TECHNISCHE
UNIVERSITÄT
DRESDEN

Institut für Kern- und Teilchenphysik

Neutron activation of materials relevant for GERDA

GERDA-meeting - Assergi / Gran Sasso

Alexander Domula

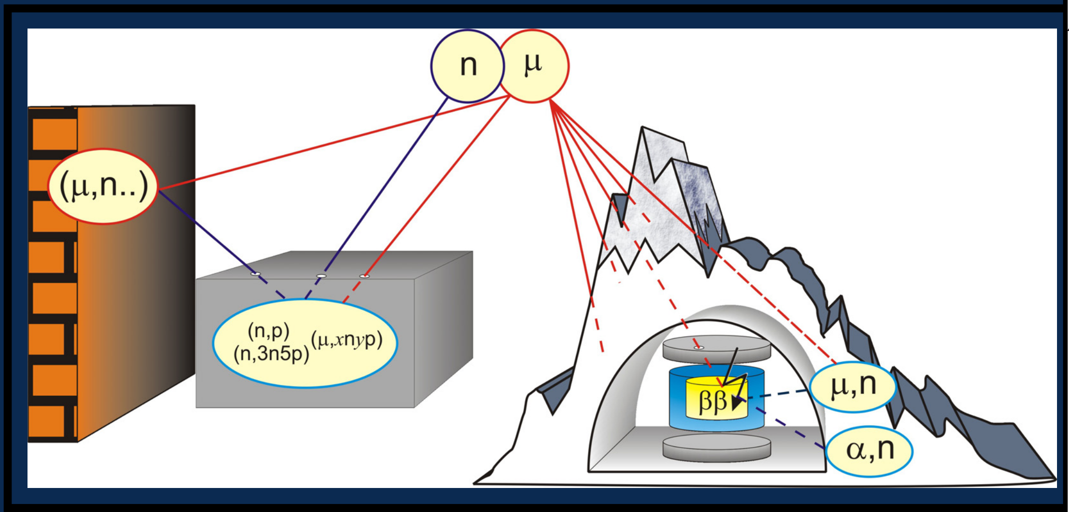
Sept 29th 2009

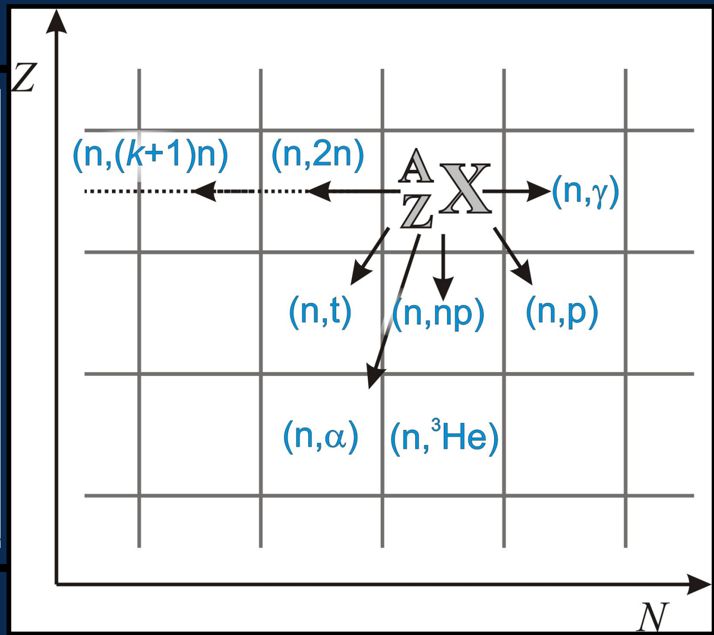
❶ Review: Integral activation of 1.4571 stainless steel and copper

❷ Cross sections @ 14 MeV

❸ Terrestrial neutron Flux

Activation by neutrons





Neutron capture

$${}_Z^A X + \mathrm{n} \rightarrow {}_Z^{A+1} X + \gamma$$

➯ $^{74}Ge(n,\gamma)^{75m}Ge$

Fast neutron activation

$$A + \mathrm{n} \rightarrow B + x$$

➯ $^{59}Co(n,p)^{59}Fe$

Activation of 1.4571 stainless steel and copper

G. Heusser, M. Laubenstein

Cosmic ray ind…

Steel 457.1 sample	
$T_{1/2}$ →	^{7}Be 53.3 d
Production → channels	spallation
G1	≤ 3.9
G2	≤ 3.0
G3	≤ 5.7
G4	9.6±2.9
G5	4.8±1.7
G6	13.6±2.5
G7	≤ 5.9
P.Rate *sea level* $[(10^3\ sec)^{-1}\ kg^{-1}]$	*4.5±0.7*

^{51}Cr: *2.0±*…

^{60}(…

G. H. GERDA collab. me…

Cosmogenic activation of Cu during 270 days at LNGS surface (≈ 930 g/cm2)

radionuclide	halflife	(saturation) activity [µBq/kg]		
cosmogenic		exposed	estimated from Cu used in HDM	estimated
^{56}Co	77.31 d	230 ± 30		557 x2
^{57}Co	271.83 d	1800 ± 400	2100	2147 ✓
^{58}Co	70.86 d	1650 ± 90	3600	3878 x2
^{60}Co	5.27 y	2100 ± 190	2100	2367 ✓
^{54}Mn	312.15 d	215 ± 21	700	791 x3
^{59}Fe	44.5 d	455 ± 120		157 :4
^{46}Sc	83.79 d	53 ± 18		93 ✓
^{48}V	15.97 d	110 ± 40		
primordial				
^{226}Ra (U)	1600 y	< 35	< 16	
^{228}Th (Th)	1.91 y	< 20	< 12	
^{40}K	1.277×10^{9} y	< 120	< 110	

Monte Carlo simulation of hadronic interaction **Cebrian S.**, 2006. (IDEA-Projekt),. http://idea.dipscfm.uninsubria.it/frontend/docs/reports/report_upgrade_codes.pdf

applying:

activity = PR/2.1 × $(1-e^{-\lambda t})$

⇒ ≤ 37 days exposed at sea level

G. H. ICRM-08, Braunschweig, 25.9.08. (6)

Activation of 1.4571 stainless steel and copper

The activity A after irradiation time t_{irr}

$$A(t_{irr}) = N \cdot \int_{0}^{E_{\max}} \sigma_{\mathrm{B}}(E) \cdot \varphi_{E}(E)\ \mathrm{d}E \cdot \left(1 - e^{-\lambda_{\mathrm{B}} \cdot t_{\mathrm{irr}}}\right)$$

should be calculated from the individual activities of the steel components

Deviations between calculation and experiment!

Activation of 1.4571 stainless steel and copper

Possible reasons:

- Neutron / muon capture cross sections
- Terrestrial neutron flux
- Low abundance isotopes can not be ignored (see Padova 2009)

Cross sections around $E_{\mathrm{n}} = 14\ \mathrm{MeV}$

- $\sigma(E_{\mathrm{n}})$ depends on:
  - Calculated cross sections
  - Experimental data

- Cross sections of steel components and copper up to 20 MeV known

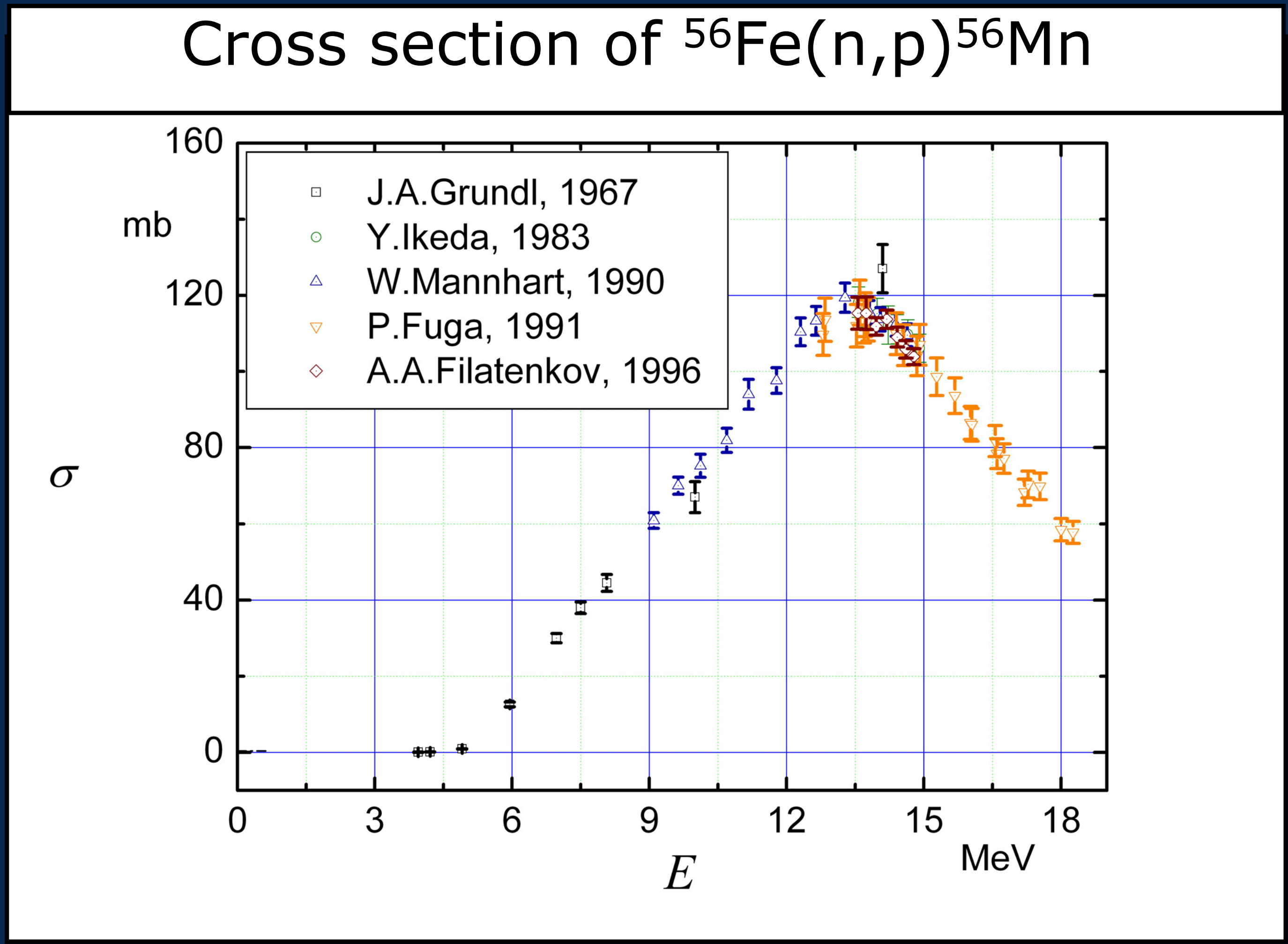
  ➢ Practice cross section determination „calibration of method"

Calibration of method

- Well measured cross section of $^{56}Fe(n,p)^{56}Mn$

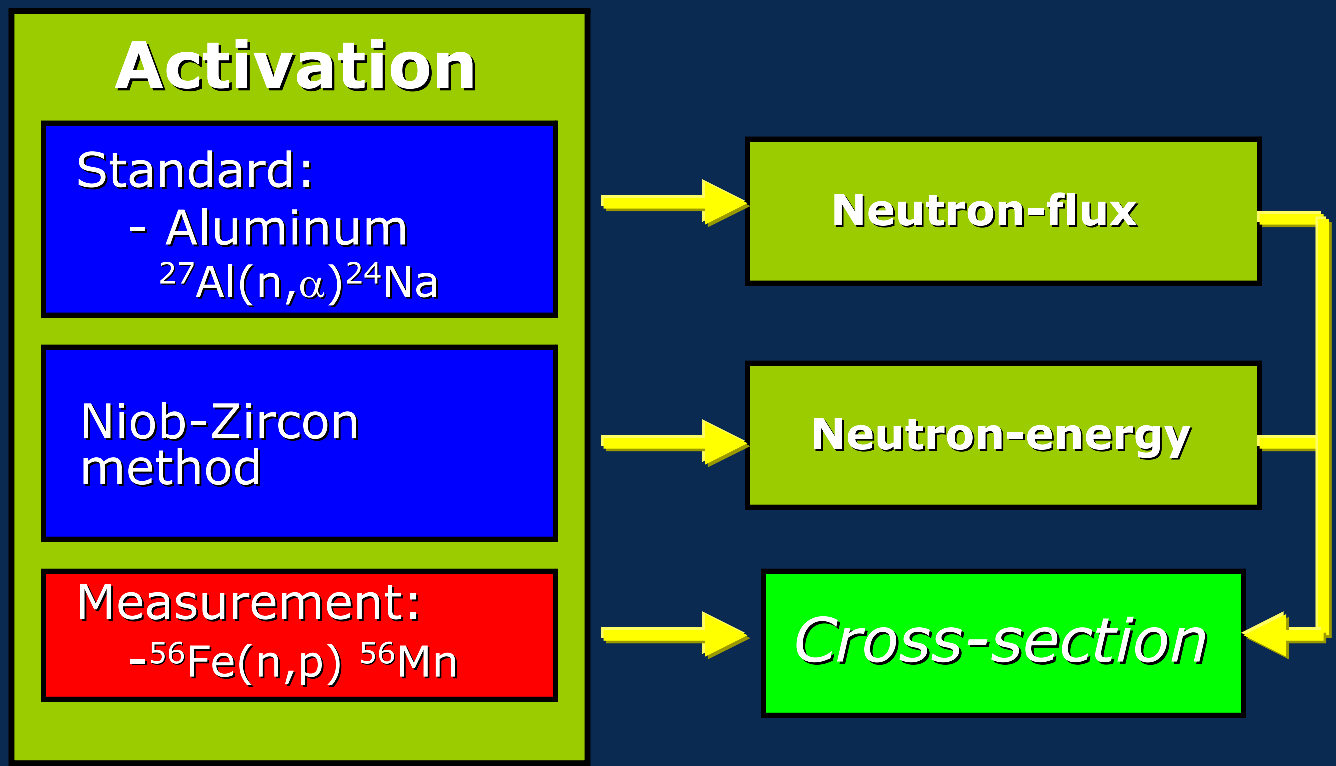
Ni54 0+ EC	Ni55 212.1 ms 7/2- EC	Ni56 6.077 d 0+ EC	Ni57 35.60 h 3/2-	Ni58 0+ 68.077	Ni59 7.6E+4 y 3/2- EC	Ni60 0+ 26.223	Ni61 3/2- 1.140	Ni62 0+ 3.634	Ni63 100.1 y 1/2- β-	Ni64 0+ 0.926	Ni65 2.5172 h 5/2- β-
Co53 240 ms (7/2-) * EC	Co54 193.23 ms 0+ * EC	Co55 17.53 h 7/2- EC	Co56 77.27 d 4+ EC	Co57 271.79 d 7/2- EC	Co58 70.82 d 2+ * E	Co59 7/2- 100	Co60 5.2714 y 5+ *	Co61 1.650 h 7/2- β-	Co62 1.50 m 2+ * β-	Co63 27.4 s (7/2)- β-	Co64 0.30 s 1+ β-
Fe52 8.275 h 0+ * EC	Fe53 8.51 m 7/2- * EC	Fe54 0+ 5.8	Fe5[illegible] 2.73 3/2- EC	Fe56 0+ 91.72	Fe[illegible]7 1/2- 2.2	Fe58 0+ 0.28	Fe59 44.503 d 3/2- β-	Fe60 1.5E+6 y 0+ β-	Fe61 5.98 m 3/2-,5/2- β-	Fe62 68 s 0+ β-	Fe63 6.1 s (5/2)- β-
Mn51 46.2 m 5/2- EC	Mn52 5.591 d 6+ * EC	Mn53 3.74E+6 y 7/2- EC	Mn54 312.3 d 3+ EC,β-	Mn55 5/2- 100	Mn56 2.5785 h 3+ β-	[illegible]n57 [illegible]5.4 s [illegible]/2- β-	Mn58 3.0 s 0+ * β-	Mn59 4.6 s 3/2-,5/2- β-	Mn60 51 s 0+ * β-	Mn61 0.71 s (5/2-) β-	Mn62 0.88 s (3+) β-
Cr50 1.8E+17 y 0+ ECEC 4.345	Cr51 27.702 d 7/2- EC	Cr52 0+ 83.789	Cr53 3/2- 9.501	Cr54 0+ 2.365	Cr55 3.497 m 3/2- β-	Cr56 5.94 m 0+ β-	Cr57 21.1 s 3/2-,5/2-,7/2- β-	Cr58 7.0 s 0+ β-	Cr59 0.74 s β-	Cr60 0.57 s 0+ β-	Cr61

Calibration of method

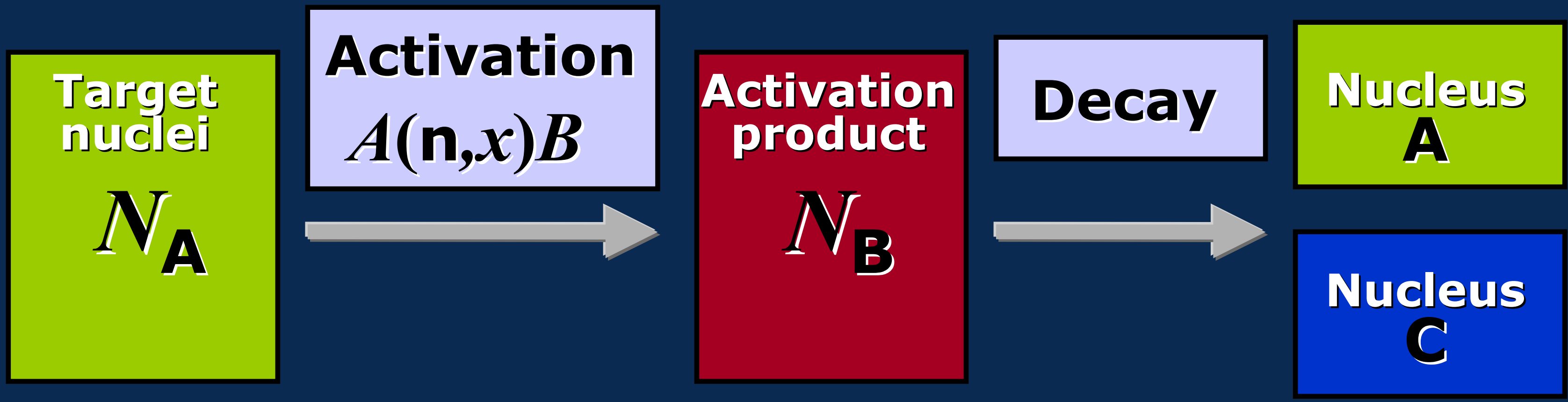


Calibration of method

- Principle of relative measurement



Calibration of method



- Production of the nucleus B

$$\left(\frac{\mathrm{d}N_{\mathrm{B}}}{\mathrm{d}t}\right) = N_{\mathrm{A}} \cdot \int_{0}^{E_{\max}} \sigma_{\mathrm{B}}(E) \cdot \varphi_{E}(E)\ \mathrm{d}E$$

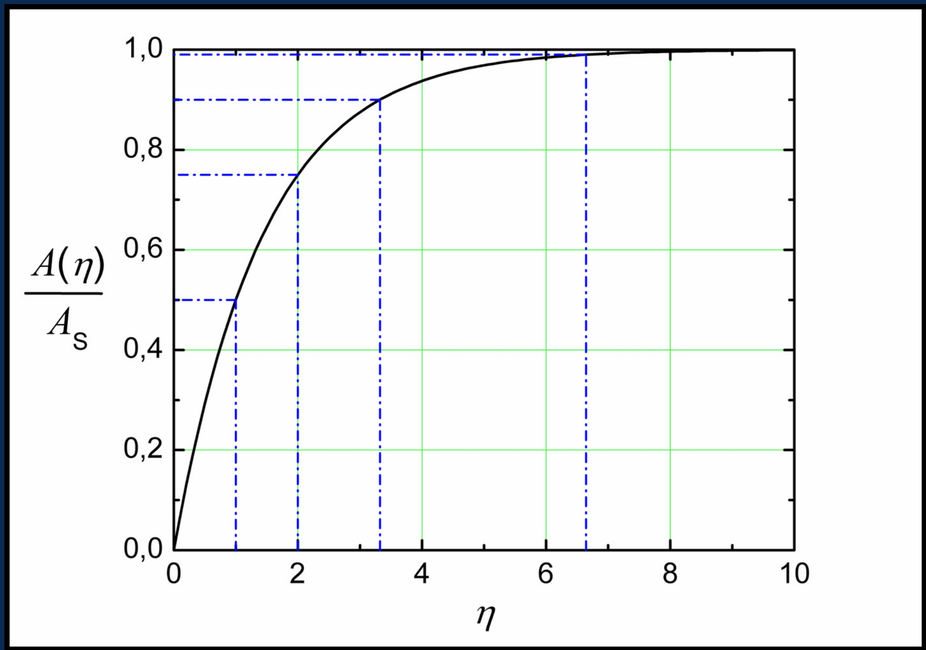
- Decay of the nuclei B:

$$\left(\frac{\mathrm{d}N_{\mathrm{B}}}{\mathrm{d}t}\right) = -\lambda \cdot N_{\mathrm{B}}$$

Calibration of method

- 50% saturation activity reached after $t_{irr} = T_{1/2}$

$$A(t_{irr}) = N \cdot \int_0^{E_{max}} \sigma_B(E) \cdot \varphi_E(E)\ \mathrm{d}E \cdot \left(1 - e^{-\lambda_B \cdot t_{irr}}\right)$$



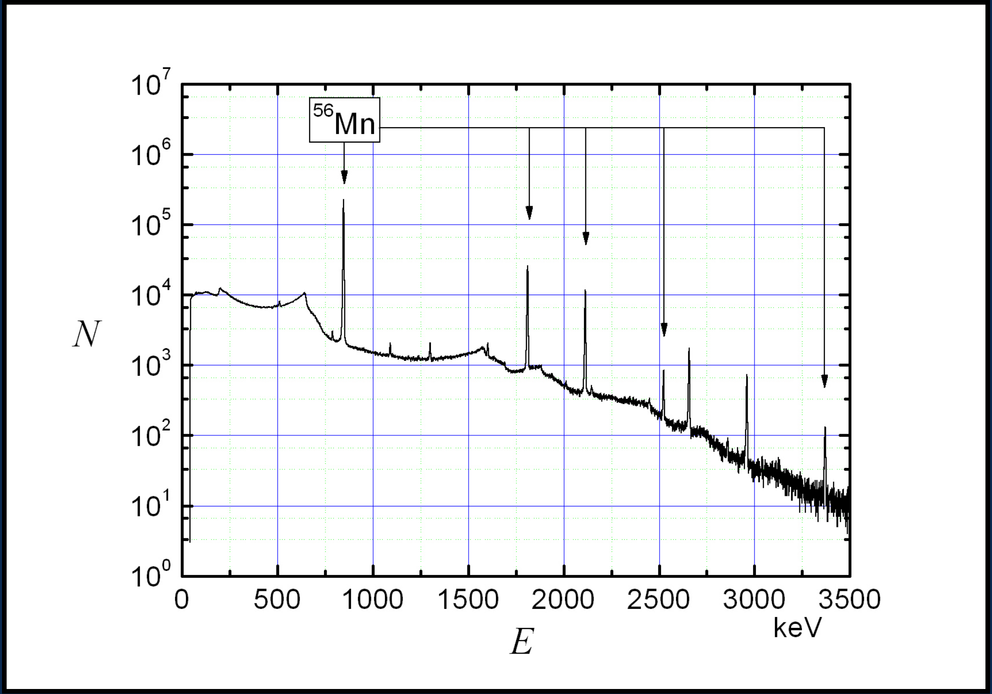
$$A_S = N \cdot \int_0^{E_{max}} \sigma_B(E) \cdot \varphi_E(E)\ \mathrm{d}E$$

Important quantity!!!

$$\eta = \frac{t_{irr}}{T_{1/2}}$$

Calibration of method

- Determination of sample activities by HP-Ge detector, taking into account:
  - Self absorption
  - Summing correction



E [keV]	Nuclid
846,8	*56-Mn*
1811,38	*56-Mn*
2114,04	*56-Mn*
2524,18	*56-Mn*
3371,28	*56-Mn*

Cross section of $^{56}Fe(n,p)^{56}Mn$

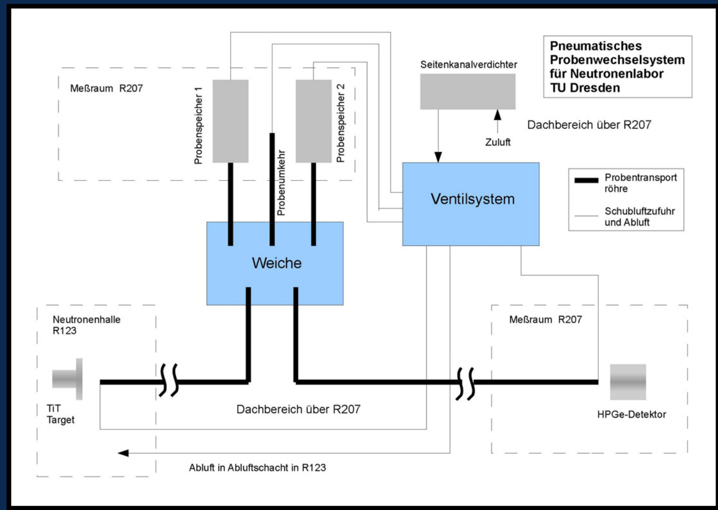
- Evaluated cross section σ = 115,2±4 mb (EXFOR)

- Determined cross sections:
  - σ = 122 mb ($^{93}Nb(n,2n)^{92m}Nb$)
  - σ = 123 mb ($^{27}Al(n,\alpha)^{24}Na$)

- Good agreement, method okay

- Ready to determine unknown cross sections

Next steps on 14 MeV neutrons



- Shorter half lifes
  - Pneumatic tube system
- Lower cross sections
  - Higher fluxes with rotation target
  - Anti compton veto
- In addition measurements at higher energies

Terrestrial neutron flux – searching for datapoints

- IBM paper James F. Ziegler:
  - Most known paper Hess et. al 1959:
    - Authors died or not found
    - E. L. Chupp does not agree with Ziegler, advised Gordons paper
  - Hughes et al. 1966, J. Geophys. Rev. 21, 1435
    $\rightarrow$ archive: both authors died

Terrestrial neutron flux – searching for datapoints

- Ashton et al. 1971, J. Phys. A: Gen. Phys. 4, 352
  $\rightarrow$ Not reachable anymore
- Heidbreder et al. 1971, J. Geophys. Rev. 76, 2905
  $\rightarrow$ Measuring points not available anymore
- Preszler et al. 1974. J. Geophys. Rev. 79, 17
  $\rightarrow$ Measuring points disappeared

Terrestrial neutron flux – searching for datapoints

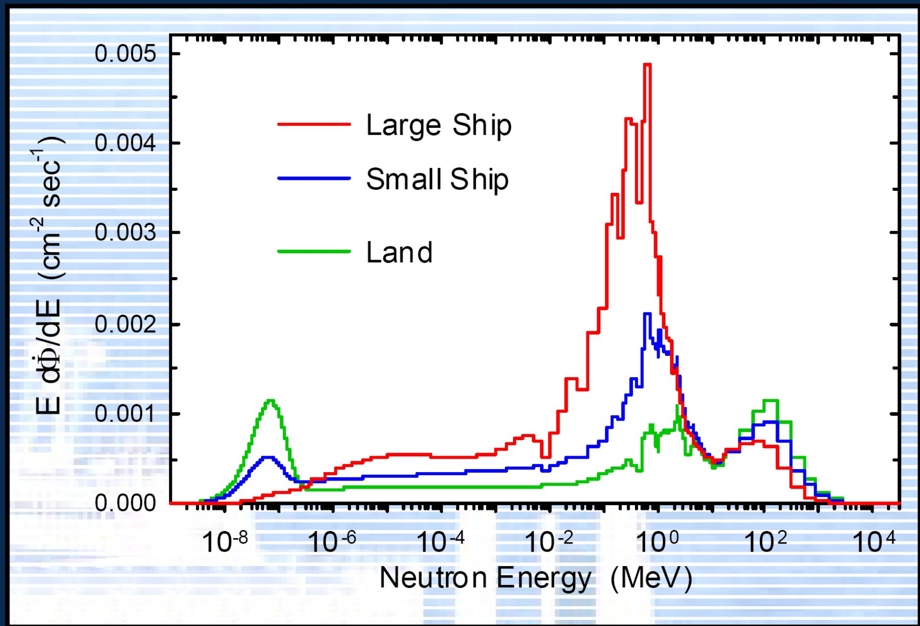
- J. F. Ziegler: data is missing

- Only data: - Gordon (2004)
  - IAEA Report 2001

→ We need at least a 2nd valid measurement to trust the spectra!!

Terrestrial neutron flux – searching for datapoints

- Ship effect: influence of the surrounding matter on the neutron spectra
  → Moderation of neutrons takes effect on activation



- P. Goldhagen

- Conclusion: Plan for new measurement

Conclusions

- Ready for cross section measurement @ 14 MeV
  - Shorter half lifes
  - Lower cross sections

- Measurement of cross sections at higher neutron energies foreseen

- Need for investigations for the terrestrial neutron flux, we plan an experimental setup