What we really do at n_TOF

Alberto Mengoni, on behalf of the n_TOF Collaboration

1. Nuclear astrophysics

2. Advanced nuclear technologies

3. Basic nuclear science & applications

INTC, 24 June 2020

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1. Nuclear astrophysics

nucleosynthesis of the heavy (Z>26) elements
stellar evolution
primordial nucleosynthesis (BBN)

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2. Advanced nuclear technologies

Fission reactors (ADS, Gen-IV)
Nuclear Data for Fusion applications
Transmutation of nuclear waste
Neutron capture therapy

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nuclear interactions

nuclear structure effects in fission

high energy nuclear reactions

3. Basic nuclear science & applications

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1. Nuclear astrophysics
2. Advanced nuclear technologies
3. Basic nuclear science & applications

s-process

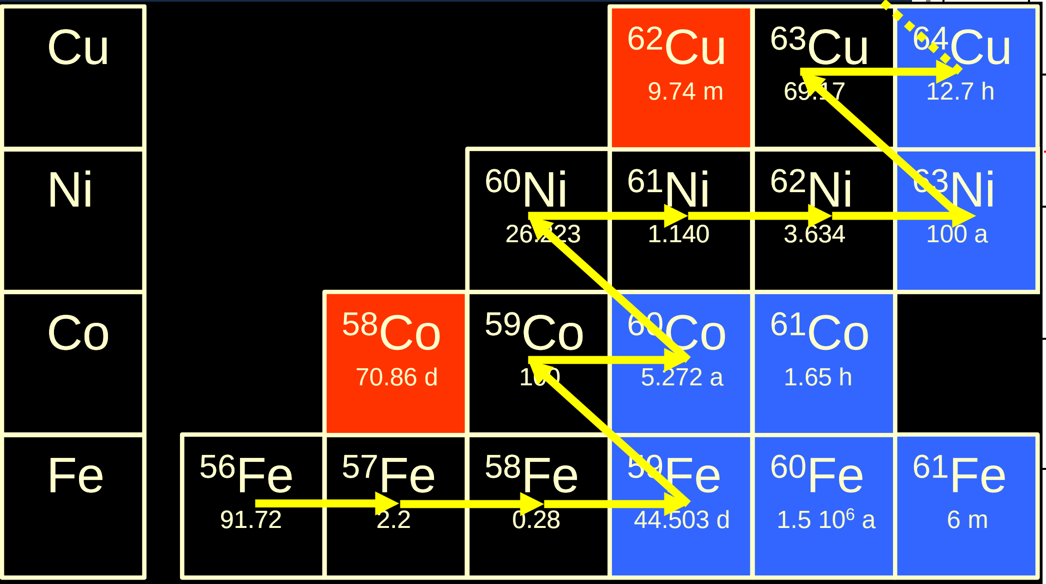
The lifetime of a nucleus against (n,γ) is:

$$\tau_{n,\gamma} \equiv \frac{1}{N_n \langle \sigma_{n,\gamma} v \rangle}$$

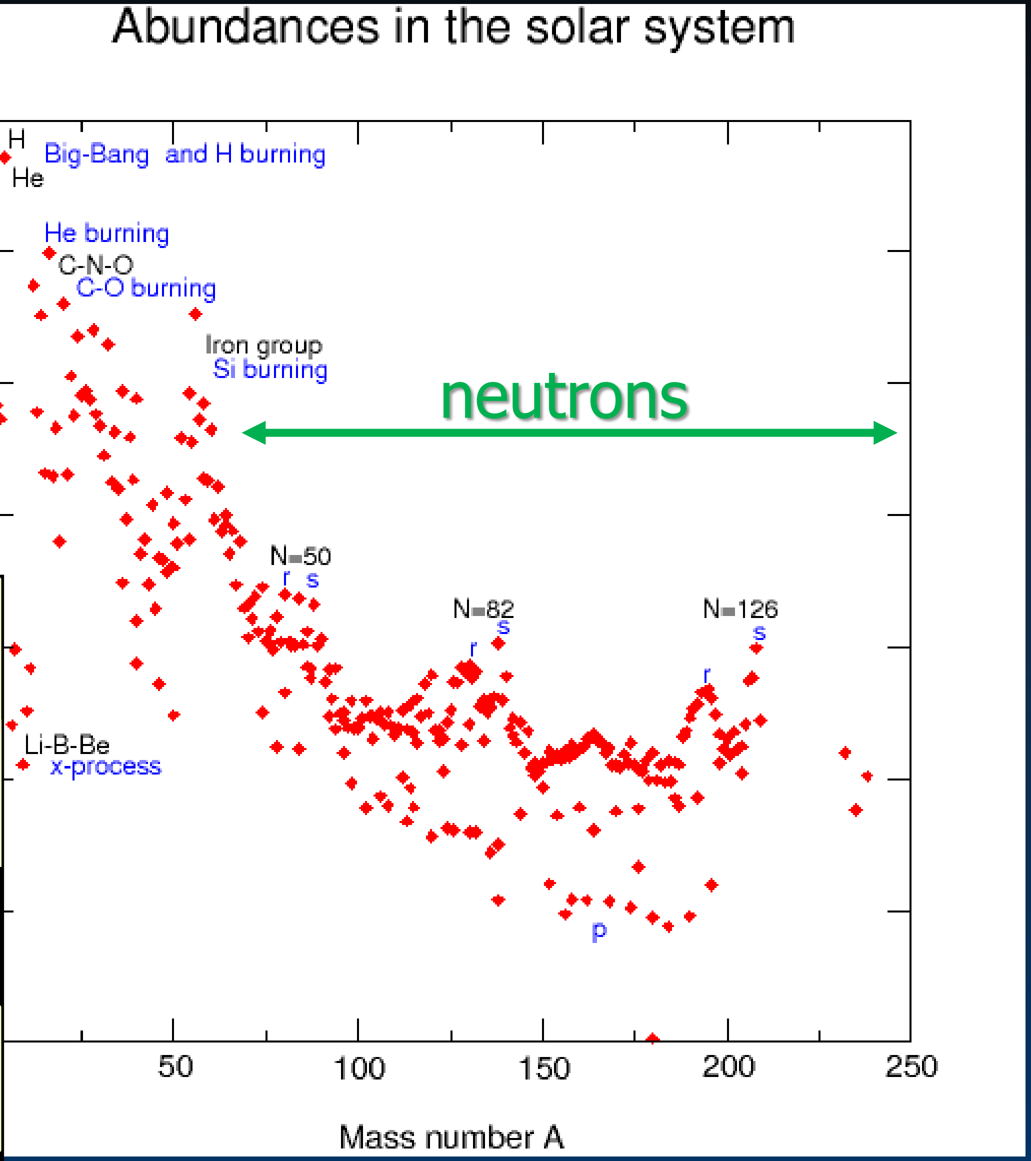
For $\sigma_{(n,\gamma)} \approx 100$ mb and $kT \approx 30$ keV, it is:

$$\tau_{n,\gamma} \approx \frac{10^9}{N_n}\, yr$$

The canonical s-process



Cu				^{62}Cu 9.74 m	^{63}Cu 69.17	^{64}Cu 12.7 h
Ni			^{60}Ni 26.223	^{61}Ni 1.140	^{62}Ni 3.634	^{63}Ni 100 a
Co		^{58}Co 70.86 d	^{59}Co 100	^{60}Co 5.272 a	^{61}Co 1.65 h	
Fe	^{56}Fe 91.72	^{57}Fe 2.2	^{58}Fe 0.28	^{59}Fe 44.503 d	^{60}Fe 1.5 10^6 a	^{61}Fe 6 m


Abundances in the solar system

MACS-30

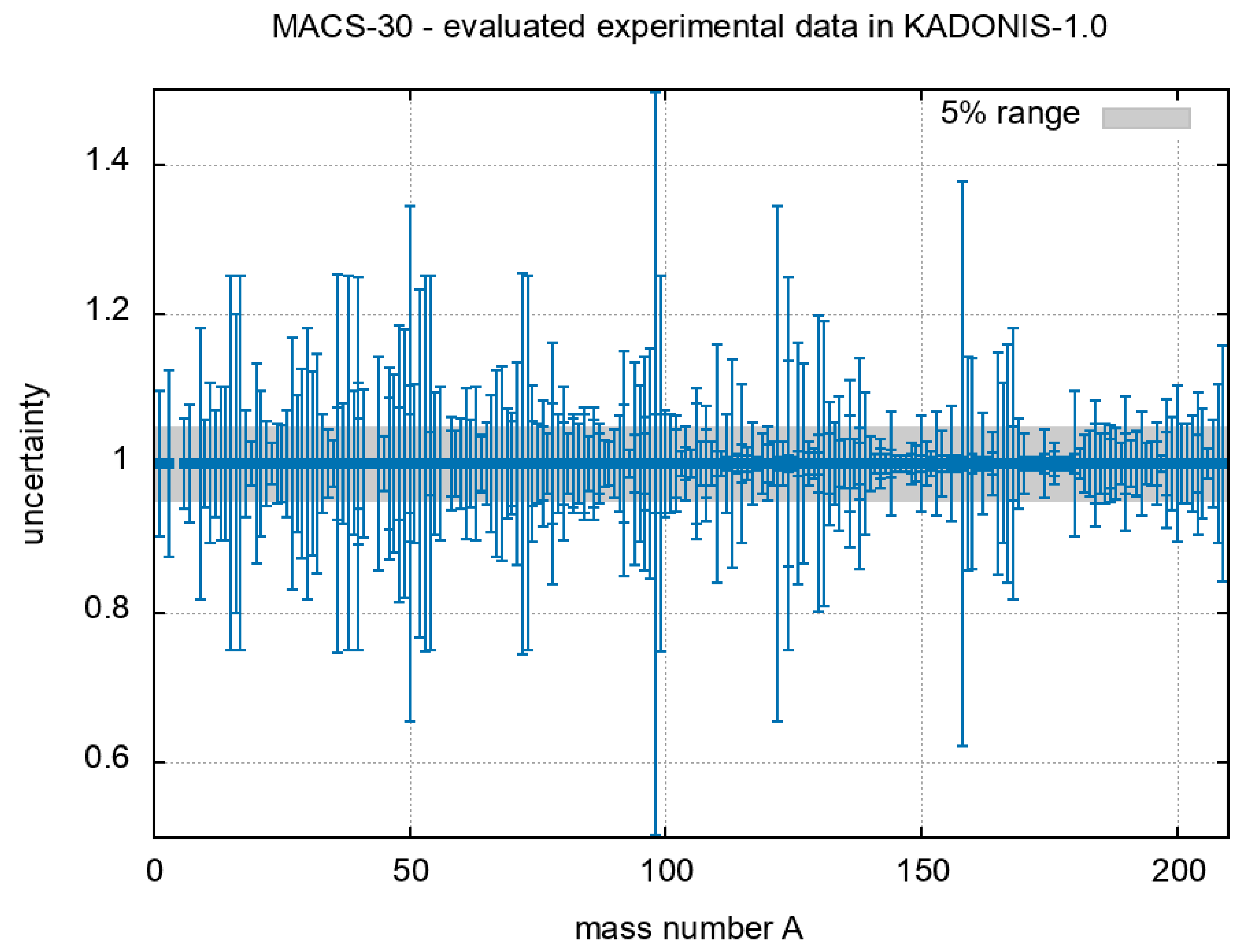
https://exp-astro.de/kadonis1.0/

276 nuclides

154 nuclides
with $\Delta\sigma > 5\%$

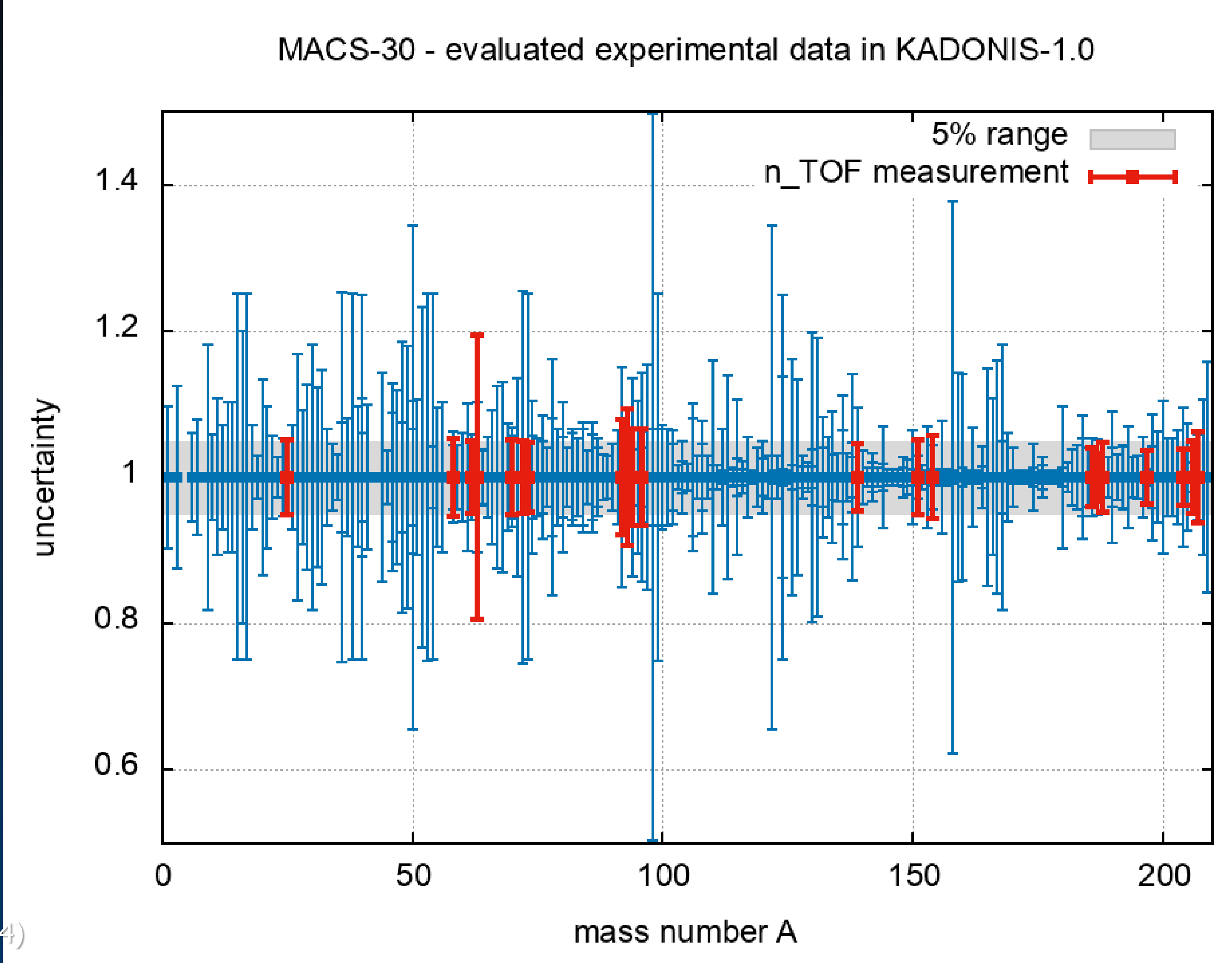
69 nuclides
with $\Delta\sigma > 10\%$

16 nuclides
with $\Delta\sigma > 20\%$



MACS-30

https://exp-astro.de/kadonis1.0/



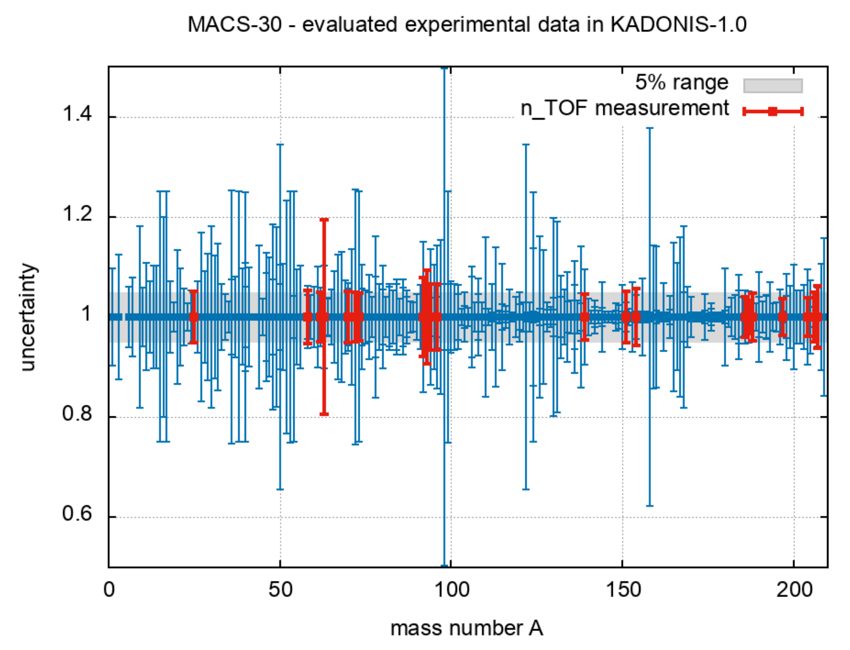
Evaluated data files cannot solve the problem of the accuracy of neutron cross sections data

n_TOF can!

(*) exception: ^{63}Ni, $t_{1/2}$ = 100 yr
first measurement at n_TOF
C Lederer-Woods et al., PRC **89** (2014)

Better MACS-30 means more

Reducing the uncertainty in the MACS is not only a question of better nuclear data: higher accuracy in the reaction rates opens the possibility to investigate new astrophysical scenarios



[nuclear clocks, constrains on the BBN, AGB modeling, nucleosynthesis conditions in explosive scenarios, others]

Accurate cross section data are key to:

1. Nuclear astrophysics
2. Advanced nuclear technologies
3. Basic nuclear science & applications

2. Advanced Nuclear Technologies

“Several parameters, particularly safety parameters of reactors and other nuclear facilities, need to be known with a precision well below 0.1% resulting in **nuclear data precisions better than a few percent, some times better than 2%, and this is a serious challenge**. In other cases the precision needed can range from 5 to 20% but the isotope or material to be measured is highly radioactive or very scarce raising a different but also important challenge.”

cit. “SUPPLYING ACCURATE NUCLEAR DATA FOR ENERGY AND NON-ENERGY APPLICATIONS – SANDA”, EU H2020 Nuclear Data Project, started in September 2019 (4 years duration)

Resonance Integrals: capture

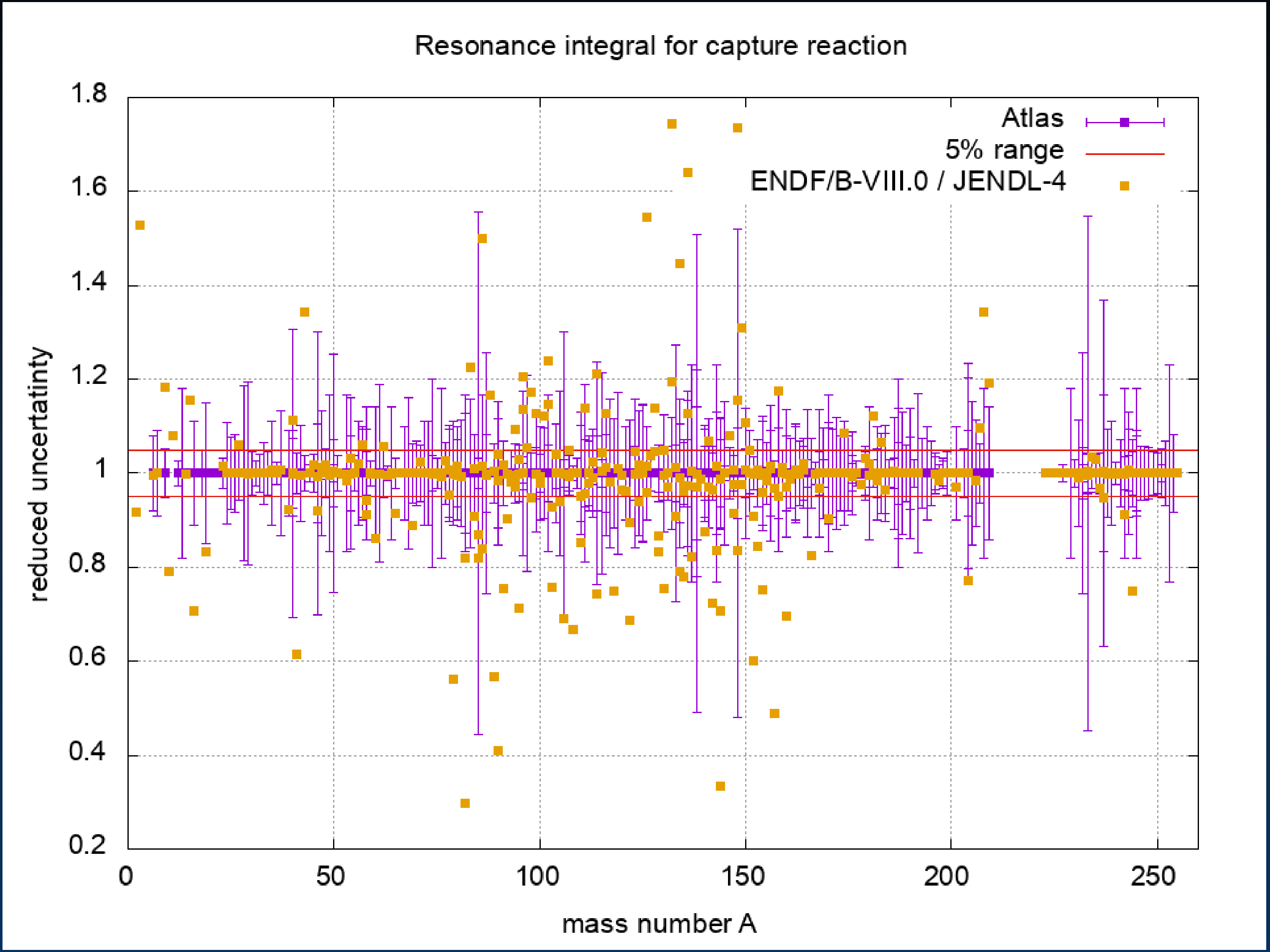
$$\int_{0.5\ \mathrm{eV}}^{\infty} \sigma(E)\,\frac{dE}{E}$$

328 nuclides

231 nuclides with $\Delta\sigma > 5\%$

120 nuclides with $\Delta\sigma > 10\%$

21 nuclides with $\Delta\sigma > 20\%$



Data source: S Mughabghab, Atlas of Neutron Resonances (2006)

Resonance Integrals: fission

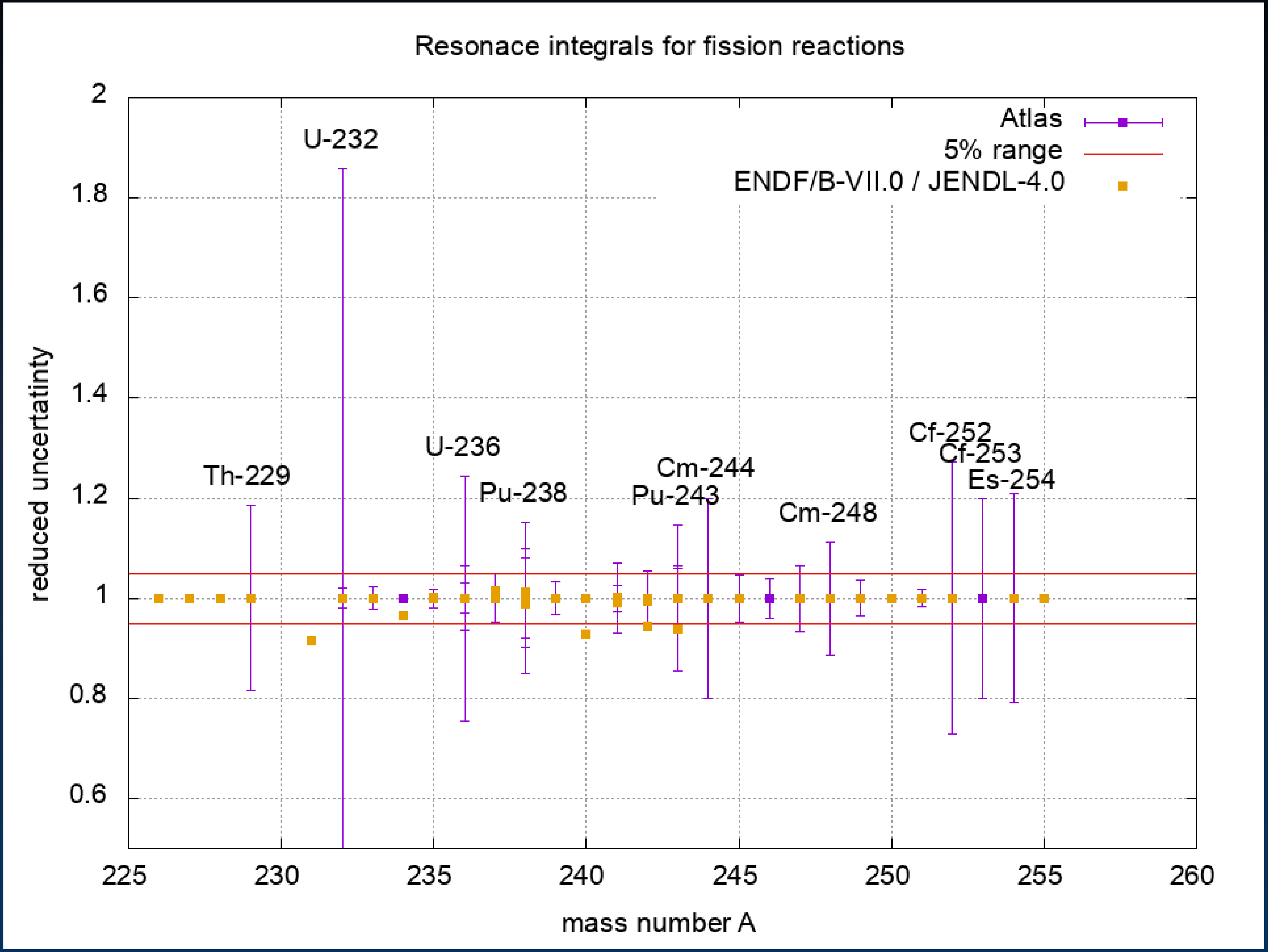
$$\int_{0.5\text{ eV}}^{\infty} \sigma(E)\,\frac{dE}{E}$$

29 nuclides

18 nuclides
with $\Delta\sigma > 5\%$

10 nuclides
with $\Delta\sigma > 10\%$

4 nuclides
with $\Delta\sigma > 20\%$



Data source: S Mughabghab, Atlas of Neutron Resonances (2006)

Conclusion-1

There is enough “raw material” for building up a strong experimental program for the

n_TOF **Phase-2021**

- Commissioning
- New experimental proposals

Phase-2021: Commissioning

Group	Task
EN-STI + groups from ATS and HSE	Coordination of the facility, target systems and technical components, collimators, R2E and R2M for NEAR
	Extraction, optics, p-beam parameters, SEM, VISTAR
	Alignment, DAQ
	Radiation measurements in the target area (and in the EARs)
n_TOF Collaboration	n-flux, beam profile, background conditions, beam resolution, new detectors

A joint CERN groups + n_TOF Collaboration WG forming

Phase-2021: New proposals

reaction	field of interest	note
^{94,95,96}Mo(n,γ)	– s-process AGB stars, SiC grains – fp, fuel alloys	stable samples (*)
^{94}Nb(n,γ)	– anomalies in pre-solar grains – strong contributor to the long-term radiotoxicity among fp	radioactive sample $t_{1/2}$ = 20 ka
^{79}Se(n,γ)	– s-process thermometer – strong contributor to the long-term radiotoxicity among fp	radioactive sample $t_{1/2}$ = 300 ka
^{50,53}Cr(n,γ)	– criticality safety (major element in stainless steel)	stable samples
^{40}K(n,p) ^{40}K(n,α)	– radiogenic heating in earth-like exoplanets (destruction vs production mechanisms)	stable samples

continue…

(*) part of a EU H2020 nuclear data project

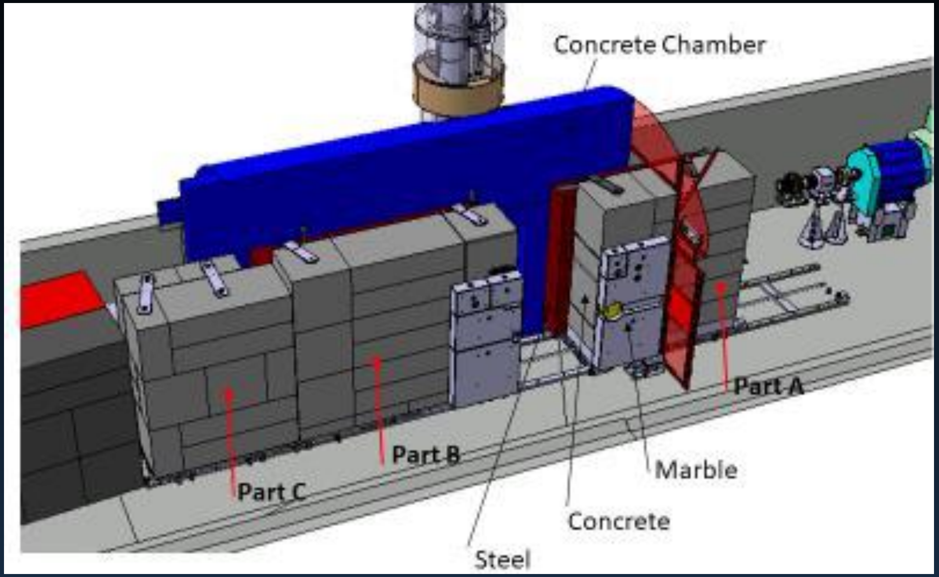
Phase-2021: New proposals

reaction	field of interest	note
^{239}Pu(n,γ) and α-ratio	– advanced nuclear technologies	radioactive sample $t_{1/2}$ = 24.1 ka (*)
n + d → p + 2n	– nn scattering length	basic nuclear physics application
^{243}Am(n,f)	– contributes to production of ^{239}Pu (by α + β^- decays)	radioactive sample $t_{1/2}$ = 7364 a
(…)		under discussion

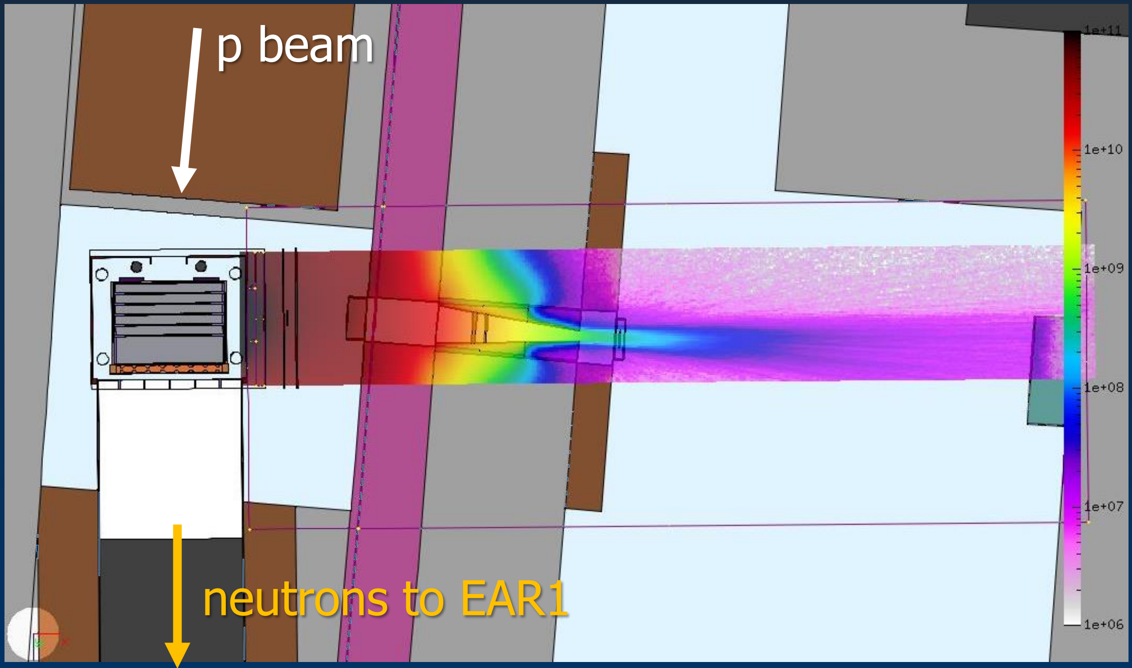
(*) part of a EU H2020 nuclear data project

Program for Phase-2021: NEAR

during the design studies
of the new shielding around
the target station...



the opportunity for a new
near-target experimental area
appeared (NEAR station)



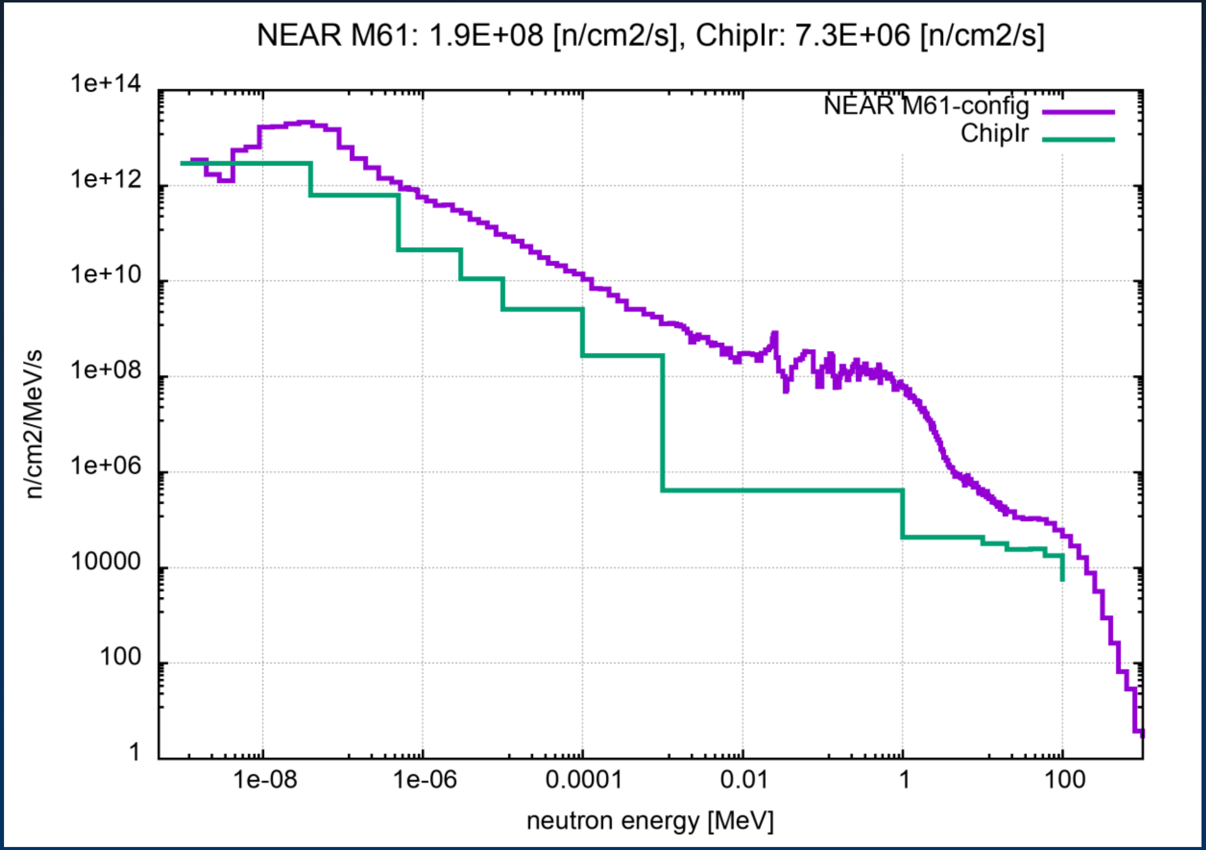
Program for Phase-2021: NEAR

WG on the NEAR station established

collect infos & ideas, provide technical specs for collimation

feasibility of activation measurements, others

example of simulations of the neutron beam in the NEAR area in comparison to the new ChipIr facility at ISIS(*)



(*)D Chiesa et al., NIMA 902 (2018) 14

Program for Phase-2021

Proposals to INTC

- Commissioning: November 2020
- New experiments: November 2020 & February 2021

The End

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Additional material

Phase-2021: Commissioning

purpose	detectors in EAR1	detectors in EAR2
neutron flux small/large collimators	SiMON, MGAS, PTB chamber PPACs, MGAS	SiMON-2D, MGAS, PPACs MGAS, PPACs
beam profile small/large collimators	CR39, PPACS	SiMON-2D, XYMGAS, PPAC, CR39 PPAC, CR39, MGAS
beam resolution	C6D6 (L6D6, Bicron), TAC	C6D6 (Bicron, L6D6)
background conditions	C6D6, TAC, i-TED	CR39, C6D6, MGAS (^{3}He, TLDs, ^{6}Li-glass, Timepix BC501)
tests for new detectors	$LaBr_3$, NaI, CsI-Si, new-SiMON, HPGe	$LaBr_3$, $LaCl_3$, $CeBr_3$, NaI, CsI/Si arrays, new detectors

(n,γ) on Molybdenum

Applications in nuclear astrophysics include studies to interpret traces of s-process pollution in SiC grains and by providing strong constrains on the main s-process component in AGB stars (C-13 pocket).

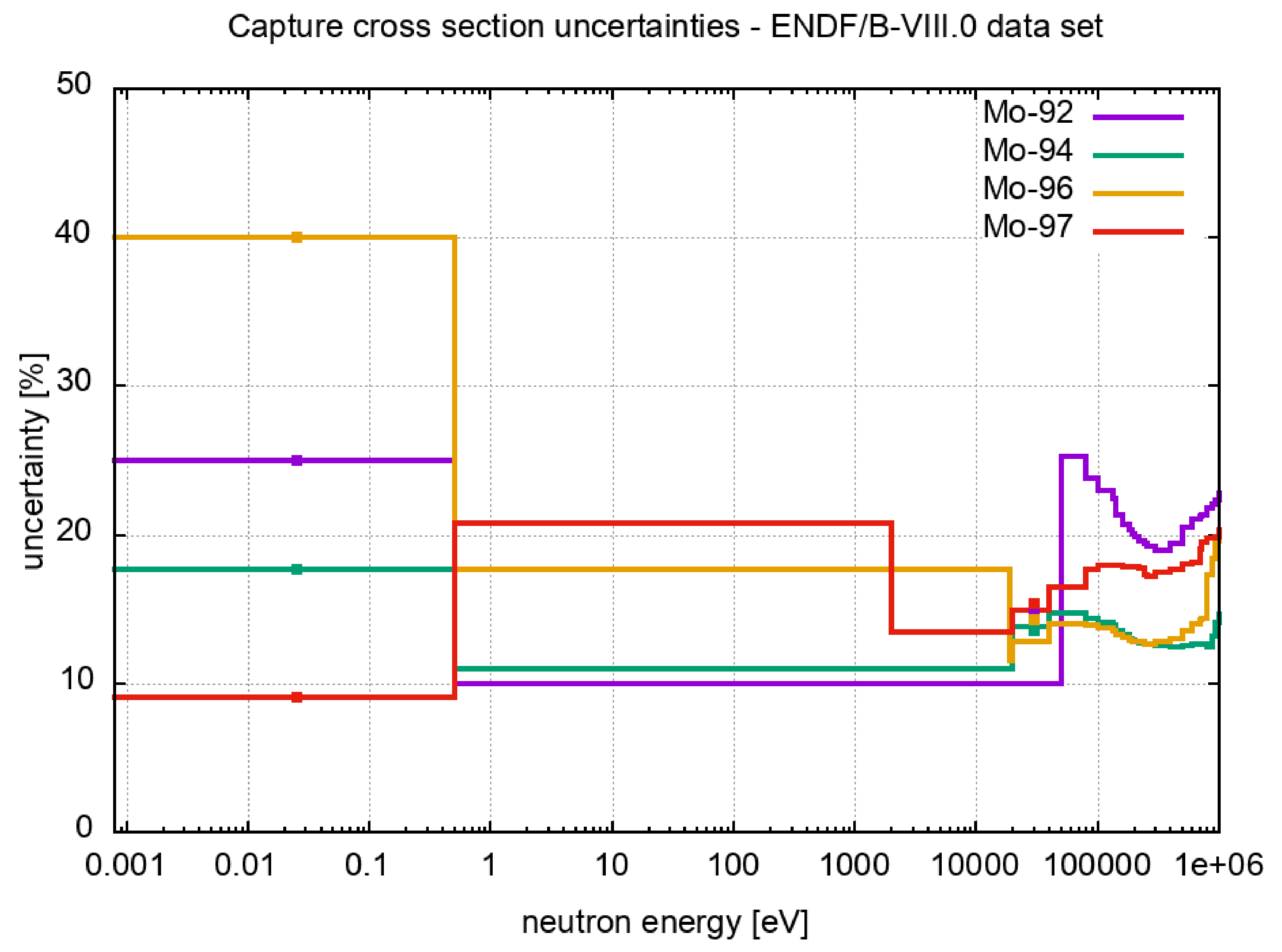
Mo isotopes are currently found in nuclear reactors as fission products or in Mo-alloys in research or naval or space reactors. Moreover, in nuclear cycle Mo isotopes are taken into account in criticality safety studies for transport casks or irradiated fuel storage (use in burn-up credit) or in reprocessing plants (for example: UPu-MoZr deposits in reprocessing plant equipment).

additional:

^{92}Mo(n,p) in NEA/HPRL

^{94}Rh 25.80 s	^{95}Rh 5.02 m	^{96}Rh 9.90 m	^{97}Rh 30.70 m	^{98}Rh 8.72 m	^{99}Rh 16.10 d	^{100}Rh 20.80 h	^{101}Rh 3.30 a	^{102}Rh 206.94 d
^{93}Ru 59.70 s	^{94}Ru 51.80 m	^{95}Ru 1.64 h	^{96}Ru 5.54	^{97}Ru 2.79 d	^{98}Ru 1.87	^{99}Ru 12.76	^{100}Ru 12.6	^{101}Ru 17.06
^{92}Tc 4.25 m	^{93}Tc 2.75 h	^{94}Tc 4.88 h	^{95}Tc 20.00 h	^{96}Tc 4.28 d	^{97}Tc 4.21 Ma	^{98}Tc 4.20 Ma	^{99}Tc 211.11 ka	^{100}Tc 15.80 s
^{91}Mo 15.49 m	^{92}Mo 14.84	^{93}Mo 4.00 ka	^{94}Mo 9.25	^{95}Mo 15.92	^{96}Mo 16.68	^{97}Mo 9.55	^{98}Mo 24.13	^{99}Mo 2.75 d
^{90}Nb 14.60 h	^{91}Nb 680.04 a	^{92}Nb 34.70 Ma	^{93}Nb 100	^{94}Nb 20.30 ka	^{95}Nb 34.99 d	^{96}Nb 23.35 h	^{97}Nb 1.20 h	^{98}Nb 2.86 s
^{89}Zr 3.27 d	^{90}Zr 51.45	^{91}Zr 11.22	^{92}Zr 17.15	^{93}Zr 1.53 Ma	^{94}Zr 17.38	^{95}Zr 64.03 d	^{96}Zr 2.8	^{97}Zr 16.74 h
^{88}Y 106.62 d	^{89}Y 100	^{90}Y 2.67 d	^{91}Y 58.51 d	^{92}Y 3.54 h	^{93}Y 10.18 h	^{94}Y 18.70 m	^{95}Y 10.30 m	^{96}Y 5.34 s
^{87}Sr 7	^{88}Sr 82.58	^{89}Sr 50.57 d	^{90}Sr 28.90 a	^{91}Sr 9.63 h	^{92}Sr 2.66 h	^{93}Sr 7.42 m	^{94}Sr 1.25 m	^{95}Sr 23.90 s
^{86}Rb 18.64 d	^{87}Rb 49.69x10^9 y	^{88}Rb 17.77 m	^{89}Rb 15.15 m	^{90}Rb 2.63 m	^{91}Rb 58.40 s	^{92}Rb 4.49 s	^{93}Rb 5.84 s	^{94}Rb 2.70 s

(n,γ) on Molybdenum



^{238}U(n,n′)

high(est) priority in the NEA/HPRL

feasible with our new HPGe?

Progress in Nuclear Energy 106 (2018) 372–386

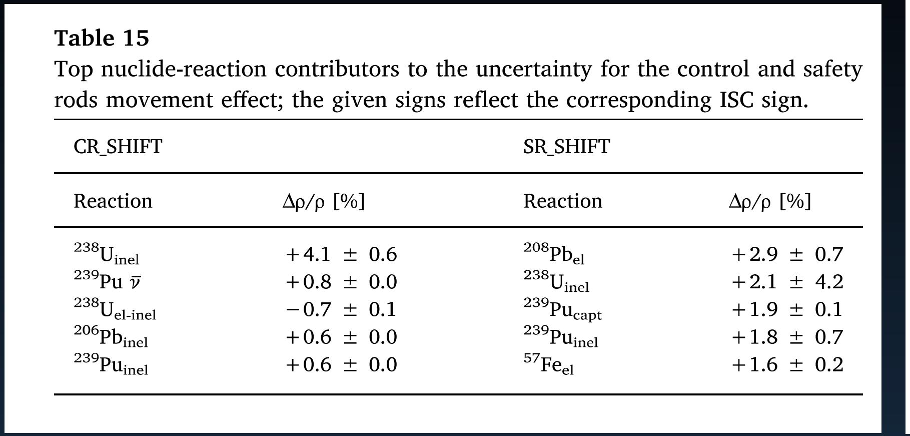
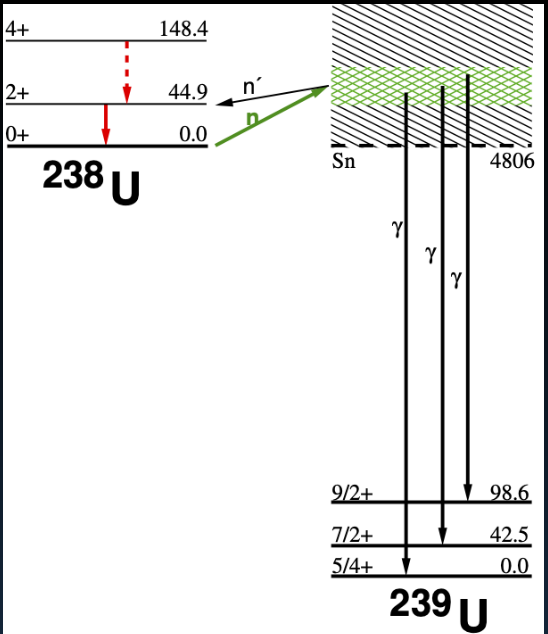
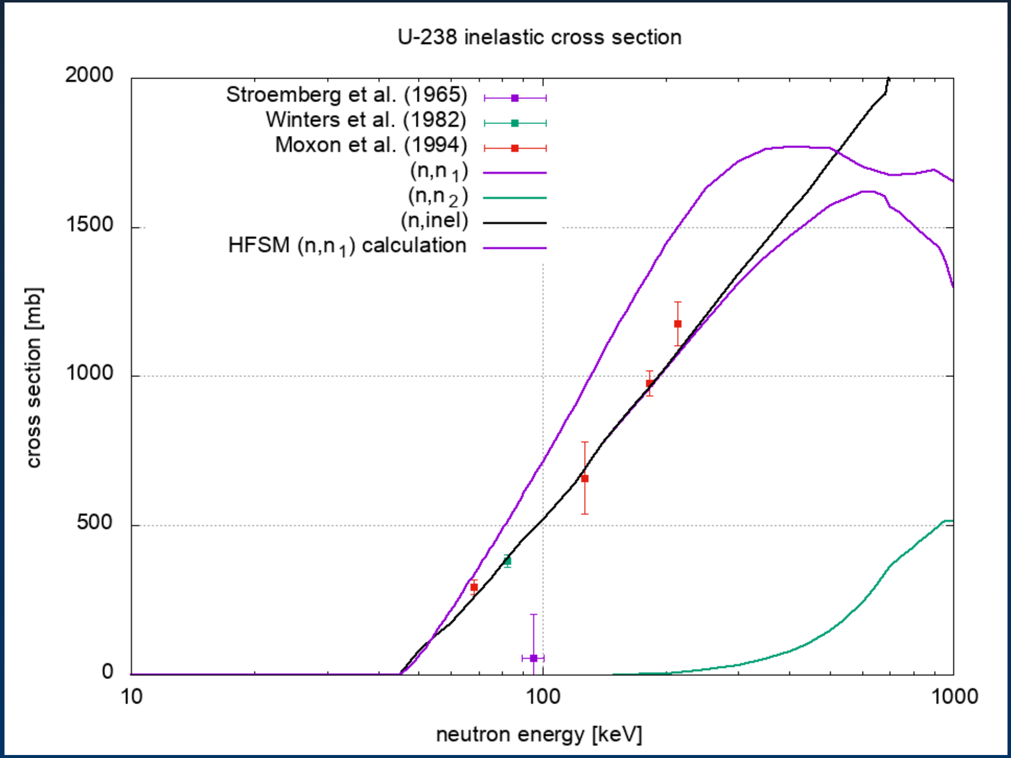
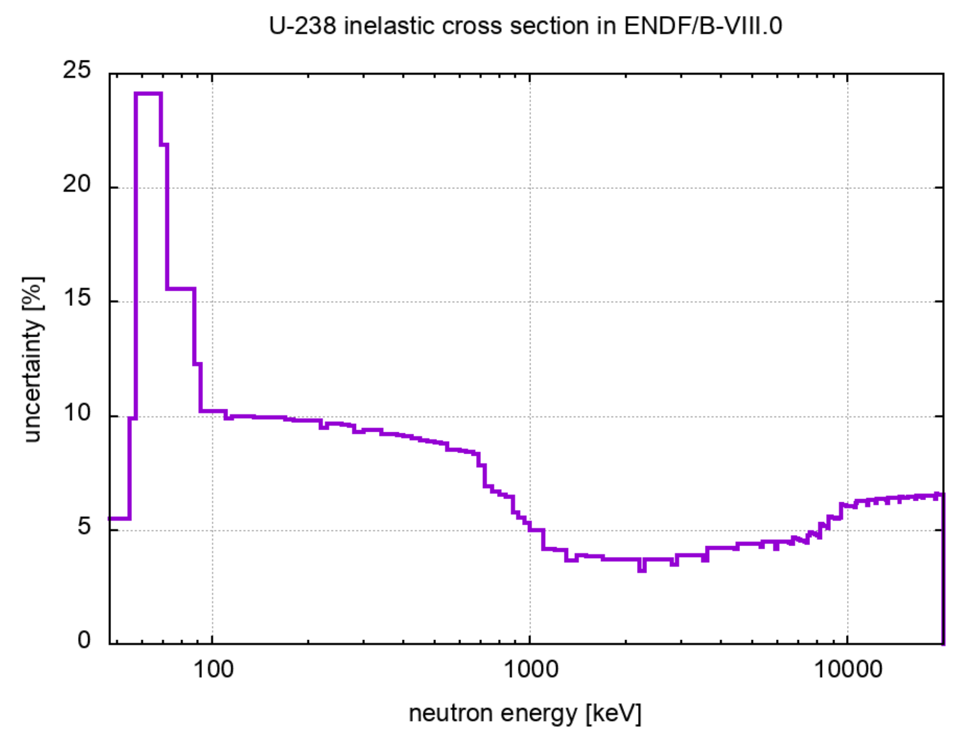


Table 15
Top nuclide-reaction contributors to the uncertainty for the control and safety rods movement effect; the given signs reflect the corresponding ISC sign.

CR_SHIFT		SR_SHIFT	
Reaction	Δρ/ρ [%]	Reaction	Δρ/ρ [%]
$^{238}\mathrm{U}_{\mathrm{inel}}$	+4.1 ± 0.6	$^{208}\mathrm{Pb}_{\mathrm{el}}$	+2.9 ± 0.7
$^{239}\mathrm{Pu}\ \bar{\nu}$	+0.8 ± 0.0	$^{238}\mathrm{U}_{\mathrm{inel}}$	+2.1 ± 4.2
$^{238}\mathrm{U}_{\mathrm{el\text{-}inel}}$	−0.7 ± 0.1	$^{239}\mathrm{Pu}_{\mathrm{capt}}$	+1.9 ± 0.1
$^{206}\mathrm{Pb}_{\mathrm{inel}}$	+0.6 ± 0.0	$^{239}\mathrm{Pu}_{\mathrm{inel}}$	+1.8 ± 0.7
$^{239}\mathrm{Pu}_{\mathrm{inel}}$	+0.6 ± 0.0	$^{57}\mathrm{Fe}_{\mathrm{el}}$	+1.6 ± 0.2




U-238 inelastic cross section


U-238 inelastic cross section in ENDF/B-VIII.0

MACS-30

https://exp-astro.de/kadonis1.0/

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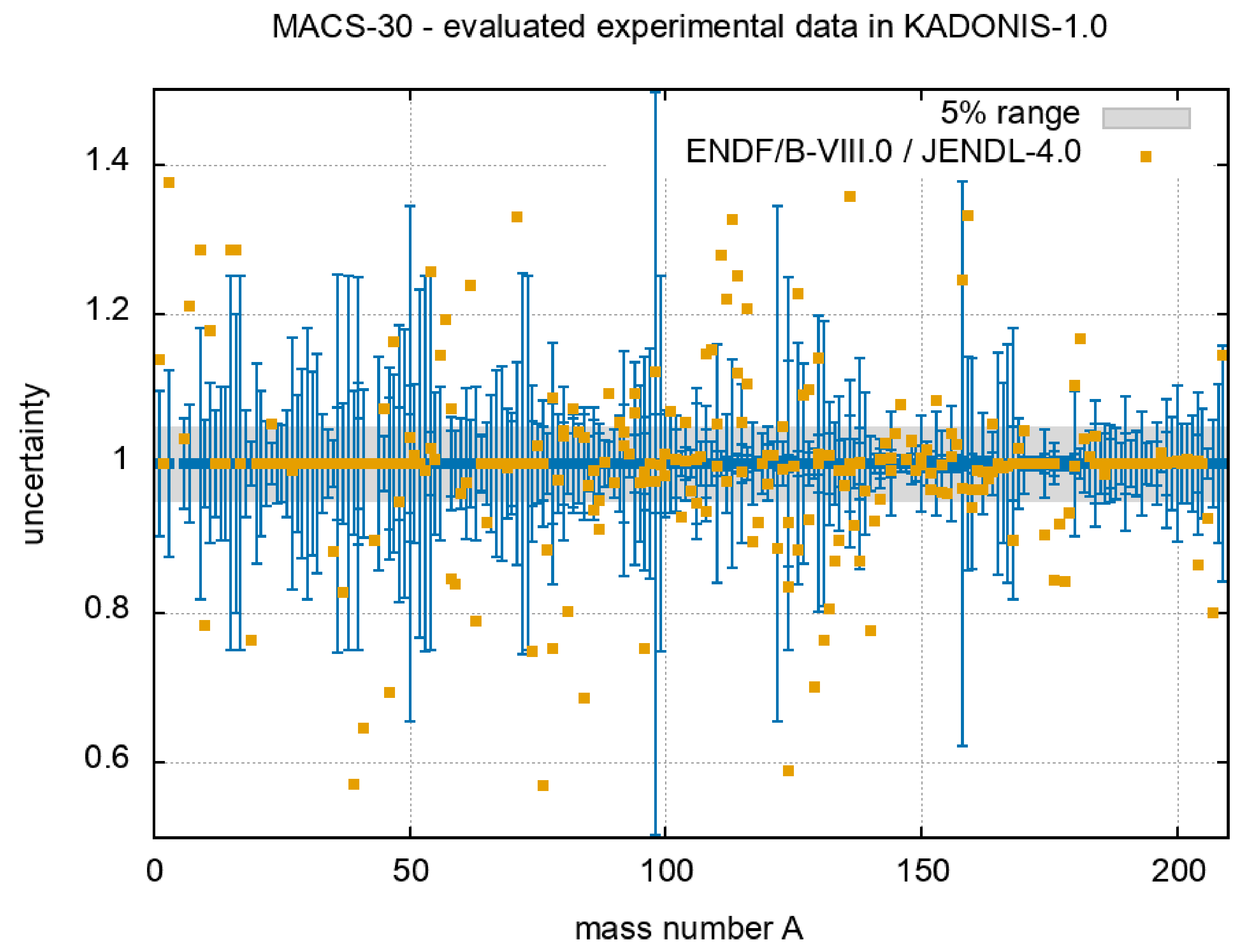
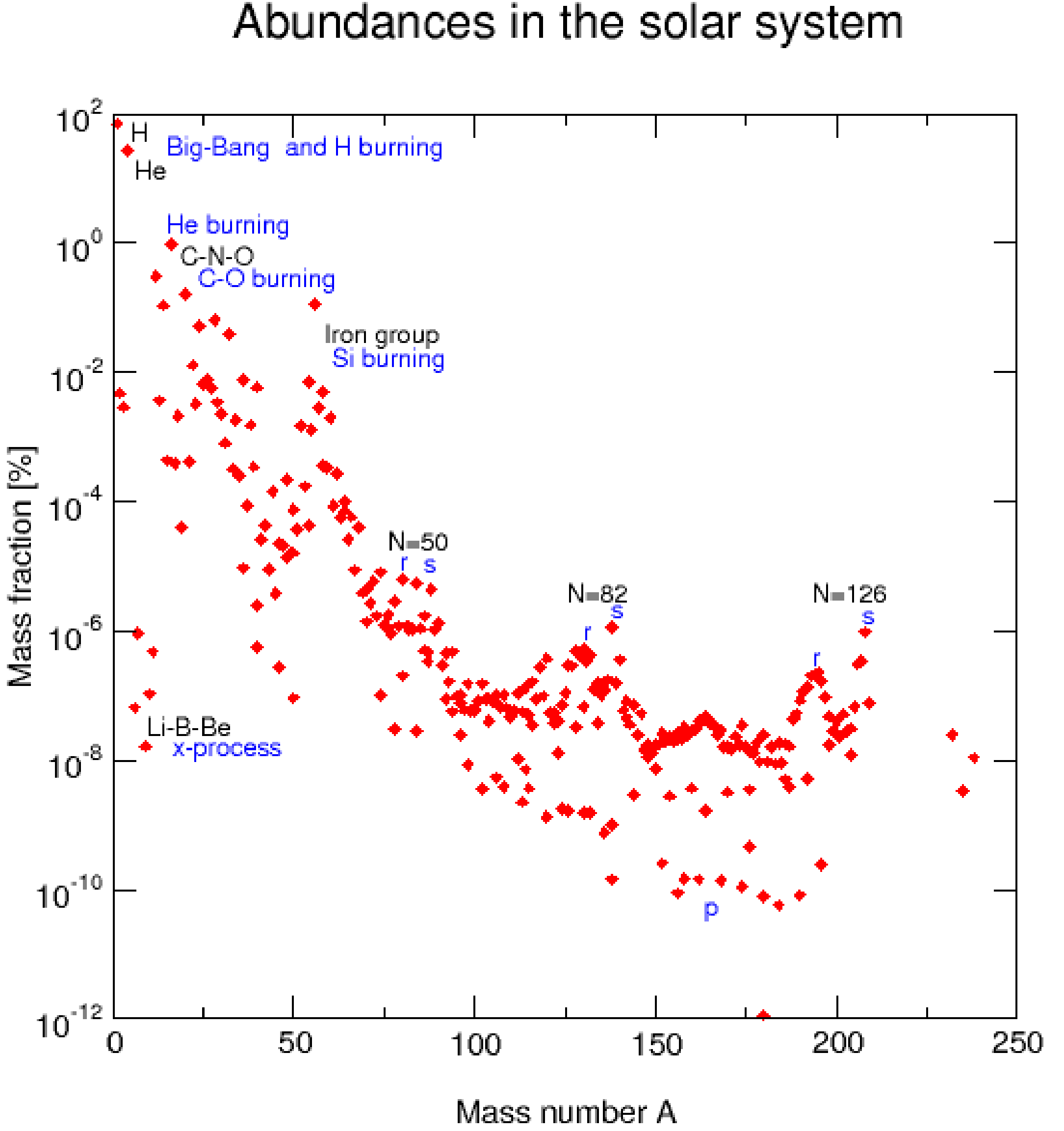
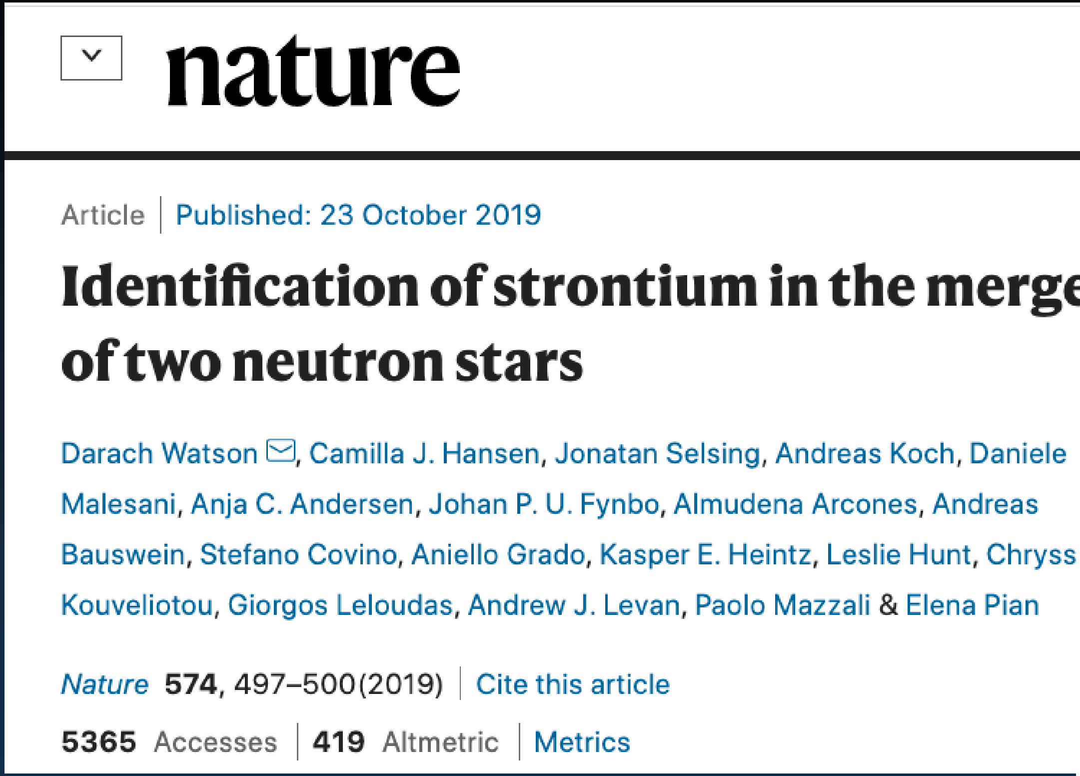


Program for Phase-2021

abundances data from Anders & Grevesse (1989)



Better MACS-30 means more



nature

Article | Published: 23 October 2019

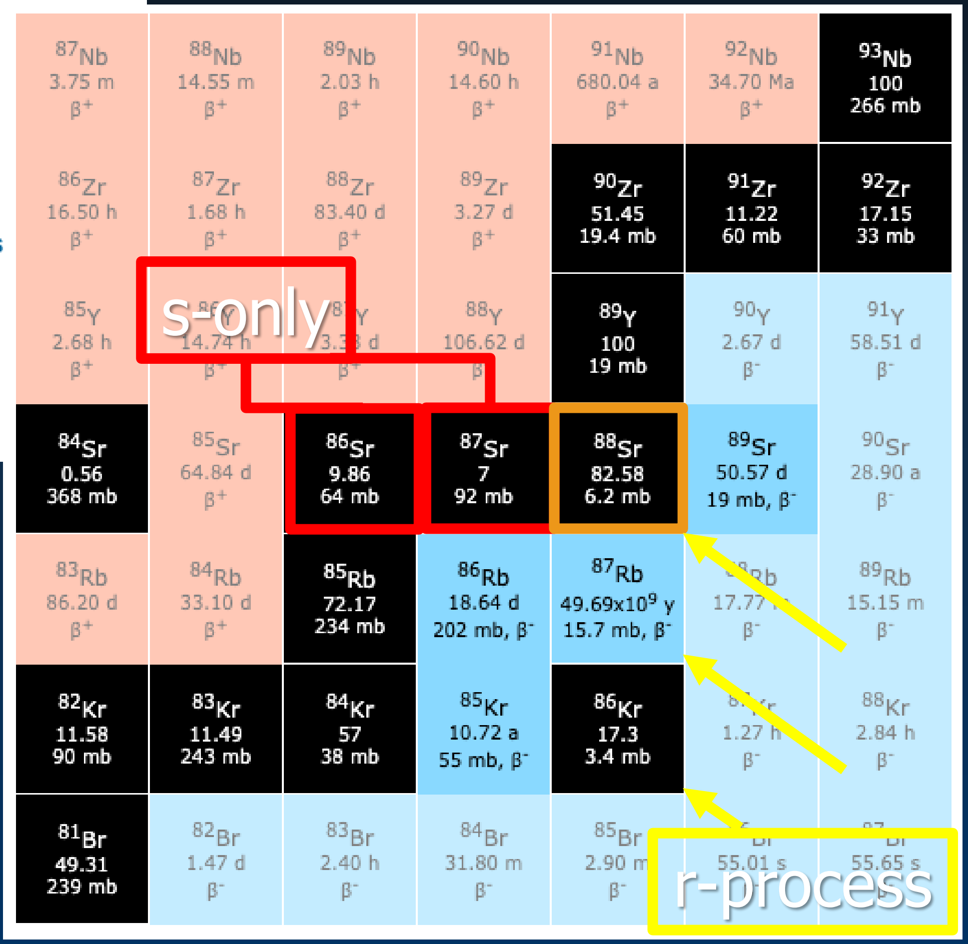
Identification of strontium in the merger of two neutron stars

Darach Watson, Camilla J. Hansen, Jonatan Selsing, Andreas Koch, Daniele Malesani, Anja C. Andersen, Johan P. U. Fynbo, Almudena Arcones, Andreas Bauswein, Stefano Covino, Aniello Grado, Kasper E. Heintz, Leslie Hunt, Chryss Kouveliotou, Giorgos Leloudas, Andrew J. Levan, Paolo Mazzali & Elena Pian

Nature **574**, 497–500(2019) | Cite this article

5365 Accesses | **419** Altmetric | Metrics

nucleosynthesis
in neutron star mergers



^{87}Nb 3.75 m β^+	^{88}Nb 14.55 m β^+	^{89}Nb 2.03 h β^+	^{90}Nb 14.60 h β^+	^{91}Nb 680.04 a β^+	^{92}Nb 34.70 Ma β^+	^{93}Nb 100 266 mb
^{86}Zr 16.50 h β^+	^{87}Zr 1.68 h β^+	^{88}Zr 83.40 d β^+	^{89}Zr 3.27 d β^+	^{90}Zr 51.45 19.4 mb	^{91}Zr 11.22 60 mb	^{92}Zr 17.15 33 mb
^{85}Y 2.68 h β^+	^{86}Y 14.74 h β^+	Y 3.3[illegible] d β^+	^{88}Y 106.62 d β^+	^{89}Y 100 19 mb	^{90}Y 2.67 d β^-	^{91}Y 58.51 d β^-
^{84}Sr 0.56 368 mb	^{85}Sr 64.84 d β^+	^{86}Sr 9.86 64 mb	^{87}Sr 7 92 mb	^{88}Sr 82.58 6.2 mb	^{89}Sr 50.57 d 19 mb, β^-	^{90}Sr 28.90 a β^-
^{83}Rb 86.20 d β^+	^{84}Rb 33.10 d β^+	^{85}Rb 72.17 234 mb	^{86}Rb 18.64 d 202 mb, β^-	^{87}Rb 49.69x10^9 y 15.7 mb, β^-	Rb 17.77 β^-	^{89}Rb 15.15 m β^-
^{82}Kr 11.58 90 mb	^{83}Kr 11.49 243 mb	^{84}Kr 57 38 mb	^{85}Kr 10.72 a 55 mb, β^-	^{86}Kr 17.3 3.4 mb	Kr 1.27 h β^-	^{88}Kr 2.84 h β^-
^{81}Br 49.31 239 mb	^{82}Br 1.47 d β^-	^{83}Br 2.40 h β^-	^{84}Br 31.80 m β^-	^{85}Br 2.90 m β^-	Br 55.01 s	Br 55.65 s