(NA 54) Fast Muon Induced Production of Radionuclides

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The study of the fast muon induced production of radionuclides is crucial for geophysical applications and low-level experiments. For the determination of cross sections describing the fast muon induced production of radionuclides, eleven target elements were irradiated with muons of 100 and 190 GeV, respectively. The experimental set-up for the irradiations is shown in fig. 1. Myon induced particle and photon showers were produced in 2.4 m concrete blocks. Targets were mounted behind these blocks. The lateral shower profiles were measured with iron and nickel monitor foils. Table 1 gives the results of the cross section measurements. The long-lived radionuclides ^{10}Be,^{14}C, ^{26}Al, ^{36}Cl and ^{53}Mn were measured with accelerator mass spectrometry, the short-lived ones with γ spectroscopy. The measured cross sections σ are consistent with a description by σ (E) = $\sigma_0 \cdot \mathrm{E}^\alpha$ with α in the range of 0.7 and the muon energy E in GeV. The cross sections were used to calculate the in-situ production of radionuclides in the lithosphere as function of depth and erosion rate or as function of exposure age and depth before exposure and to determine background contributions in the solar neutrino experiments BOREXINO and LENS, in the dark matter experiment CRESST, and in radionuclide measurements in Hiroshima and Nagasaki.

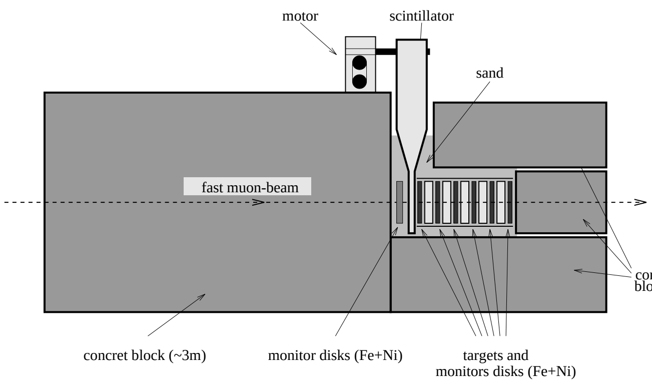

Fig. 1: Set-up for the irradiations of targets with showers from fast muons in the NA54 experiment

Target–element	nuclide	half-life	cross section 190 GeV [mb]
O	^{10}Be	$1.6 \cdot 10^6$a	0.094 ±0.013
O	^{14}C	5730 a	0.45±0.25
Al	^{26}Al	$7.16 \cdot 10^5$a	3.3±1.5
Si	^{26}Al		1.41±0.19
S	^{26}Al		0.22±0.06
Ca	^{36}Cl	$3.0 \cdot 10^5$ a	1.40±0.30
Fe	^{53}Mn	$3.7 \cdot 10^6$ a	3.85±1.1

Table 1: Targets, analysed radionuclides, half-lives and measured fast muon induced cross sections

target	nuclide	half-life	cross section [mb] 100 GeV	190 GeV
O	^{7}Be	53.29 d		0.53 ± 0.11
Al	^{24}Na	14.959 h		0.92 ± 0.15
	^{22}Na	2.6019 a		0.48 ± 0.08
Si	^{22}Na	2.6019 a		0.21 ± 0.05
Fe	^{56}Co	77.27 d	0.029 ± 0.012	0.13 ± 0.04
	^{54}Mn	312.3 d	3.04 ± 0.30	5.51 ± 0.55
	^{52}Mn	5.591 d	0.14 ± 0.02	0.25 ± 0.03
	^{51}Cr	27.702 d	1.07 ± 0.22	2.12 ± 0.41
	^{48}V	15.973 d	0.17 ± 0.04	0.31 ± 0.09
	^{47}Sc	3.345 d	0.070 ± 0.025	0.085 ± 0.030
	^{46}Sc	83.79 d	0.097 ± 0.030	0.21 ± 0.07
Ni	^{57}Ni	35.60 d	4.76 ± 0.48	8.81 ± 0.85
	^{56}Ni	5.90 d	0.14 ± 0.03	0.27 ± 0.05
	^{60}Co	5.2714 a	1.77 ± 0.35	3.42 ± 0.70
	^{58}Co	70.82 d	6.11 ± 0.62	11.7 ± 1.2
	^{57}Co	271.79 d	20.2 ± 2.0	35.8 ± 3.6
	^{56}Co	77.27 d	1.94 ± 0.20	3.60 ± 0.38
	^{54}Mn	312.3 d	0.83 ± 0.16	1.57 ± 0.31
	^{52}Mn	5.591 d	0.20 ± 0.04	0.34 ± 0.07
	^{51}Cr	27.702 d	0.68 ± 0.17	1.17 ± 0.30
	^{48}V	15.973 d	0.14 ± 0.04	0.27 ± 0.08
	^{46}Sc	83.79 d	0.044 ± 0.016	0.072 ± 0.025
Cu	^{60}Co	5.2714 a	0.46 ± 0.09	1.20 ± 0.25
	^{58}Co	70.82 d	0.63 ± 0.10	1.12 ± 0.16
	^{57}Co	271.79 d	0.28 ± 0.04	0.53 ± 0.07
	^{56}Co	77.27 d	0.076 ± 0.014	0.155 ± 0.030
	^{59}Fe	44.503 d	0.052 ± 0.010	0.120 ± 0.020
	^{54}Mn	312.3 d	0.21 ± 0.04	0.40 ± 0.08
	^{52}Mn	5.591 d	0.041 ± 0.012	0.080 ± 0.024
	^{51}Cr	27.702 d	0.185 ± 0.045	0.30 ± 0.09
	^{48}V	15.973 d		0.085 ± 0.025
	^{46}Sc	83.79 d	0.036 ± 0.012	0.072 ± 0.022
Gd	^{160}Tb	72.3 a	0.03 ± 0.01	
	^{155}Tb	5.32 d	0.07 ± 0.03	
	^{159}Gd	18.479 h	9.3 ± 1.0	
	^{153}Gd	241.6 d	2.1 ± 0.3	
	^{157}Eu	15.18 h	0.35 ± 0.11	
	^{153}Eu	15.19 d	0.11 ± 0.06	
Yb	^{172}Lu	6.7 d	0.11 ± 0.04	
	^{171}Lu	8.24 d	0.15 ± 0.03	
	^{175}Yb	4.185 d	27.7 ± 3.9	
	^{169}Yb	32.026 d	7.5 ± 1.1	
	^{166}Yb	56.7 h	0.6 ± 0.2	
	^{168}Tm	93.1 d	0.56 ± 0.25	
	^{167}Tm	9.25 d	1.4 ± 0.3	
	^{165}Tm	30.08 h	0.6 ± 0.2	
	^{172}Er	49.3 h	0.36 ± 0.09	

Table 1: continuation