IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

MINISTERIO DE CIENCIA E INNOVACIÓN

Financiado por la Unión Europea NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

AGENCIA ESTATAL DE INVESTIGACIÓN

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Production of a ^{135}Cs sample at ISOLDE for (n,ɣ) activation measurements at n_TOF-NEAR

J. Lerendegui-Marco, S. Carollo, C. Domingo-Pardo, F. Recchia, U. Köster,
V. Babiano, M. Bacak, J. Balibrea-Correa, A. Casanovas, F. Calviño, S. Cristallo, C. Guerrero, C. Lederer,
C. Massimi, P. Milazzo, N. Patronis, S. Rothe, A. Tarifeño-Saldivia,E. Stamati, S. Stegemann, D. Vescovi

UNIVERSITÀ DEGLI STUDI DI PADOVA

71st Meeting of the INTC, 8th-9th November 2022

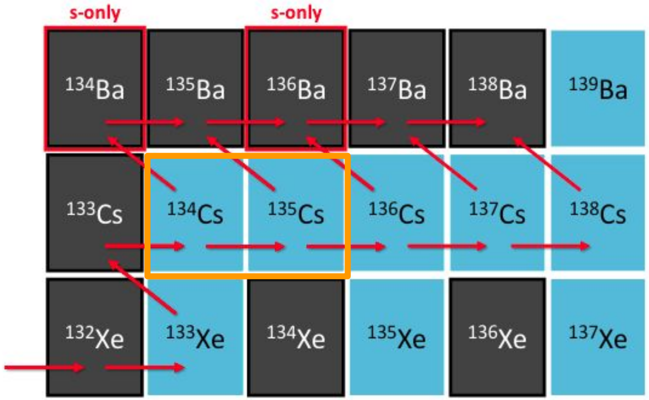
nTOF

ISOLDE

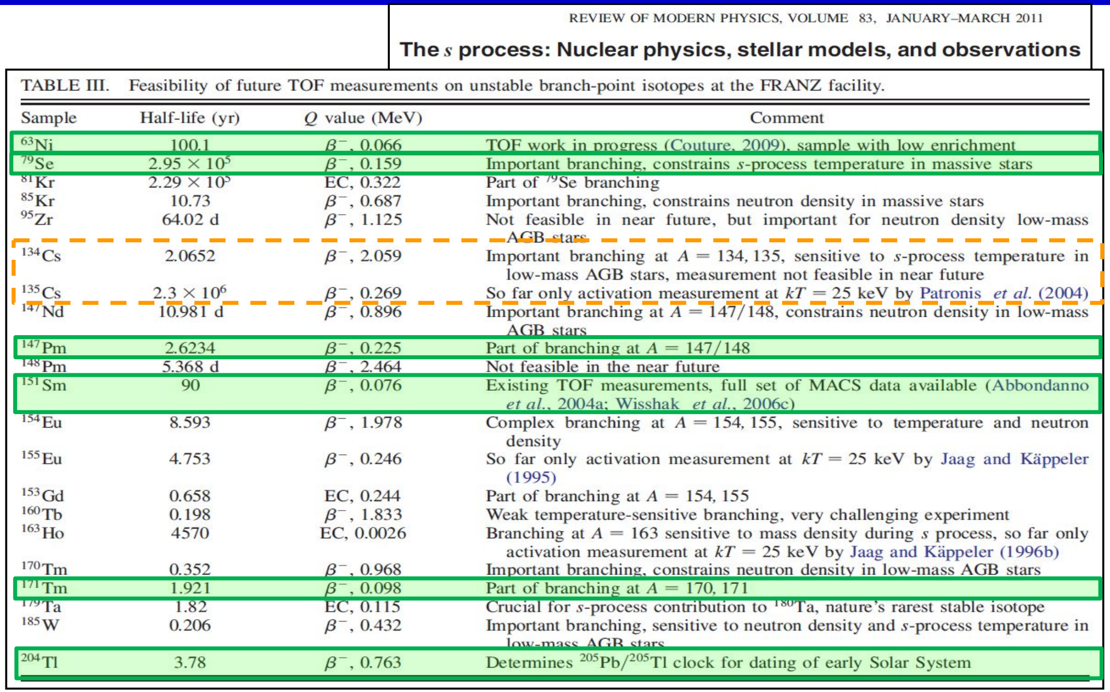
Outline

- **Motivation: ^{135}Cs(n,ɣ) cross section for nucleosynthesis & transmutation**
- ^{135}Cs(n,ɣ) activation measurement at NEAR
- ^{135}Cs sample production at ISOLDE
- Summary and outlook

Motivation: s-process



S-process branchings at ^{134}Cs and ^{135}Cs: Fix the abundance ratio of the s-only **^{134,136}Ba.** Accurately measured from SiC from presolar grains of AGB origin



REVIEW OF MODERN PHYSICS, VOLUME 83, JANUARY–MARCH 2011

The *s* process: Nuclear physics, stellar models, and observations

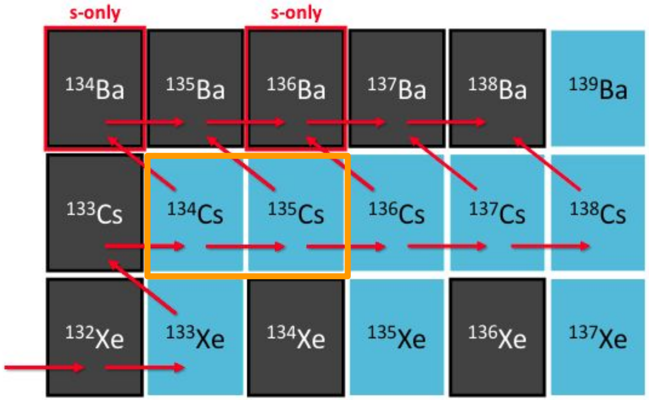
TABLE III. Feasibility of future TOF measurements on unstable branch-point isotopes at the FRANZ facility.

Sample	Half-life (yr)	Q value (MeV)	Comment
^{63}Ni	100.1	β^-, 0.066	TOF work in progress (Couture, 2009), sample with low enrichment
^{79}Se	2.95×10^5	β^-, 0.159	Important branching, constrains *s*-process temperature in massive stars
^{81}Kr	2.29×10^5	EC, 0.322	Part of ^{79}Se branching
^{85}Kr	10.73	β^-, 0.687	Important branching, constrains neutron density in massive stars
^{95}Zr	64.02 d	β^-, 1.125	Not feasible in near future, but important for neutron density low-mass AGB stars
^{134}Cs	2.0652	β^-, 2.059	Important branching at $A = 134, 135$, sensitive to *s*-process temperature in low-mass AGB stars, measurement not feasible in near future
^{135}Cs	2.3×10^6	β^-, 0.269	So far only activation measurement at $kT = 25$ keV by Patronis *et al.* (2004)
^{147}Nd	10.981 d	β^-, 0.896	Important branching at $A = 147/148$, constrains neutron density in low-mass AGB stars
^{147}Pm	2.6234	β^-, 0.225	Part of branching at $A = 147/148$
^{148}Pm	5.368 d	β^-, 2.464	Not feasible in the near future
^{151}Sm	90	β^-, 0.076	Existing TOF measurements, full set of MACS data available (Abbondanno *et al.*, 2004a; Wisshak *et al.*, 2006c)
^{154}Eu	8.593	β^-, 1.978	Complex branching at $A = 154, 155$, sensitive to temperature and neutron density
^{155}Eu	4.753	β^-, 0.246	So far only activation measurement at $kT = 25$ keV by Jaag and Käppeler (1995)
^{153}Gd	0.658	EC, 0.244	Part of branching at $A = 154, 155$
^{160}Tb	0.198	β^-, 1.833	Weak temperature-sensitive branching, very challenging experiment
^{163}Ho	4570	EC, 0.0026	Branching at $A = 163$ sensitive to mass density during *s* process, so far only activation measurement at $kT = 25$ keV by Jaag and Käppeler (1996b)
^{170}Tm	0.352	β^-, 0.968	Important branching, constrains neutron density in low-mass AGB stars
^{171}Tm	1.921	β^-, 0.098	Part of branching at $A = 170, 171$
^{179}Ta	1.82	EC, 0.115	Crucial for *s*-process contribution to ^{180}Ta, nature's rarest stable isotope
^{185}W	0.206	β^-, 0.432	Important branching, sensitive to neutron density and *s*-process temperature in low-mass AGB stars
^{204}Tl	3.78	β^-, 0.763	Determines ^{205}Pb/^{205}Tl clock for dating of early Solar System

^{134,135}Cs

→ Among the **21 key s-nuclei** listed in Kaeppeler, *Rev. Mod. Phys* 83, 157 (2011)

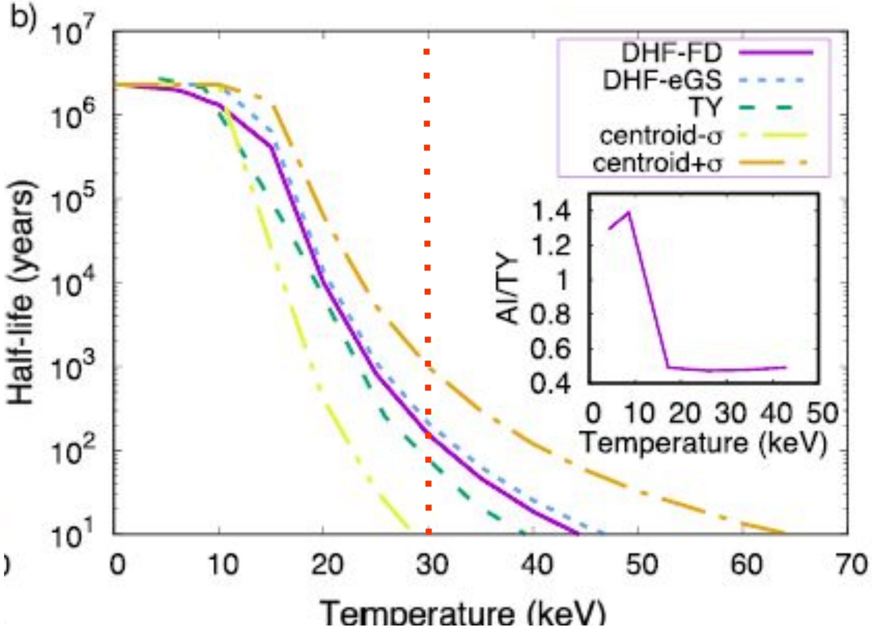
Motivation: s-process



S-process branchings at ^{134}Cs and ^{135}Cs: Fix the abundance ratio of the s-only **^{134,136}Ba.** Accurately measured from SiC from presolar grains of AGB origin

Palmerini et al. (2021).: ***Ba isotopic ratios*** *sensitive to the **(n,γ) CS of ^{134}Cs and ^{135}Cs** + **Temperature dependence** of the β−decay rates*

Accurate (n,g) cross section → Stellar thermometer



Taioli et al. (2022) : **Half-life of ^{135}Cs** reduced to **few hundred years** under TPs conditions

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Motivation: transmutation of LLFPs

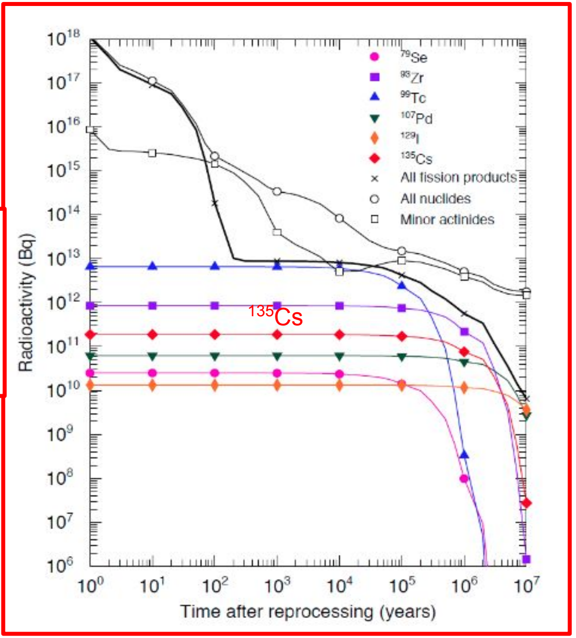
nTOF

^{135}Cs (2.3×10^6 y): among LLFPs with largest contribution to long-term radiotoxicity

Article | Open Access | Published: 24 October 2017

Method to Reduce Long-lived Fission Products by Nuclear Transmutations with Fast Spectrum Reactors

Satoshi Chiba, Toshio Wakabayashi, Yoshiaki Tachi, Naoyuki Takaki, Atsunori Terashima, Shin Okumura & Tadashi Yoshida



$$^{79}\mathrm{Se}(\mathrm{n},\gamma)^{80}\mathrm{Se}$$

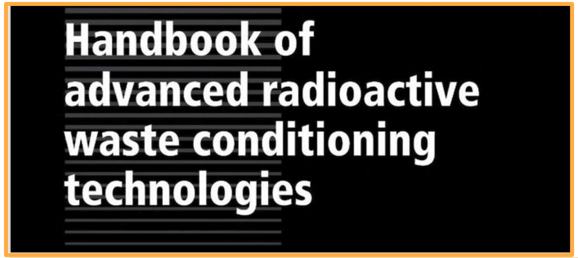
$$^{93}\mathrm{Zr}(\mathrm{n},\gamma)^{94}\mathrm{ZR}$$

$$^{99}\mathrm{Tc}(\mathrm{n},\gamma)^{100}\mathrm{Tc}\xrightarrow{T_{1/2}=15.46\ s}{}^{100}\mathrm{Ru}$$

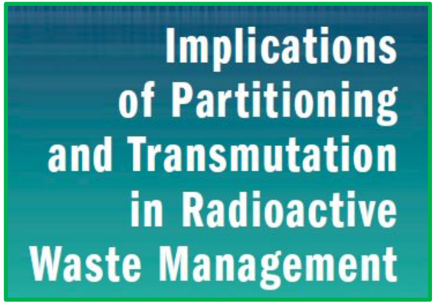
$$^{107}\mathrm{Pd}\,(\mathrm{n},\gamma)^{108}\mathrm{Pd}$$

$$^{129}\mathrm{I}(\mathrm{n},\gamma)^{130}\mathrm{I}\xrightarrow{T_{1/2}=12.36\ h}{}^{130}\mathrm{Xe}$$

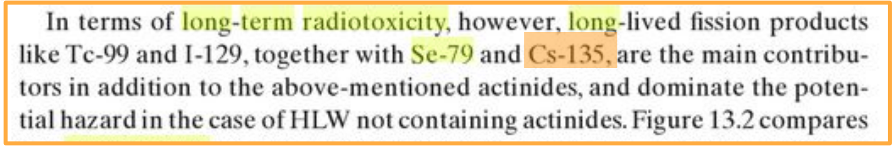
$$^{135}\mathrm{Cs}\,(\mathrm{n},\gamma)^{136}\mathrm{Cs}\xrightarrow{T_{1/2}=13.16\ d}{}^{136}\mathrm{Ba}.$$



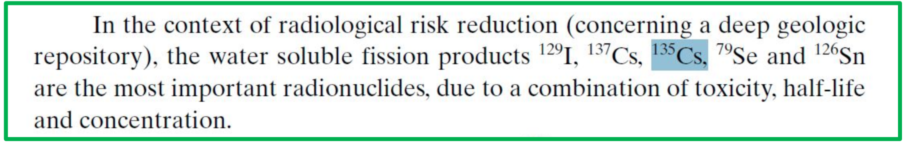
Handbook of advanced radioactive waste conditioning technologies



Implications of Partitioning and Transmutation in Radioactive Waste Management



In terms of long-term radiotoxicity, however, long-lived fission products like Tc-99 and I-129, together with Se-79 and Cs-135, are the main contributors in addition to the above-mentioned actinides, and dominate the potential hazard in the case of HLW not containing actinides. Figure 13.2 compares



In the context of radiological risk reduction (concerning a deep geologic repository), the water soluble fission products ^{129}I, ^{137}Cs, ^{135}Cs, ^{79}Se and ^{126}Sn are the most important radionuclides, due to a combination of toxicity, half-life and concentration.

Motivation: transmutation of LLFPs

^{135}Cs (2.3×10^{6} y): among LLFPs with largest contribution to long-term radiotoxicity

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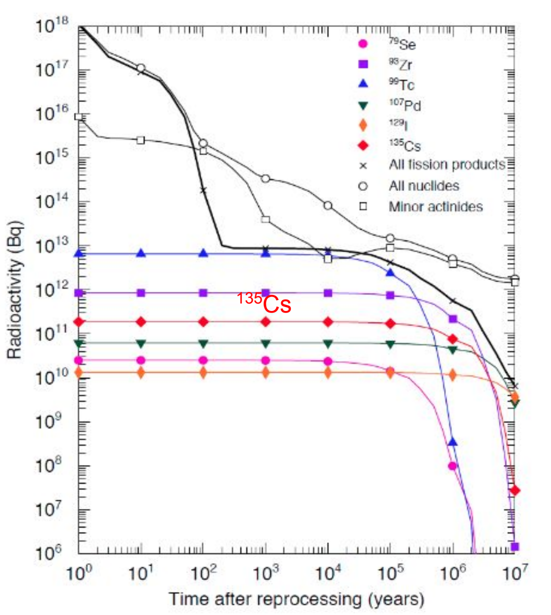

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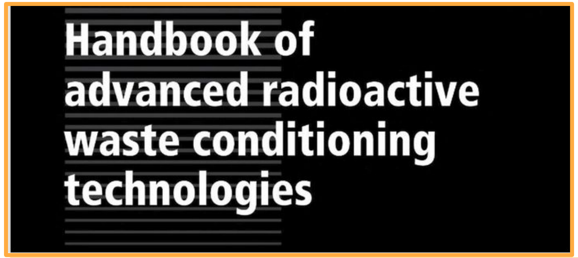
(n,g) CS: fast energy range



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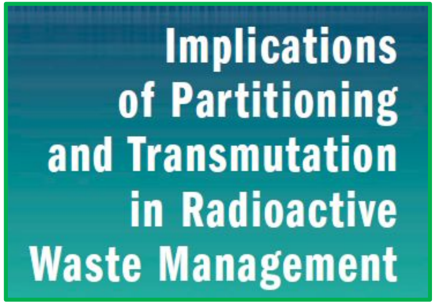

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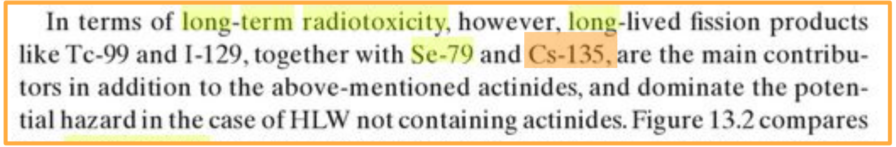

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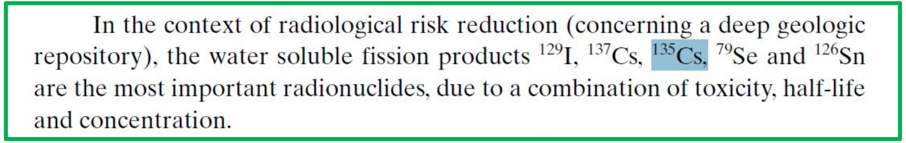

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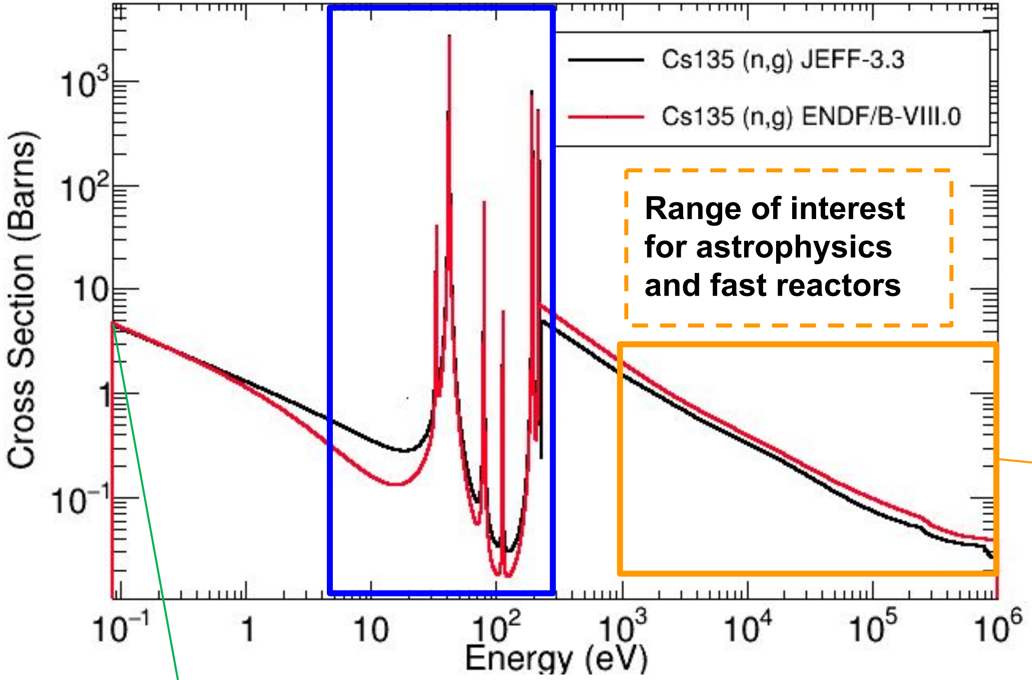
^{135}Cs(n,γ): Status of the data

RRR: 6 resonances from (n,tot)
(V.A.Anufriev 1987, not in EXFOR)

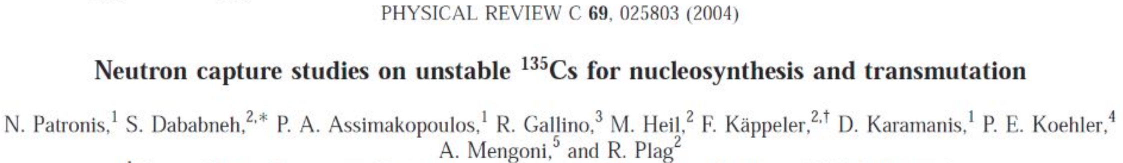


Range of interest for astrophysics and fast reactors

(n,g) →MACS via activation

- 2 Previous measurement at FZK
- Only 2 energies: **@ 30 and 500keV:**
- Corrections for the thermal contribution

Sugarma (1949), Baerg (1958), Katoh (1997) (n,g) @ thermal


PHYSICAL REVIEW C **69**, 025803 (2004)

Neutron capture studies on unstable ^{135}Cs for nucleosynthesis and transmutation

N. Patronis,[1] S. Dababneh,[2,*] P. A. Assimakopoulos,[1] R. Gallino,[3] M. Heil,[2] F. Käppeler,[2,†] D. Karamanis,[1] P. E. Koehler,[4] A. Mengoni,[5] and R. Plag[2]

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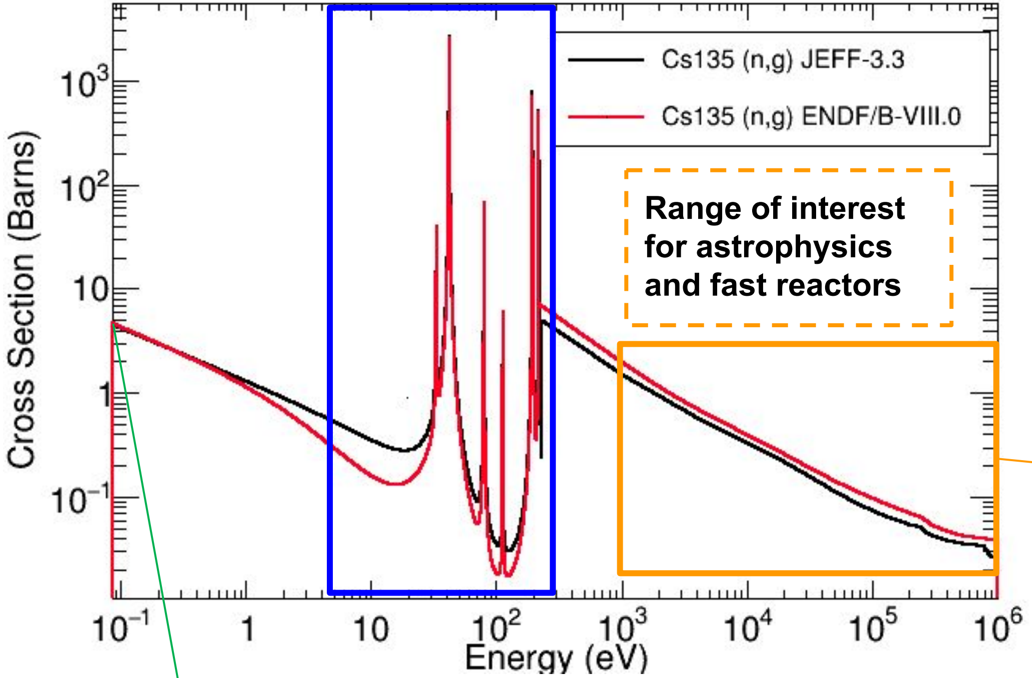

Range of interest for astrophysics and fast reactors

Sugarma (1949), Baerg (1958), Katoh (1997) (n,g) @ thermal

(n,g) via activation at NEAR:

- Capability to tune the energy spectrum
- *MACS* in a wider range (1 keV-1MeV) of interest for astrophysics & fast reactors

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- Only 2 energies: **@ 30 and 500keV:**
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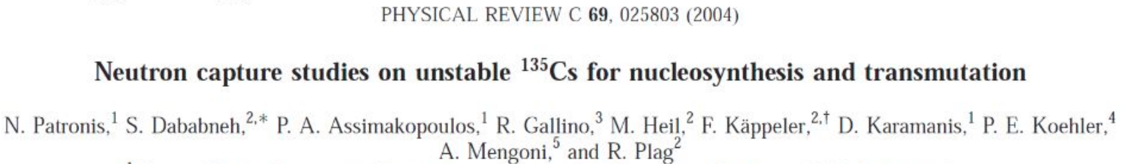

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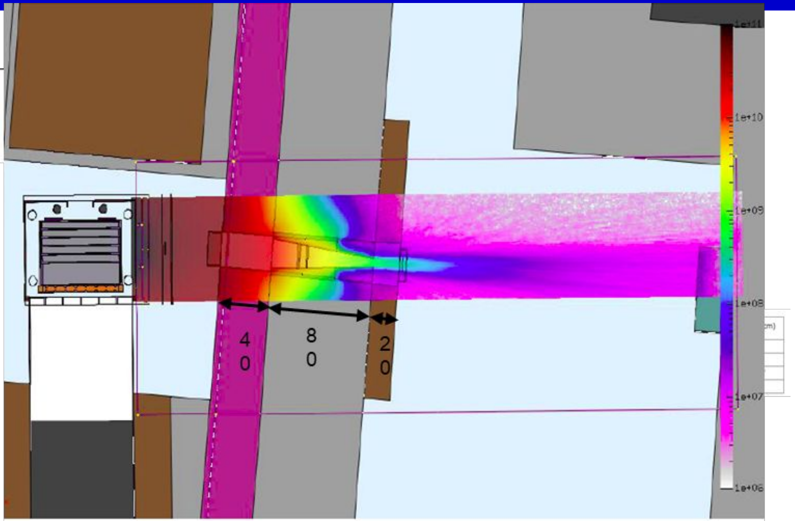
- Motivation: ^{135}Cs(n,ɣ) cross section for nucleosynthesis and transmutation
- **^{135}Cs(n,ɣ) activation measurement at NEAR**
- ^{135}Cs sample production at ISOLDE
- Summary and outlook

^{135}Cs(n,γ) at NEAR + GEAR

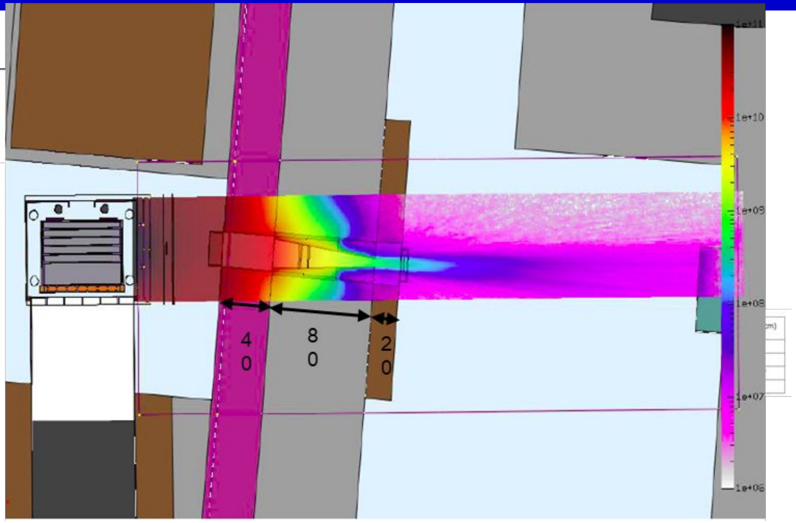


Physics at the NEAR:

- High flux (x~100 EAR2 outside the collimator)
- Activation measurements
- Small mass
- Unstable isotopes

e.g. s-process branchings not accessible via TOF

^{135}Cs(n,γ) at NEAR + GEAR



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- Small mass
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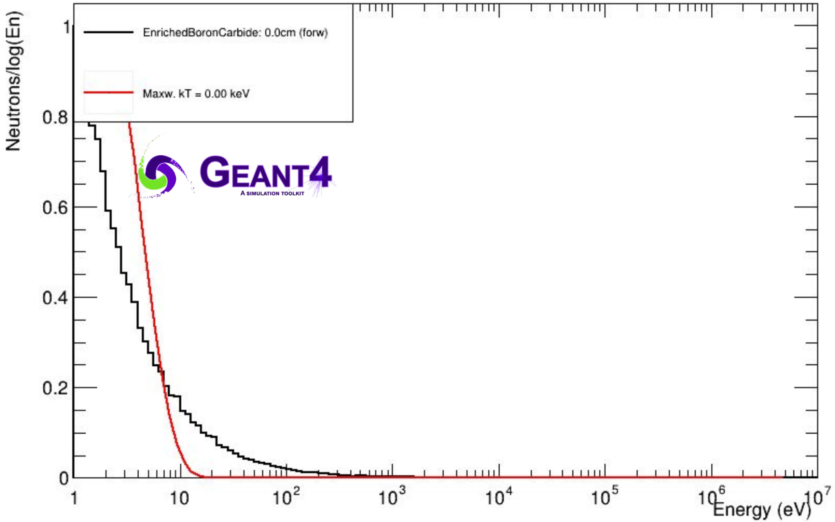
e.g. s-process branchings not accessible via TOF

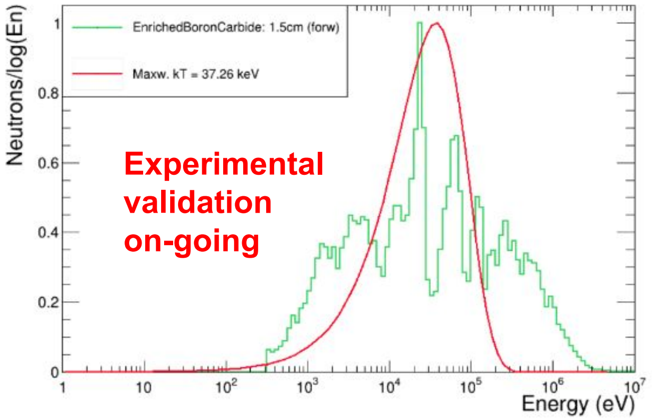
Neutron spectra + filter (B_4C, …) after the collimator exit:

- Measure SACS @ various stellar temperatures from 0.1 to several hundreds of keV.
- E. Stamati et al.,CERN-INTC-2022-008; INTC-P-623 (2022): benchmark with long-lived (n,γ) products



^{135}Cs(n,ɣ) at NEAR: minimum ^{135}Cs mass?

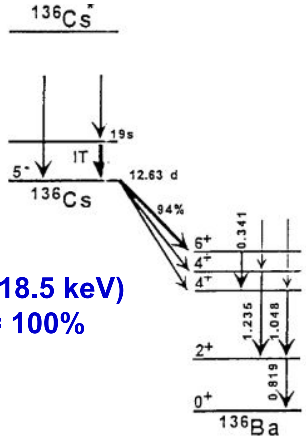
Flux: FLUKA Simulations up to marble wall + Geant4 (95% Enriched B_4C)



Experimental validation on-going

igure 3: Simulated neutron flux with enriched B_4C filter 1.5 cm thick (normalized).

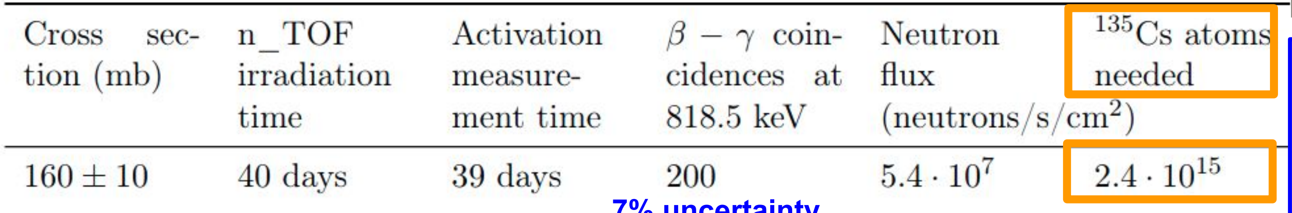
Irradiation time:
3 x $T_{1/2}$ ^{136}Cs (13 d)



Ig (818.5 keV) = 100%

Figure 4: Decay scheme of ^{136}Cs.

GEAR: HPGe decay station



Cross section (mb)	n_TOF irradiation time	Activation measurement time	$\beta-\gamma$ coincidences at 818.5 keV	Neutron flux (neutrons/s/cm^2)	^{135}Cs atoms needed
160 ± 10	40 days	39 days	200	$5.4 \cdot 10^7$	$2.4 \cdot 10^{15}$

7% uncertainty

Table 1: Summary of the data used for the calculation

HPGe Efficiency:
@ 3 cm: 1.6% @818keV
x 20% Beta-gamma coincidence
(**precise characterization ongoing + potential efficiency upgrade**)

Calculations: Sara Carollo

GEAR info: E. Stamati, N. Patronis

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^{135}Cs sample production

Why at ISOLDE?

- Yields 1 x 10^{9} - 1 x 10^{10} at/uC → 10^{15} at ^{135}Cs in several days to weeks
- Separation: GPS → neighbouring masses <0.1% + ^{136}Cs decays in few months (Ba isotopes stable)
- **Foster ISOLDE-n_TOF synergy: radioactive samples production + measurement at NEAR**

^{135}Cs sample production: yields

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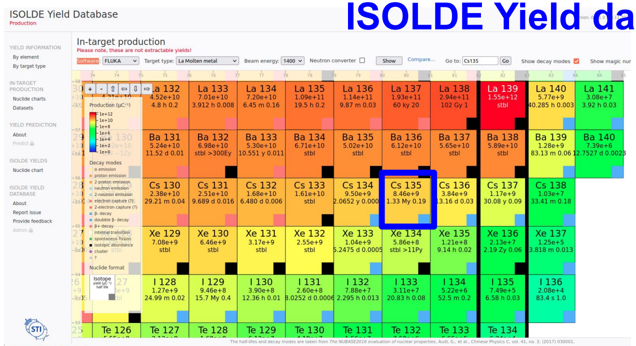
ISOLDE Yield database: FLUKA



In-target production

Please note, these are not extractable yields!

Software: FLUKA | Target type: La Molten metal | Beam energy: 1400 | Neutron converter ☐ | Show | Compare... | Go to: Cs135 | Go | Show decay modes ☑ | Show magic nur

a 132 4.52e+10 4.8 h 0.2	La 133 7.01e+10 3.912 h 0.008	La 134 7.20e+10 6.45 m 0.16	La 135 1.09e+11 19.5 h 0.2	La 136 1.14e+11 9.87 m 0.03	La 137 1.93e+11 60 ky 20	La 138 2.94e+11 102 Gy 1	La 139 1.55e+12 stbl	La 140 5.77e+9 40.285 h 0.003	La 141 3.08e+7 3.92 h 0.03
Ba 131 5.24e+10 11.52 d 0.01	Ba 132 6.98e+10 stbl >300Ey	Ba 133 5.30e+10 10.551 y 0.011	Ba 134 6.71e+10 stbl	Ba 135 5.02e+10 stbl	Ba 136 6.12e+10 stbl	Ba 137 5.65e+10 stbl	Ba 138 5.89e+10 stbl	Ba 139 1.28e+9 83.13 m 0.06	Ba 140 7.39e+6 12.7527 d 0.0023
Cs 130 2.38e+10 29.21 m 0.04	Cs 131 2.51e+10 9.689 d 0.016	Cs 132 1.68e+10 6.480 d 0.006	Cs 133 1.61e+10 stbl	Cs 134 9.50e+9 2.0652 y 0.000	Cs 135 8.46e+9 1.33 My 0.19	Cs 136 3.84e+9 13.16 d 0.03	Cs 137 1.17e+9 30.08 y 0.09	Cs 138 1.03e+7 33.41 m 0.18	
Xe 129 7.08e+9 stbl	Xe 130 6.46e+9 stbl	Xe 131 3.17e+9 stbl	Xe 132 2.55e+9 stbl	Xe 133 1.04e+9 5.2475 d 0.0005	Xe 134 5.86e+8 stbl >11Py	Xe 135 1.21e+8 9.14 h 0.02	Xe 136 2.13e+7 2.19 Zy 0.06	Xe 137 1.25e+5 3.818 m 0.013	
I 128 1.27e+9 24.99 m 0.02	I 129 9.46e+8 15.7 My 0.4	I 130 3.90e+8 12.36 h 0.01	I 131 2.60e+8 8.0252 d 0.0006	I 132 7.88e+7 2.295 h 0.013	I 133 3.11e+7 20.83 h 0.08	I 134 5.22e+6 52.5 m 0.2	I 135 7.49e+5 6.58 h 0.03	I 136 2.08e+4 83.4 s 1.0	
Te 127	Te 128	Te 129	Te 130	Te 131	Te 132	Te 133	Te 134		

Te 126

The half-lifes and decay modes are taken from *The NUBASE2016 evaluation of nuclear properties*, Audi, G., et al., Chinese Physics C, vol. 41, no. 3, (2017) 030001.

Molten La metal:
8.5e9 at/μC

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Please note, these are not extractable yields!

Software: FLUKA | Target type: U Carbide | Beam energy: 1400 | Neutron converter ☐ | Show | Compare... | Go to: Cs135 | Go | Show decay modes ☑ | Show magic numbers ☑

132 .8 h 0.2	La 133 1.01e+9 3.912 h 0.008	La 134 9.08e+8 6.45 m 0.16	La 135 1.12e+9 19.5 h 0.2	La 136 9.03e+8 9.87 m 0.03	La 137 1.09e+9 60 ky 20	La 138 9.55e+8 102 Gy 1	La 139 1.33e+9 stbl	La 140 1.06e+9 40.285 h 0.003	La 141 1.62e+9 3.92 h 0.03	La 142 1.56e+9 91.1 m 0.5	La 143 2.04e+9 14.2 m 0.1
a 131 .07e+9 .52 d 0.01	Ba 132 1.50e+9 stbl >300Ey	Ba 133 1.16e+9 10.551 y 0.011	Ba 134 1.49e+9 stbl	Ba 135 1.16e+9 stbl	Ba 136 1.60e+9 stbl	Ba 137 1.53e+9 stbl	Ba 138 2.51e+9 stbl	Ba 139 1.93e+9 83.13 m 0.06	Ba 140 2.70e+9 12.7527 d 0.002	Ba 141 2.23e+9 18.27 m 0.07	Ba 142 2.91e+9 10.6 m 0.2
s 130 .49e+9 21 m 0.04	Cs 131 1.87e+9 9.689 d 0.016	Cs 132 1.52e+9 6.480 d 0.006	Cs 133 1.92e+9 stbl	Cs 134 1.65e+9 2.0652 y 0.00	Cs 135 2.44e+9 1.33 My 0.19	Cs 136 2.52e+9 .16 d 0.03	Cs 137 3.84e+9 30.08 y 0.09	Cs 138 2.48e+9 33.41 m 0.18	Cs 139 3.36e+9 9.27 m 0.05	Cs 140 2.73e+9 63.7 s 0.3	Cs 141 3.18e+9 24.84 s 0.16
e 129 .94e+9 stbl	Xe 130 2.59e+9 stbl	Xe 131 1.99e+9 stbl	Xe 132 2.79e+9 stbl	Xe 133 2.42e+9 5.2475 d 0.0005	3.68e+9 stbl >11Py	Xe 135 3.34e+9 9.14 h 0.02	Xe 136 4.36e+9 2.19 Zy 0.06	Xe 137 2.86e+9 3.818 m 0.013	Xe 138 3.32e+9 14.14 m 0.05	Xe 139 3.07e+9 39.68 s 0.14	Xe 140 3.14e+9 13.60 s 0.10
128 .60e+9 .99 m 0.02	I 129 3.39e+9 15.7 My 0.4	I 130 2.69e+9 12.36 h 0.01	I 131 3.69e+9 8.0252 d 0.0006	I 132 3.09e+9 2.295 h 0.013	I 133 4.15e+9 20.83 h 0.08	I 134 3.69e+9 52.5 m 0.2	I 135 4.15e+9 6.58 h 0.03	I 136 3.14e+9 83.4 s 1.0	I 137 3.08e+9 24.13 s 0.12	I 138 2.36e+9 6.23 s 0.03	I 139 1.35e+9 2.282 s 0.010

The half-lifes and decay modes are taken from *The NUBASE2016 evaluation of nuclear properties*, Audi, G., et al., Chinese Physics C, vol. 41, no. 3, (2017) 030001.

U carbide:
2.4e9 at/μC

In-target production

Please note, these are not extractable yields!

Software: FLUKA | Target type: La Carbide | Beam energy: 1400 | Neutron converter ☐ | Show | Compare... | Go to: Cs135 | Go | Show decay modes ☑ | Show magic numbers ☑

32 .8 h 0.2	La 133 8.84e+9 3.912 h 0.008	La 134 8.55e+9 6.45 m 0.16	La 135 1.21e+10 19.5 h 0.2	La 136 1.19e+10 9.87 m 0.03	La 137 1.98e+10 60 ky 20	La 138 2.54e+10 102 Gy 1	La 139 3.79e+10 stbl	La 140 1.22e+8 40.285 h 0.003	La 141 2.48e+6 3.92 h 0.03
a 131 .98e+9 .52 d 0.01	Ba 132 9.11e+9 stbl >300Ey	Ba 133 6.90e+9 10.551 y 0.011	Ba 134 8.72e+9 stbl	Ba 135 6.57e+9 stbl	Ba 136 8.08e+9 stbl	Ba 137 7.76e+9 stbl	Ba 138 8.34e+9 stbl	Ba 139 3.45e+7 83.13 m 0.06	Ba 140 4.58e+5 12.7527 d 0.0023
s 130 .38e+9 1 m 0.04	Cs 131 3.48e+9 9.689 d 0.016	Cs 132 2.30e+9 6.480 d 0.006	Cs 133 2.25e+9 stbl	Cs 134 1.35e+9 2.0652 y 0.00	Cs 135 1.26e+9 1.33 My 0.19	s 136 5.64e+8 .16 d 0.03	Cs 137 1.74e+8 30.08 y 0.09	Cs 138 1.19e+6 33.41 m 0.18	
e 129 .07e+9 stbl	Xe 130 9.64e+8 stbl	Xe 131 4.59e+8 stbl	Xe 132 3.73e+8 stbl	Xe 133 1.50e+8 5.2475 d 0.0005	8.52e+7 stbl >11Py	e 135 1.81e+7 9.14 h 0.02	Xe 136 3.39e+6 2.19 Zy 0.06		
128 .97e+8 .9 m 0.02	I 129 1.42e+8 15.7 My 0.4	I 130 5.67e+7 12.36 h 0.01	I 131 3.62e+7 8.0252 d 0.0006	I 132 1.08e+7 2.295 h 0.013	I 133 4.54e+6 20.83 h 0.08	I 134 7.07e+5 52.5 m 0.2	I 135 4.16e+4 6.58 h 0.03		

The half-lifes and decay modes are taken from *The NUBASE2016 evaluation of nuclear properties*, Audi, G., et al., Chinese Physics C, vol. 41, no. 3, (2017) 030001.

La carbide:
1.3e9 at/μC

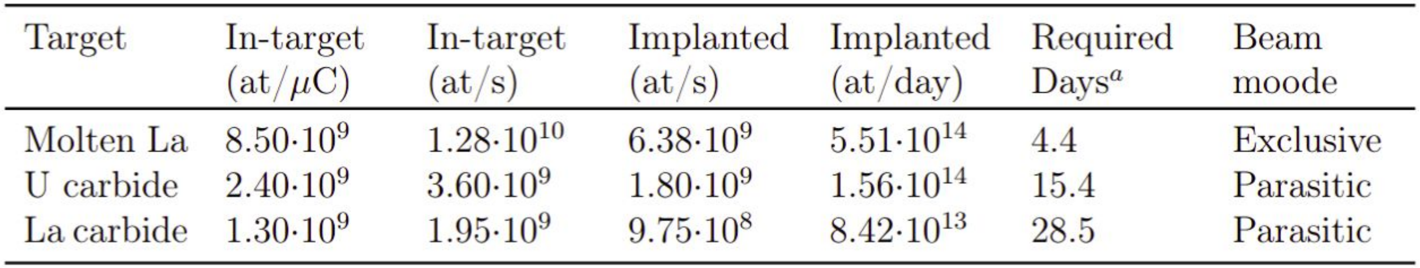
Sample production at ISOLDE: options

ISOLDE Yields: FLUKA

1.5 uA (avg) protons

Extract eff. >=50%

To implant 2.4e15 at



Target	In-target (at/μC)	In-target (at/s)	Implanted (at/s)	Implanted (at/day)	Required Days^a	Beam moode
Molten La	$8.50 \cdot 10^9$	$1.28 \cdot 10^{10}$	$6.38 \cdot 10^9$	$5.51 \cdot 10^{14}$	4.4	Exclusive
U carbide	$2.40 \cdot 10^9$	$3.60 \cdot 10^9$	$1.80 \cdot 10^9$	$1.56 \cdot 10^{14}$	15.4	Parasitic
La carbide	$1.30 \cdot 10^9$	$1.95 \cdot 10^9$	$9.75 \cdot 10^8$	$8.42 \cdot 10^{13}$	28.5	Parasitic

Information: U. Köster, S. Rothe, S. Stegemann

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Extract eff. >=50%

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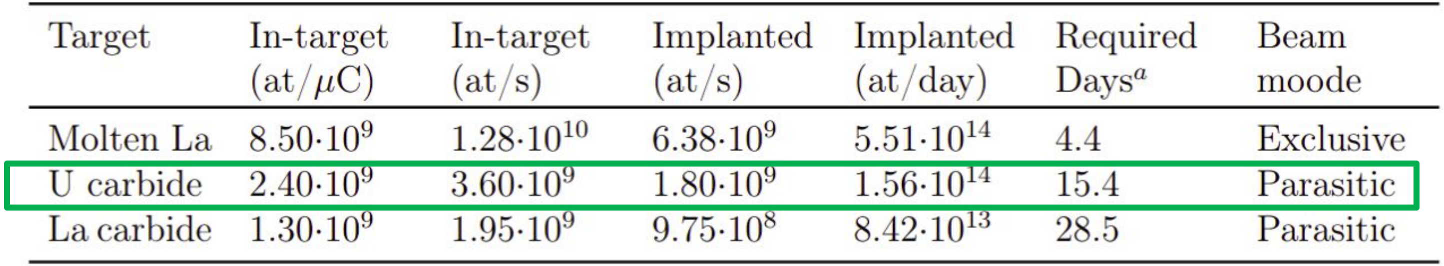

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Proposed production alternatives:

1) **U Carbide target "parasitic mode"** : in parallel to other running experiments one could collect in the SSP collection chamber (@ GLM or GHM beamlines). **15 days required for 2.4 x 10^{15} atoms.**

2) **U carbide target "parasitic mode" + offline GPS**: Old U Carbide target @ ISIS irradiation point at GPS until sufficient ^{135}Cs → GPS (when available) & collection @ GLM or GHM. **Advantages: irradiation and collection separated in time** → scheduling could be facilitated + ion beam would be optimized for the collection.

Information: U. Köster, S. Rothe, S. Stegemann

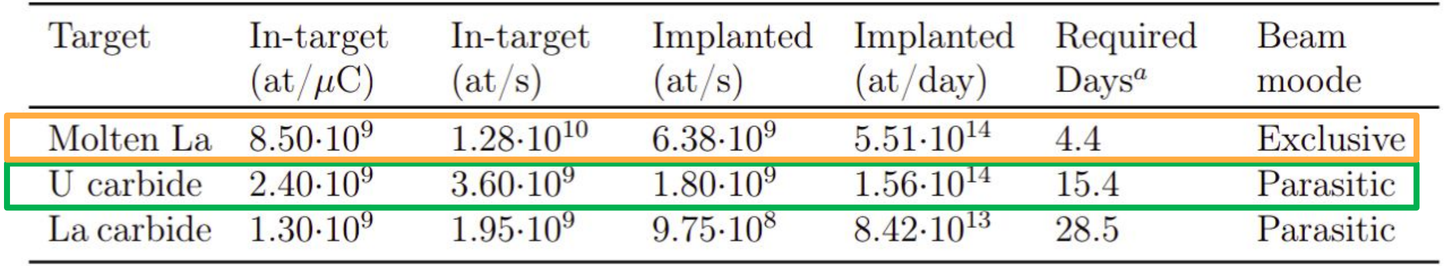
Sample production at ISOLDE: options

ISOLDE Yields: FLUKA

1.5 uA (avg) protons

Extract eff. >=50%

To implant 2.4e15 at



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3) **Molten La target:** Highest yield but less/not compatible to other experiments → **exclusive shifts.**

Information: U. Köster, S. Rothe, S. Stegemann

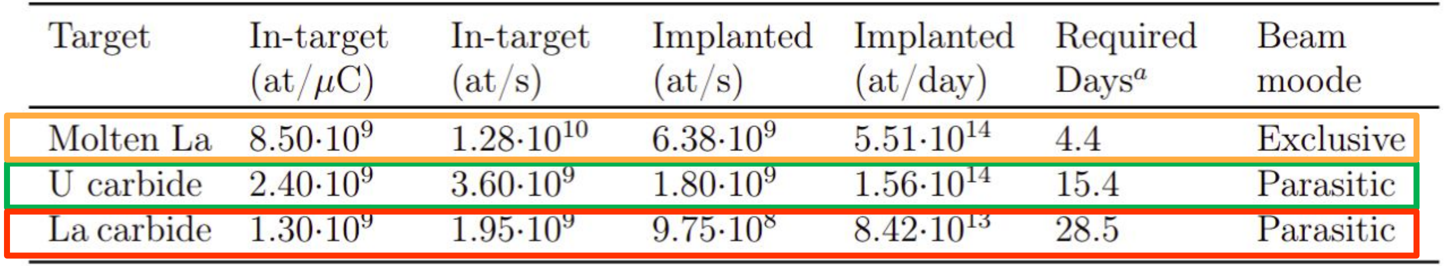
Sample production at ISOLDE: options

ISOLDE Yields: FLUKA

1.5 uA (avg) protons

Extract eff. >=50%

To implant 2.4e15 at



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x~2 lower yield
→Unfavoured

Proposed production alternatives:

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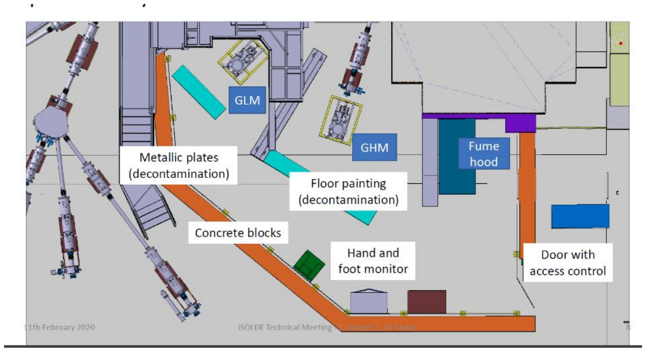
Information: U. Köster, S. Rothe, S. Stegemann

Sample production at ISOLDE: + Details

TECHNICAL DETAILS:

Information: Ulli Köster



Beam-lines

- Low mass (GLM) or high mass (GHM) beam lines parasitic to HIE- ISOLDE experiments with In, Sn, Sb, Te, Cs or Ba beams in the central beamline

Implantation matrix

- Should be conductive (e.g. Be, Al, C or metallized mylar, etc.)

Sample size

- Small diameter (about 3 mm without much losses) possible.
- Limit self-sputtering of the sample → spread the beam over an area of (cm2)+ adapt to n_TOF optimum size

Isotopic purity

- GPS mass separator: <0.1% of neighbouring masses
- ^{136}Cs: Sample cooled for > 10 x $T_{1/2}$(13 d)→ remove ^{136}Cs
- ^{134}Cs: kBq activities but strongest gamma lines of ^{134}Cs decay are below those of ^{136}Cs
- Cleaner spectrum with β-Ɣ coincidences: ^{136}Cs decay g-rays emitted delayed (^{136m}Ba isomer with $T_{1/2}$=0.3s)

^{135}Cs mass characterization

- Preliminary estimation: Beam current (upper limit for the ^{135}Cs content due to the presence of isobaric ^{135}Ba)
- Final determination: After the n_TOF experiment by dissolving the target + ICP-MS.

Outline

- Motivation: ^{135}Cs(n,ɣ) cross section for nucleosynthesis and transmutation
- Project: Combining direct & surrogate reactions to measure ^{134,135}Cs(n,ɣ)
- ^{135}Cs(n,ɣ) activation measurement at NEAR
- ^{135}Cs sample production at ISOLDE
- **Summary and outlook**

Summary & outlook

Motivation

- ^{134}Cs & ^{135}Cs(n,ɣ): relevant s-process branching → s-only ^{134,136}Ba (SiC presolar grains)
- ^{135}Cs(n,ɣ) ($T_{1/2}$ = 2e6 y)→ also relevant for transmutation of LLFP

^{135}Cs(n,ɣ): NEAR + GEAR

- Previous MACS @ 30 and 500 keV (N. Patronis, FZK, 2004).
- Aim of the experiment at NEAR: Covering a wider energy range thank to the spectrum-shaping capability.
- Preliminary study: neutron spectra from MC simulations & experimental efficiency of the GEAR setup.
- Estimated minimum required mass of ^{135}Cs: 2.4 x 10^{15} atoms

Aim of the Proposal: ^{135}Cs sample production at ISOLDE

- Strengthen collaboration ISOLDE/MEDICIS for the production of future samples of interest for (n,g) at NEAR.
- Technical feasibility and details have been discussed with ISOLDE experts.
- **Options for production:**

1. Parasitic production/implantation (I): U carbide target while other experiments running → 15 days for the aimed number of atoms
2. Alternative Parasitic approach (II): ^{135}Cs in Old U carbide + offline extraction when GPS available
3. Alternative exclusive shifts (III): 4 days with Molten metallic La target

Outlook towards the ^{135}Cs(n,ɣ) at NEAR + GEAR

- Experimental characterization / validation of the NEAR “quasi-estelar” beams + upgrade of the GEAR setup
- Final beam-time estimation for the ^{135}Cs(n,g) via activation at NEAR + GEAR → **INTC Proposal**

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AGENCIA ESTATAL DE INVESTIGACIÓN

THANK YOU FOR YOUR ATTENTION!