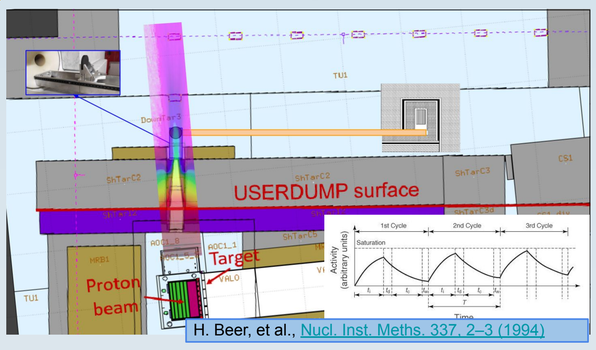
Irradiation station at 3 m from n-source for activations
Higher sensitivity (lower mass, unstable isotopes for astroph.)





Limitation: Activated nuclei's $T_{1/2}$>h

CYCLING @ NEAR [12]

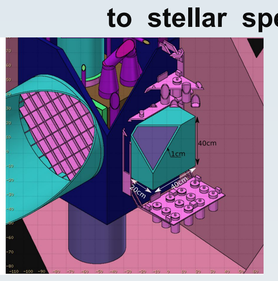


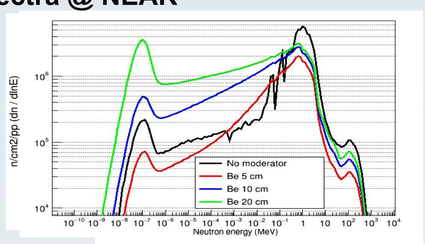
H. Beer, et al., Nucl. Inst. Meths. 337, 2–3 (1994)

Goal: Access short lived products (s, min)
Concept **validation at HisPANOS-CNA**

SCAN IT TO SEE AN ANIMATION OF THE CYCLIC ACTIVATION

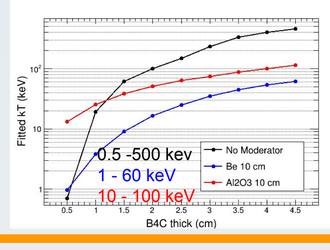
Moderator for improved matching to stellar spectra @ NEAR





Goal: MACS ratio (vs Au reference) closer to SACS ratio

SCAN IT TO SEE THE SPECTRA AT VARIOUS STELLAR TEMP.



Future prospects

Current spallation target

Before LS4

TOF Measurements on lower mass unstable (s-process):

- Improve detection efficiency & sensitivity (larger arrays, solid d-stil scintillators, …)
- Improve signal-to-background: New shieldings and collimator for EAR2
- Modification of EAR2 with walls and ceiling further from setup
- Beamline looking to moderator → less background from high energy neutrons
- New beamlines: 10 m flightpath, backwards,
- Higher intensity per pulse & higher rep. rate with similar t-resolution.

Beyond LS4

New (V4) spallation target

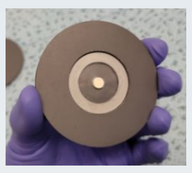
Activations on short-lived isotopes (s/i-process)

- Installation of NEAR moderator (@target)→ Closer to "stellar".
- Cycling: Rabbit system NEAR-ISR and (if feasible) decay station at NEAR.
- Activations inside the target shielding (factor x100 flux) → Rabbit system.
- Strengthen Synergy ISOLDE-NEAR
- Average intensity x10 higher with worse t-resol (suitable only for NEAR).
- New n_ACT with rabbit @ BDF Facility: 1000 x flux a-NEAR

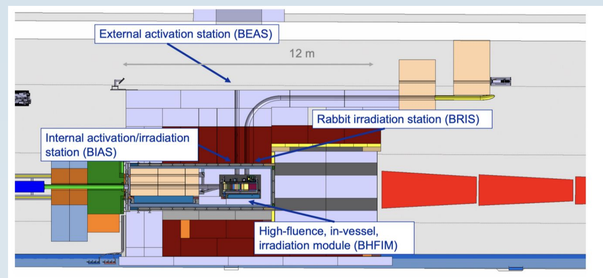
n_TOF - ISOLDE /MEDICIS Synergy

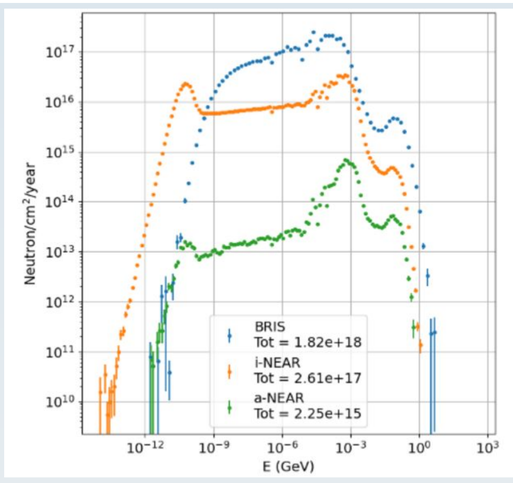
Production of targets of **unstable isotopes for (n,γ) at n_TOF**

First case: **^{135}Cs [13]**



Plans for a new facility: n_ACT @ BDF [14]





- Located at the Beam Dump facility (BDF) at CERN
- **Very high flux (a-NEAR x1000)** station for neutron activations with rabbit system

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Acknowledgments

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