Half-Life of ^{60}Fe

Georg Rugel
supported by DFG (EXC 153)

Nuclei in the Cosmos XI, July 19th-23th 2010, Heidelberg

KARLSRUHER NUKLIDKARTE 7. Auflage 2006

CHART OF THE NUCLIDES, 7th Edition 2006
CARTE DES NUCLÉIDES, 7ème Edition 2006
CARTA DE NUCLEIDOS, 7ª Edición 2006
Таблица радионуклидов, 7-е издание 2006
核素图，第7版

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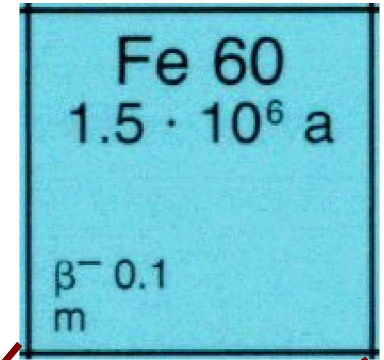
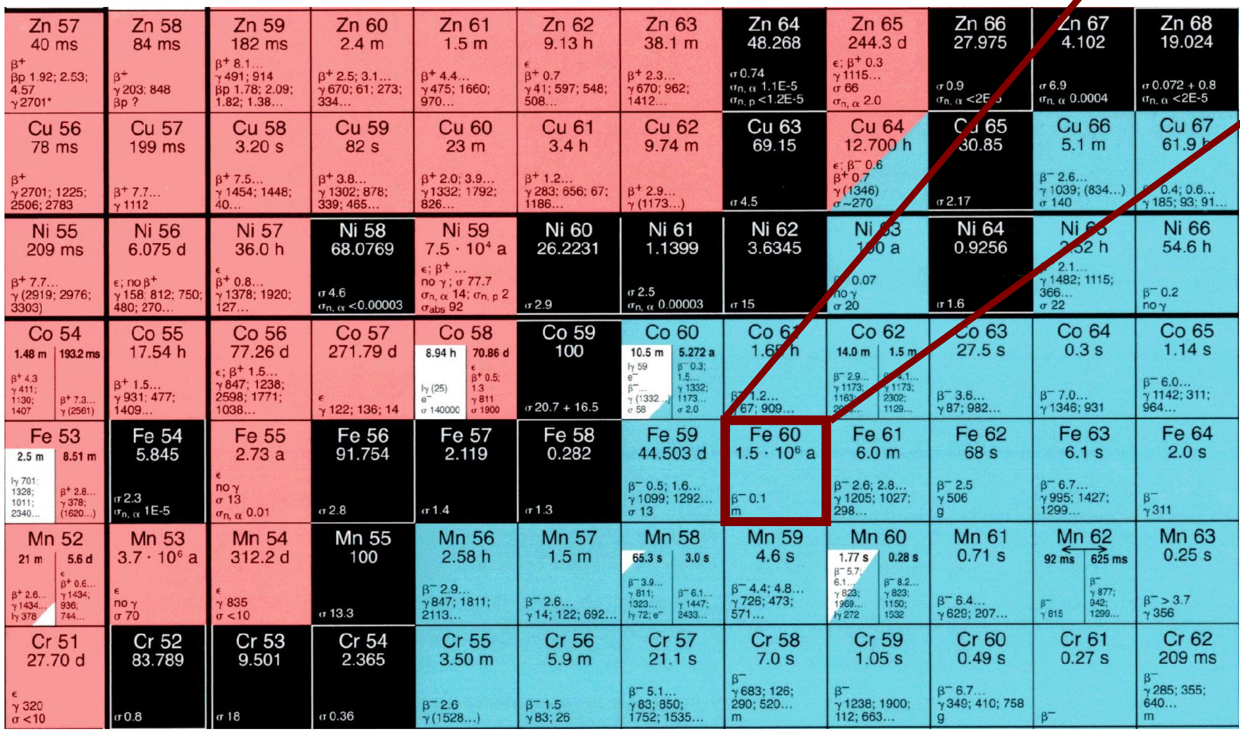
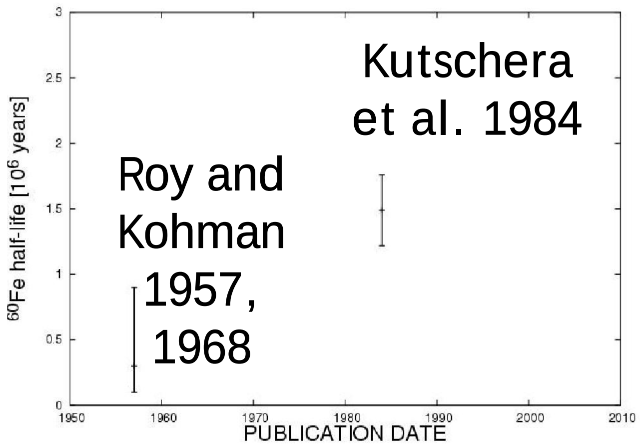
Status $T_{1/2}$ (^{60}Fe) 02/2009



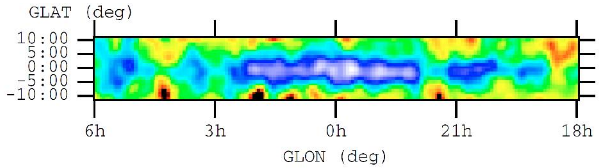


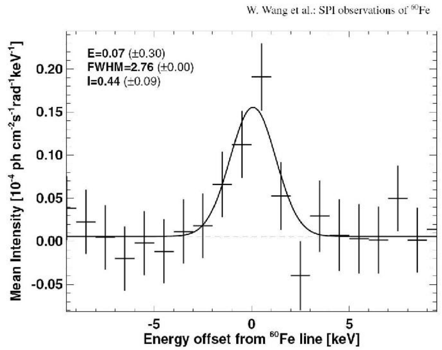
(1.49 ± 0.27) Myr



Motivation $T_{1/2}$ ^{60}Fe

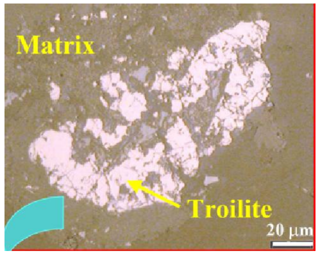
- **Nucleosynthesis in the Galaxy**
  see e.g talk NIC_XI_333 R. Diehl

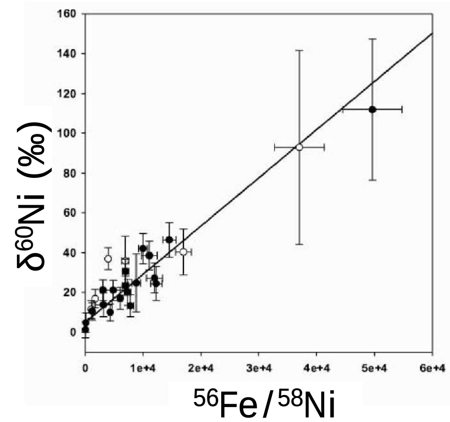




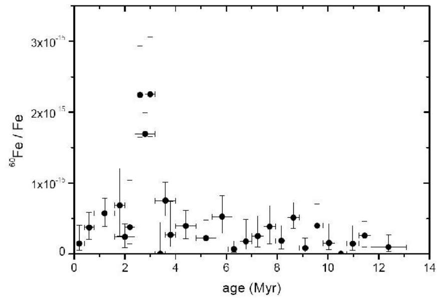
- **History of the Early Solar System**
  e.g. A. Shukolyukov and G.W. Lugmair, Science 1993

e.g: S. Mostefaoui et al., 2005



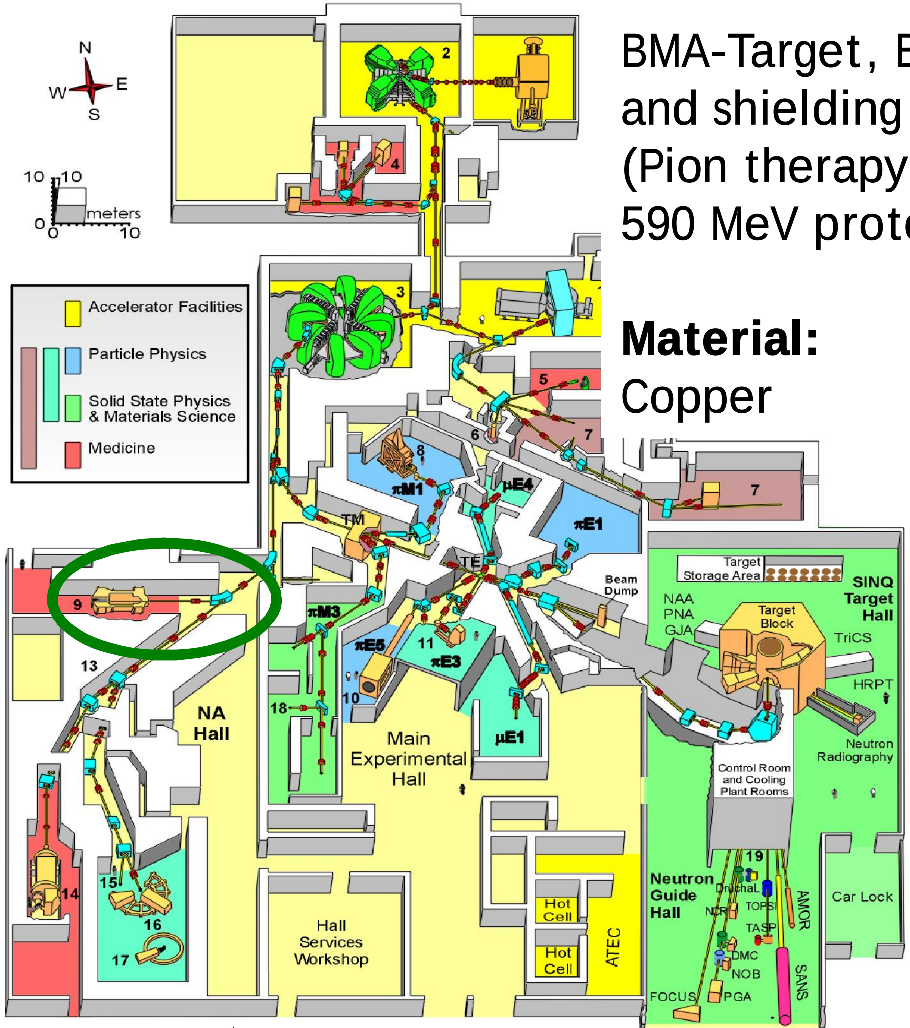


- **Deposits of supernova ejecta on Earth**
  e.g. K. Knie et al., PRL 2004;
  C. Fitoussi et al., PRL 2008



We need ^{60}Fe !

$$A_{^{60}Fe} = \lambda_{^{60}Fe} \cdot N_{^{60}Fe} = \frac{ln(2)}{T_{1/2}(^{60}Fe)} \cdot \frac{N_{^{60}Fe}}{N_{Fe}} \cdot N_{Fe}$$



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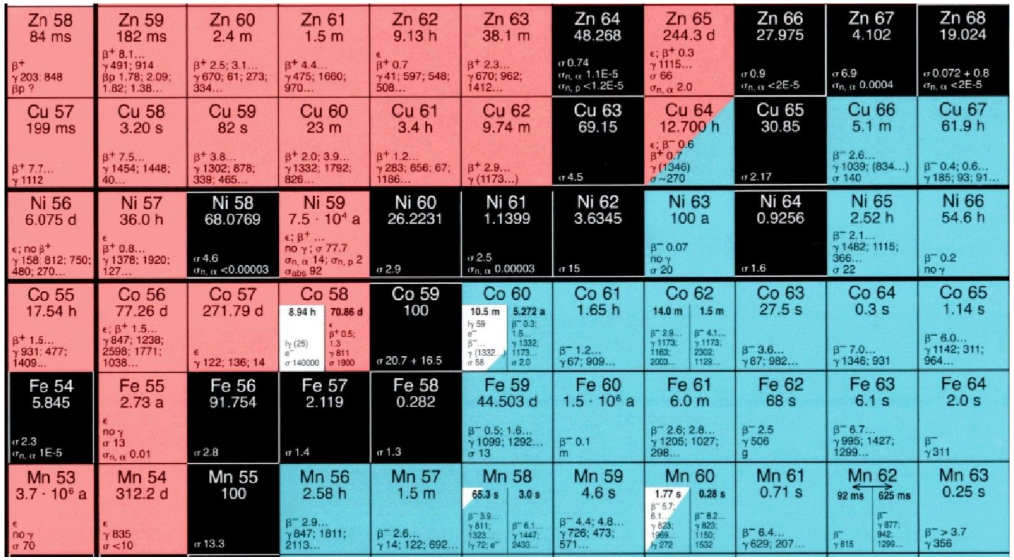
BMA-Target, Beam dump and shielding
(Pion therapy station,
590 MeV protons, 0.1Ah)

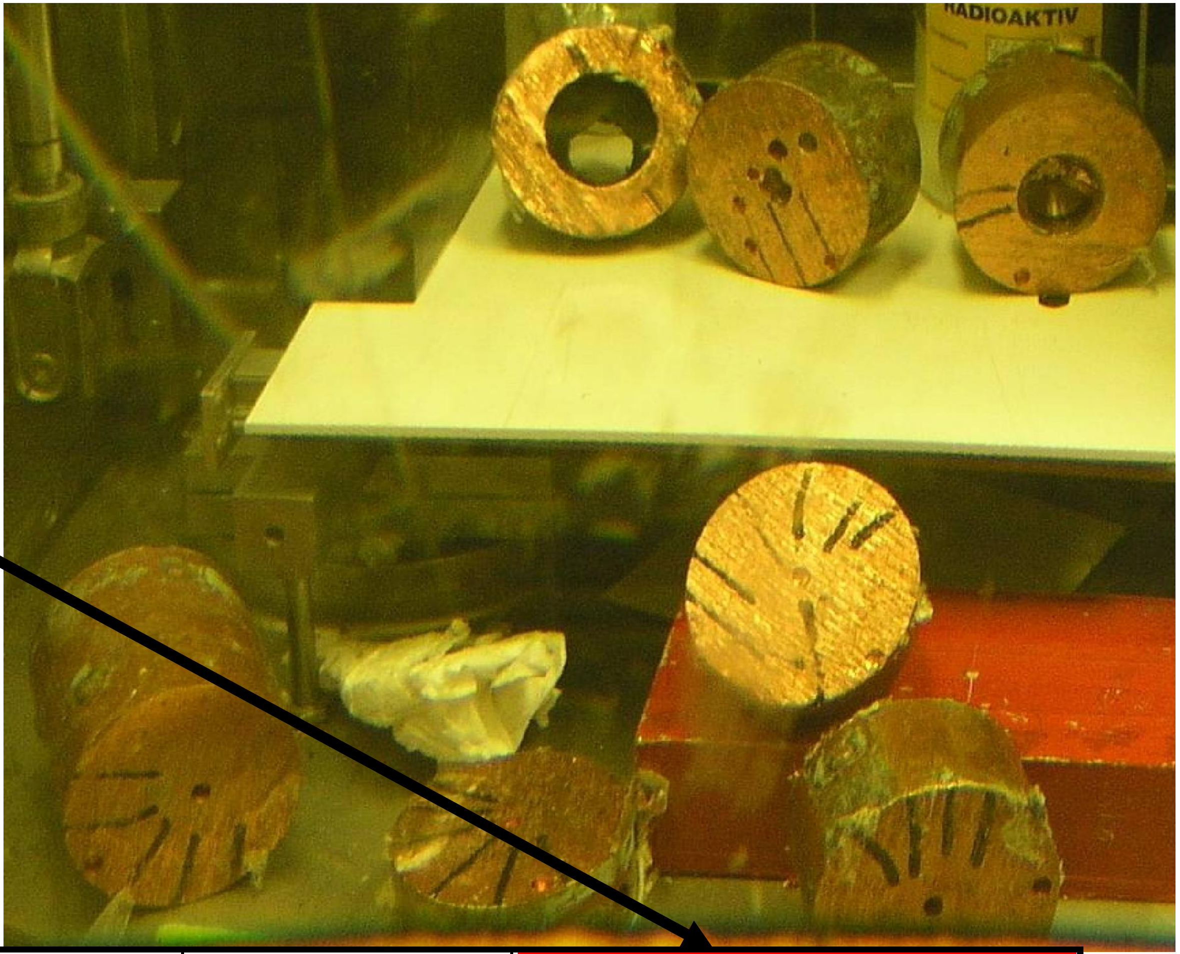
Material:
Copper

Irradiated from
1980 till Sept. 1992



Drilling a hole into central part:

3.86g copper



Activation measurement of 2kg of the beamdump:

Date	Activity ^{60}Co [Bq]	^{60}Co atoms	Initial sample ^{60}Co [Bq]	Initial sample ^{60}Co atoms
01.09.1992	7×10^{9}	1.8×10^{18}	1.4×10^{7}	**3.5×10^{15}**
08.07.2005	1.4×10^{9}	3.3×10^{17}	2.6×10^{6}	6.4×10^{14}

$$A_{^{60}\text{Fe}} = \lambda_{^{60}\text{Fe}} \cdot N_{^{60}\text{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\text{Fe})} \cdot \frac{N_{^{60}\text{Fe}}}{N_{\text{Fe}}} \cdot N_{\text{Fe}}$$

Volume: 4000 µl
from master solution (~ 1nHCl)
Weight: 4.036 g

+ 1000 µl H_2O

→ Germanium detector

Same material used for ICP-MS
(March 2008)

$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$

Efficiency calibration of the detector:

Avoiding geometrical corrections etc.

Calibration source (^{60}Co) with the same geometry:

5ml 0.1 nHCl

102.0 (± 1.5) Bq ^{60}Co

(all uncertainties 1 sigma)

→ Germanium detector

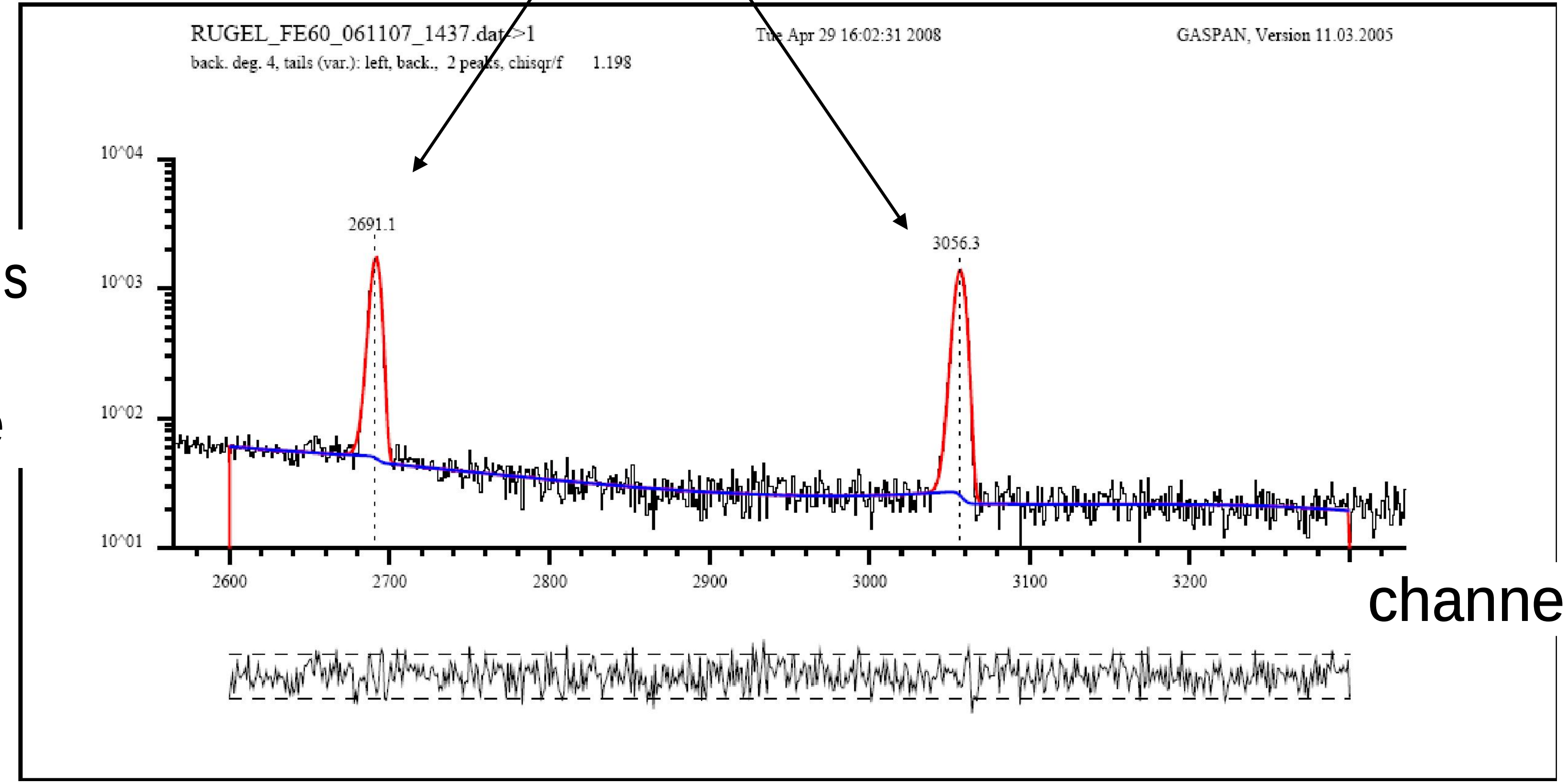
$$A_{^{60}Fe} = \lambda_{^{60}Fe} \cdot N_{^{60}Fe} = \frac{ln(2)}{T_{1/2}(^{60}Fe)} \cdot \frac{N_{^{60}Fe}}{N_{Fe}} \cdot N_{Fe}$$

^{60}Co

12710±130 cts

11450±120 cts

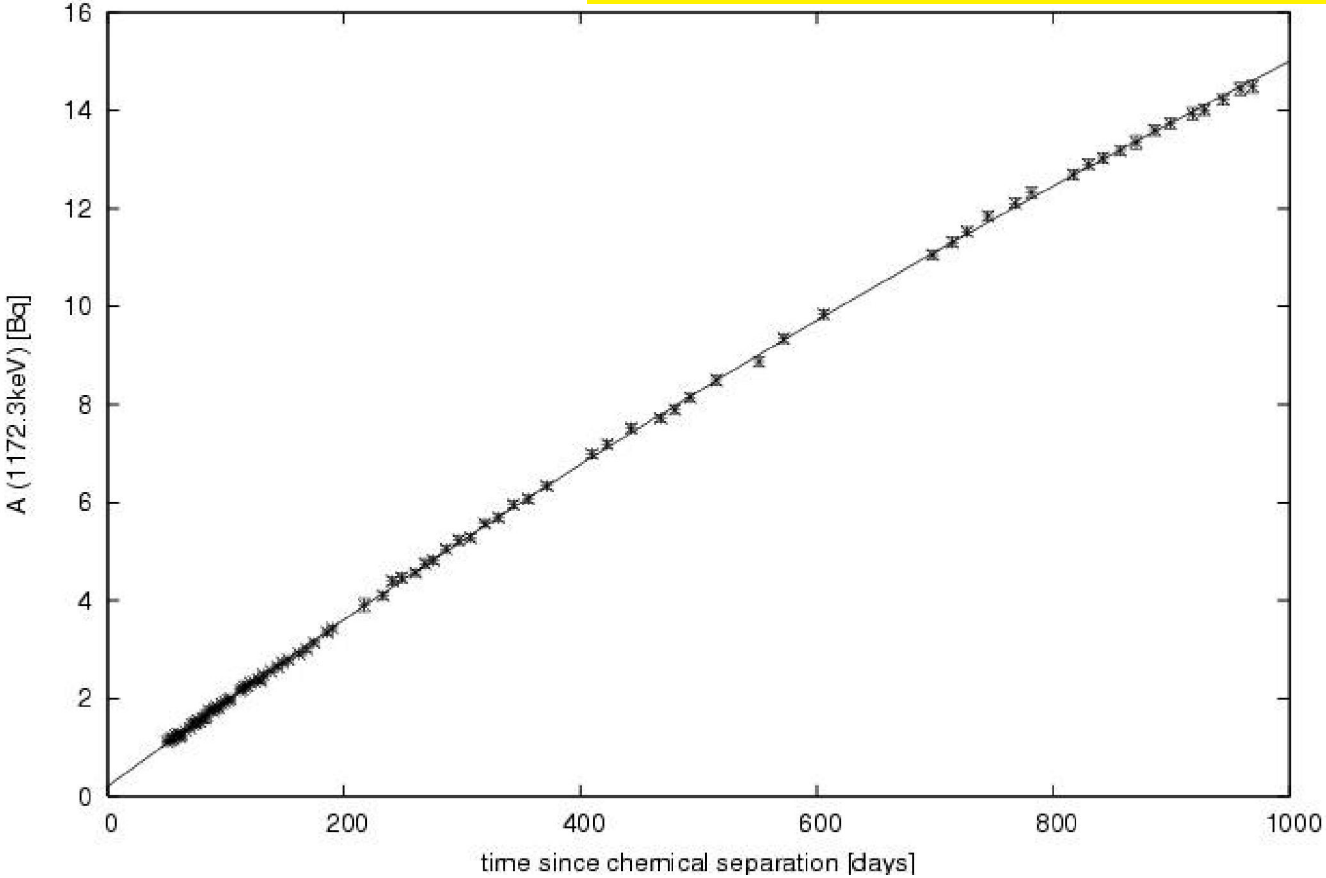
Counts log scale



channel

Build-up of ^{60}Co

$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$



T= 0

^{60}Co ~ 0.2 Bq

Chemical reduction at least 10^7 !

Saturation activity

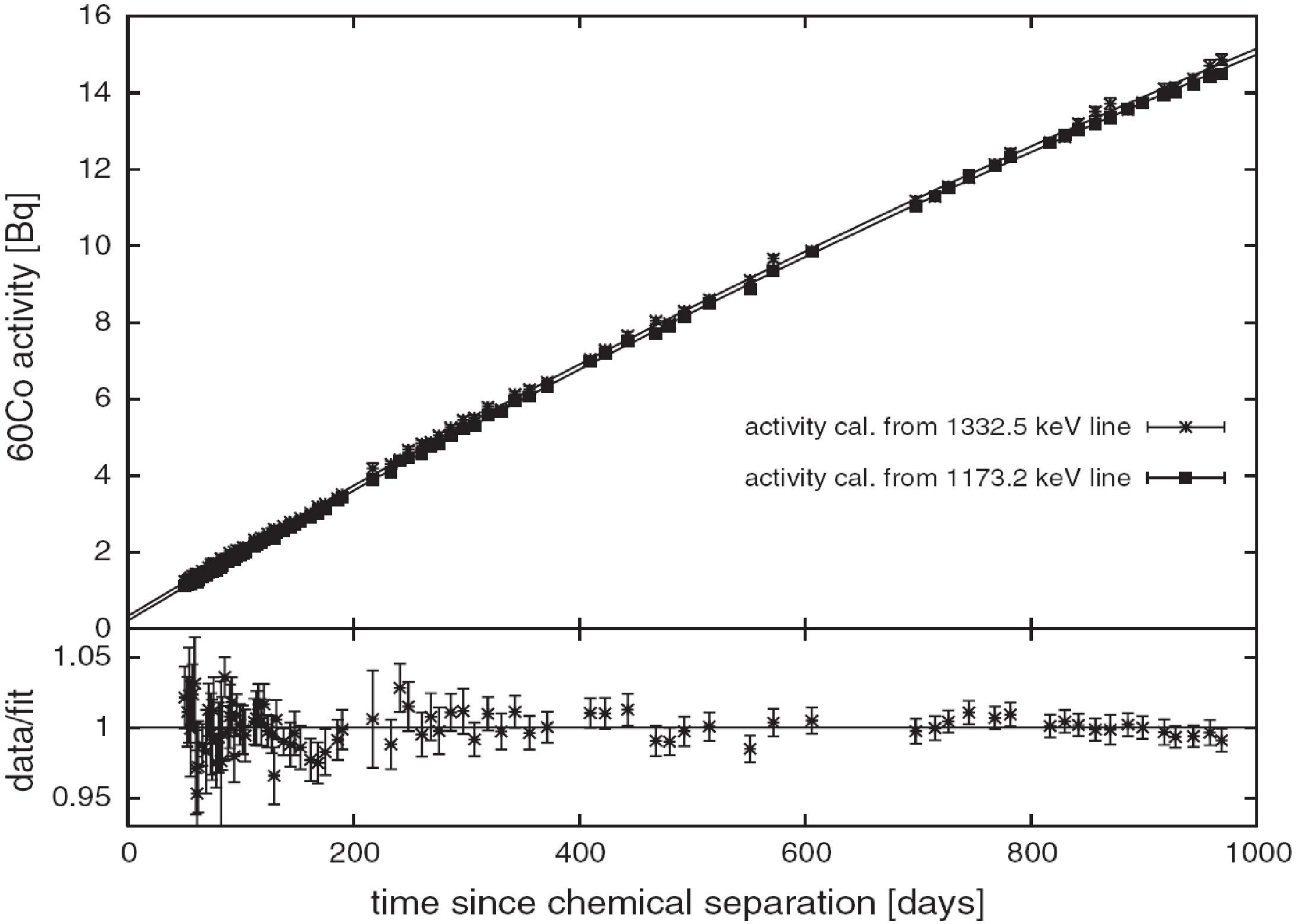
49.14±0.08 Bq

$$A_{60_{Co}} = N_{60_{Fe}} \lambda_{60_{Fe}} \cdot (1 - e^{-\lambda_{60_{Co}} \cdot t})$$

$$\approx N_{60_{Fe}} \cdot \lambda_{60_{Fe}} \cdot \lambda_{60_{Co}} \cdot t$$

for $t << T_{1/2,^{60}\mathrm{Co}}$

Lower Data Normalized to the Fit



Combined result: 49.19±0.11 Bq

Master Sample (TUM) transferred to PSI

$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$

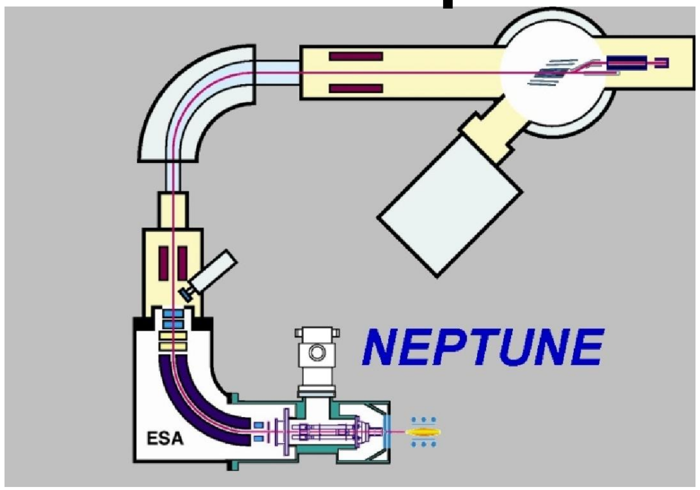
Determination of N

Subsamples taken gravimetrically after opening

$$\cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}}$$

$$\cdot N_{\mathrm{Fe}}$$

Multicollector - Inductively Coupled Plasma Mass Spectrometry MC-ICP-MS



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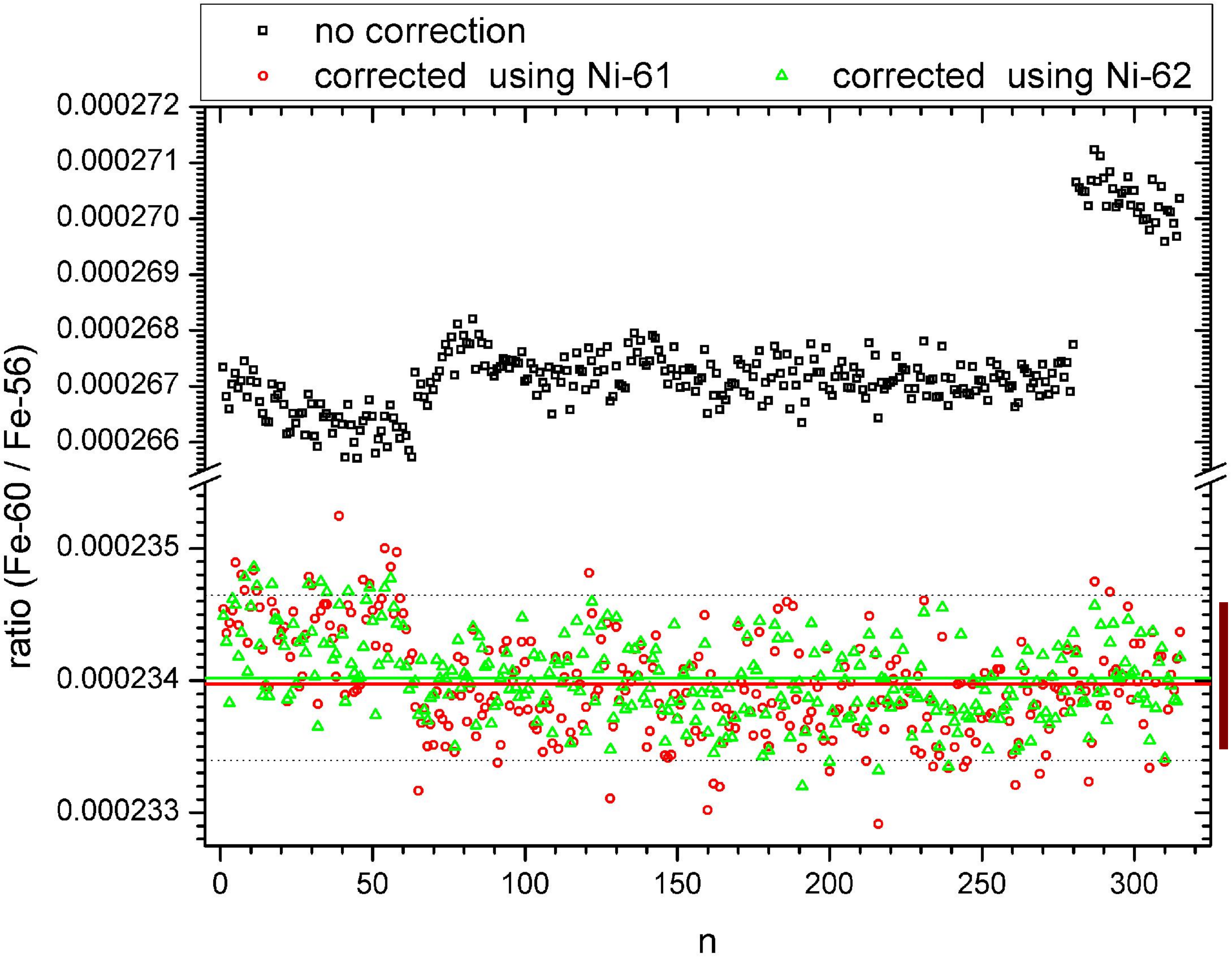
^{60}Ni interference correction

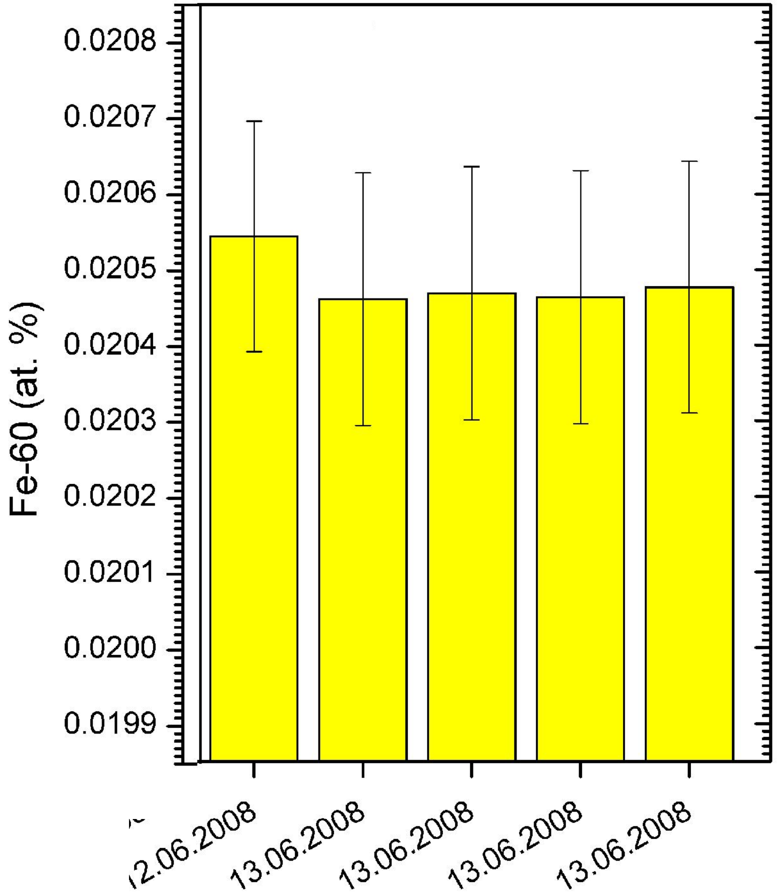


Uncertainty: 0.17% !

From N. Kivel

Isotopic composition

$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$



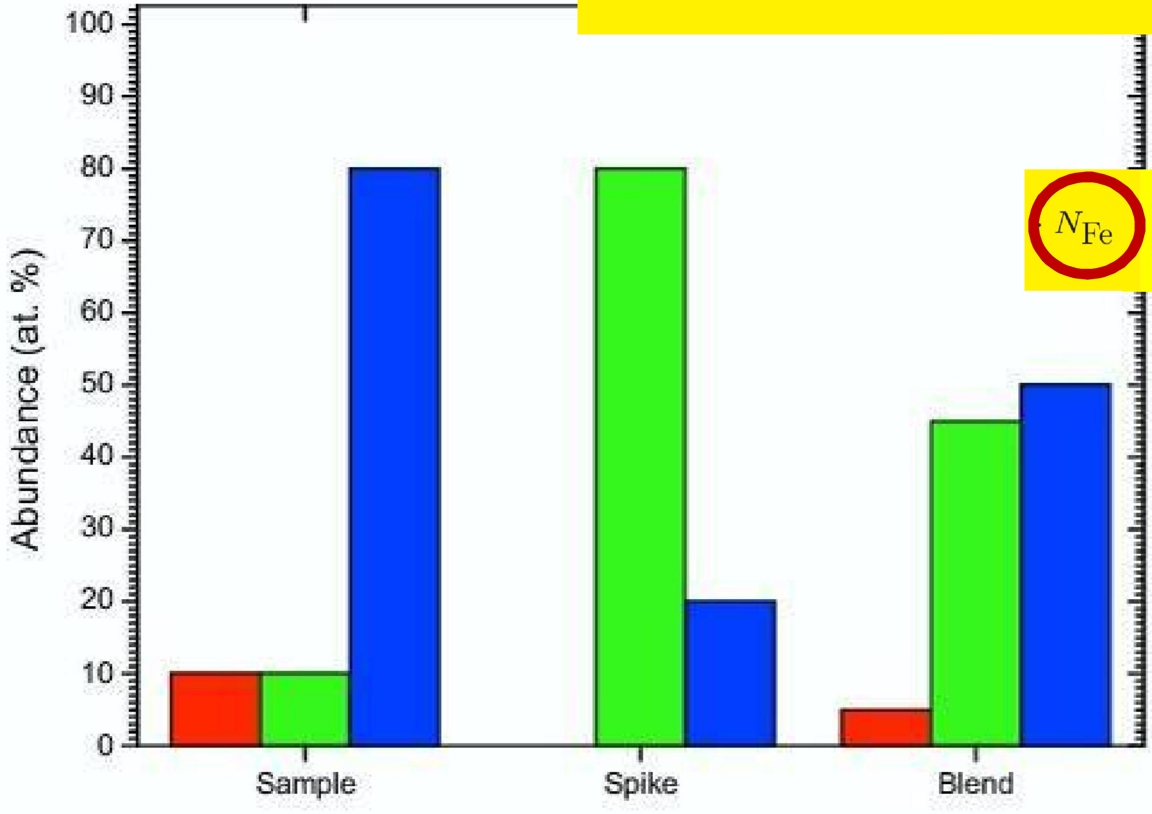
$(2.0483 \pm 0.0035) \times 10^{-4}$

Isotope Dilution MS

isotope	^{54}Fe	^{56}Fe	^{57}Fe	^{58}Fe
percentage [%]	-	3.11	95.10	1.79

$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$

N_{Fe} **(2.662±0.009)mg**



$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$

TABLE II: The various contributions to the uncertainty (1 σ) of the three measurements are listed.

	Rel. Uncertainty [%]	
	stat.	syst.
$A_{^{60}\mathrm{Fe}}$ (*master sample*)		
^{60}Co standard		1.5%
fit	0.23%	
N_{Fe} (*ID sample*)		
weighing		0.18%
ID-ICP-MS	0.28%	
$N_{^{60}\mathrm{Fe}}/N_{\mathrm{Fe}}$ (*N sample*)		
ICPMS	0.18%	
total	0.4%	1.51%

Combination

$$A_{^{60}\mathrm{Fe}} = \lambda_{^{60}\mathrm{Fe}} \cdot N_{^{60}\mathrm{Fe}} = \frac{ln(2)}{T_{1/2}(^{60}\mathrm{Fe})} \cdot \frac{N_{^{60}\mathrm{Fe}}}{N_{\mathrm{Fe}}} \cdot N_{\mathrm{Fe}}$$

$(2.62 \pm 0.04) \times 10^6$ yr

PRL **103,** 072502 (2009) PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2009

New Measurement of the ^{60}Fe Half-Life

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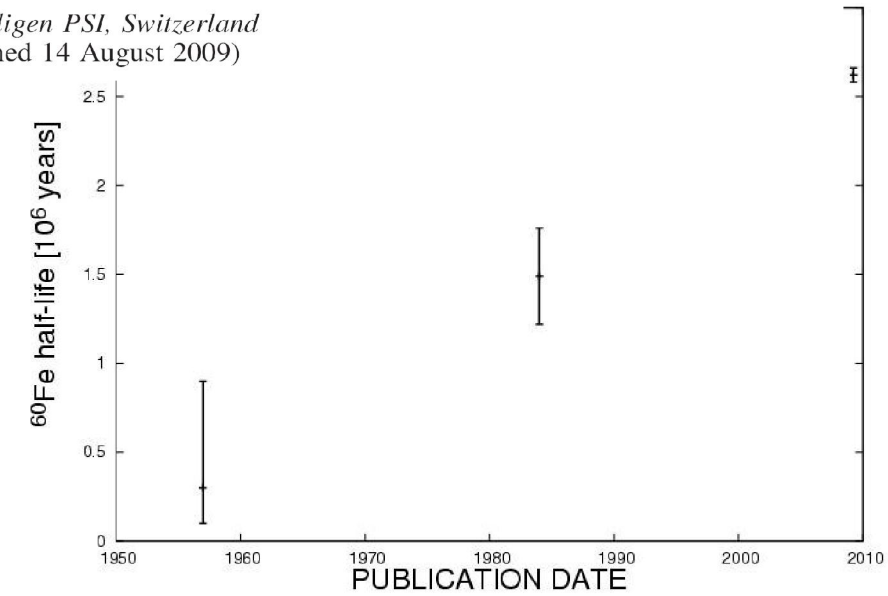
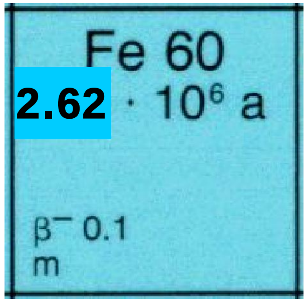
(Received 25 March 2009; published 14 August 2009)



TOI: $T_{1/2}(^{60}\mathrm{Fe})$: (1.49 ± 0.27) Myr

Thanks to my colleagues



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