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PHOTOPROTON REACTIONS ON NATURAL MIXTURE OF STRONTIUM

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s-process – slow neutron capture
r-process – fast neutron capture
p-process – sequential photonuclear reactions (γ,1*n*) or multiparticle reactions (γ,2*n*)

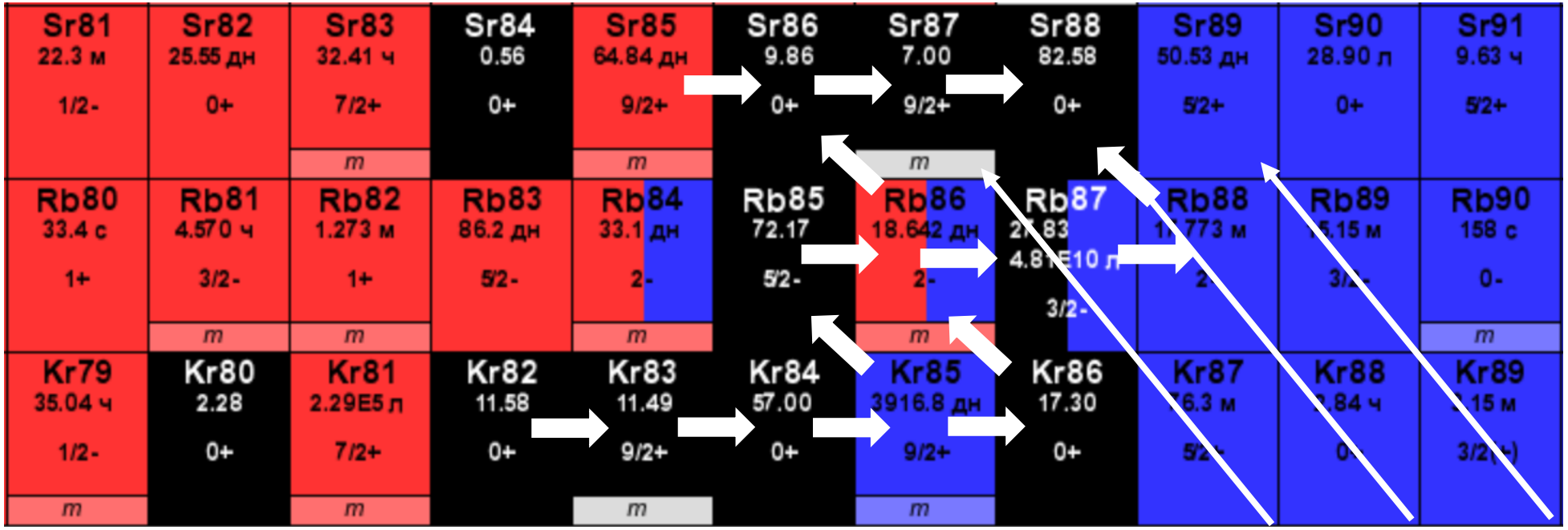


Figure.1. The trajectory of the *s*-process is a wide white line, the *r*-process is a thin white line for isotopes Kr, Rb and Sr Z=36-38

E_{max} = 55 MeV

$t_{short.irr.}$ = 325 s

$t_{long.irr}$ = 3617 s

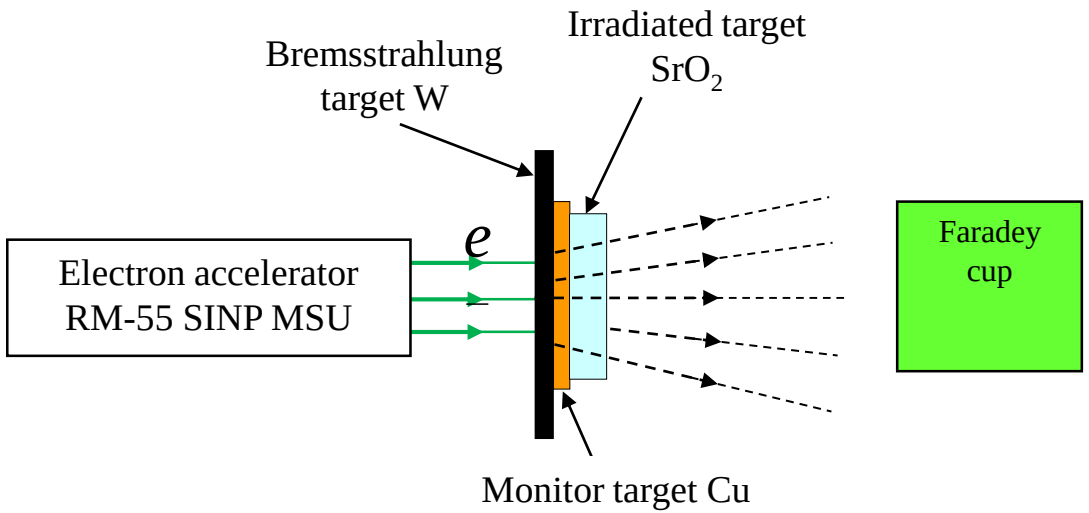
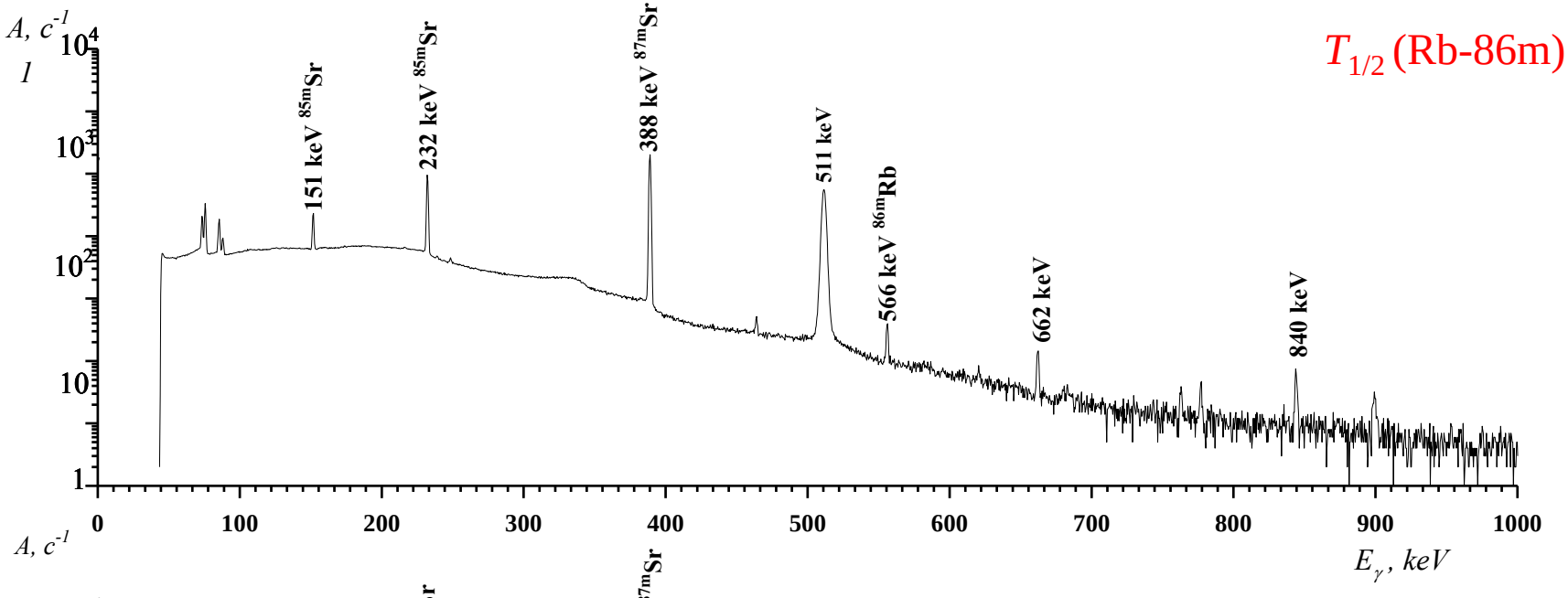
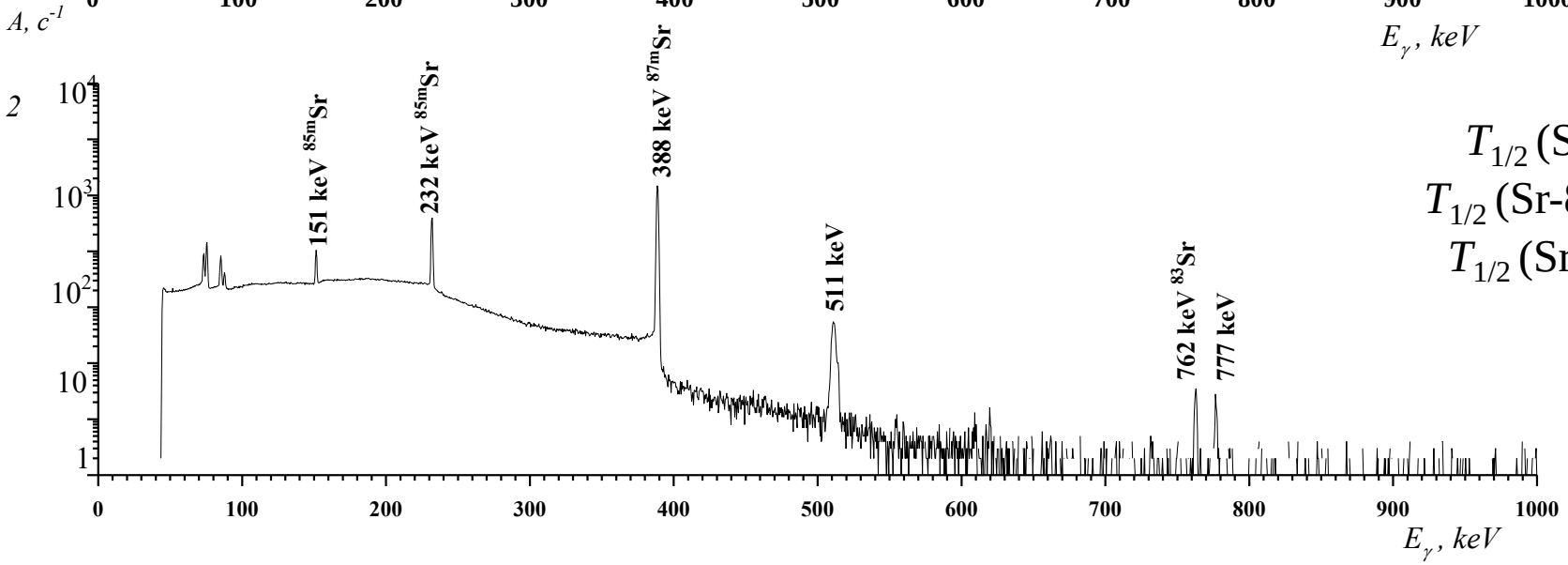


Figure 2. Scheme of the experiment

^{84}Sr (0.56%) + ^{86}Sr (9.86%) + ^{87}Sr (7.00%) + ^{88}Sr (82.58%)



$T_{1/2}$ (Rb-86m) = 1.017 min



$T_{1/2}$ (Sr-83) = 32.41 h
$T_{1/2}$ (Sr-85m) = 67.63 min
$T_{1/2}$ (Sr-87m) = 2.803 h

Figure 3a. Spectra of the residual activity of the irradiated strontium target for 4 min and 1.58 h after the end of irradiation. The duration of spectrum measurements was 30 min (short irradiation)

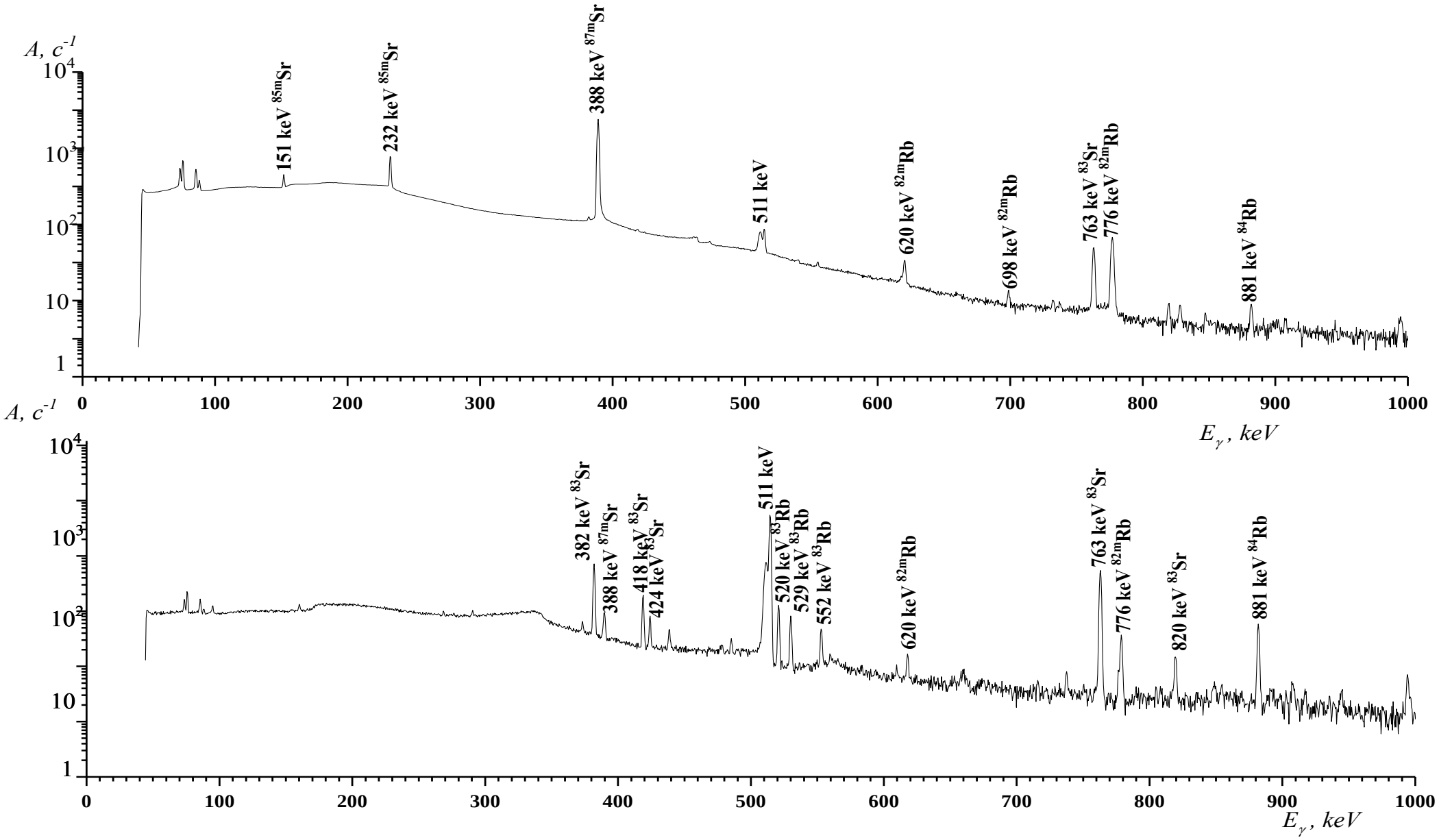


Figure 3b. Spectra of the residual activity of the irradiated strontium target for 2.83 hours and 3.04 days after the end of irradiation. The duration of the spectra measurements was 3 hours

$$y_1 = \frac{N_{10}}{e^{-\lambda_1 t_1} \sum_{i=0}^{t} I(t_i) \cdot e^{\lambda_1 t_i} \Delta t} \quad (1)$$

$$N_{10} = \frac{S}{k \cdot (e^{-\lambda_1 (t_2 - t_1)} - e^{-\lambda_1 (t_3 - t_1)})} \quad (2)$$

where

N_{10} — number of nuclei at the end of irradiation

λ — decay constant

S — photopeak area

I(t) — accelerator current

t_1 — irradiation time

t_2 — start time of spectra measurement

t_3 — end time of spectrum measurement

k — coefficient taking into account cascade transitions and the effect of self-absorption in the target ($k = \varepsilon \cdot I_\gamma \cdot T_{cc}$)

Table 1. Experimental yields of $^{nat}Sr(\gamma,xn1p)$ reaction products produced using bremsstrahlung end-point energy of 55 MeV

№	A	E, keV (I_γ, %)	Y_{exp}, 1/*e*	$T_{1/2}$
1	^{81}Rb	190.46 (64.9), 446.15 (23.5)	$(1.44 \pm 0.11)\cdot 10^{-9}$	4.57 h
2	^{82m}Rb	554.35 (62.4), 619.11 (37.98), 698.37 (26.3), 776.52 (84.39), 827.83 (21), 1007.59 (7.17), 1044.08 (32.07), 1317.43 (23.7), 1474.88 (15.5)	$(5.01 \pm 0.59)\cdot 10^{-10}$	6.47 h
3	^{83}Rb	520.39 (45), 529.59 (29.3), 552.55 (16)	$(3.34 \pm 0.26)\cdot 10^{-8}$	86.2 d
4	^{84}Rb	881.60 (68.9)	$(1.22 \pm 0.39)\cdot 10^{-8}$	32.77 d
5	^{86}Rb	1077.0 (8.64)	$(1.06 \pm 0.04)\cdot 10^{-8}$	18.63 d
6	^{86m}Rb	556.07 (98.21)	$(2.48 \pm 0.04)\cdot 10^{-8}$	1.017 min

The theoretical yield of isotope formation, taking into account all possible reactions leading to the formation of the selected isotope, was calculated by Equation (3):

$$Y = \lambda\alpha\sum_i \eta_i \int_{E_i}^{E_m} \phi(E_\gamma, E_m)\sigma_i(E_\gamma)dE_\gamma \qquad (3)$$

where

λ — a decay constant, α is the number of studied nuclei per 1 cm^2 of target;

index *i* corresponds to the number of the reaction contributing to the formation of studied isotope;

η_i — the percentage of the strontium isotope on which the reaction occurs in a natural mixture of isotopes;

E_i — the threshold of the corresponding reaction, E_m is the maximum energy of the bremsstrahlung spectrum;

$\sigma_i(E_\gamma)$ — the cross-section of the corresponding photoproton reaction;

$\varphi(E_\gamma, E_m)$ — the bremsstrahlung spectrum on the target.

Table 2. Comparison of experimental Y_{exp} and theoretical yields of photonuclear reactions on strontium isotopes, calculated on the basis of TALYS (Y_{TALYS}) . For partial reactions, the second column gives a coefficient equal to the content of stable selenium isotopes in the natural mixture, on which reactions occur, leading to the formation of the studied isotopes

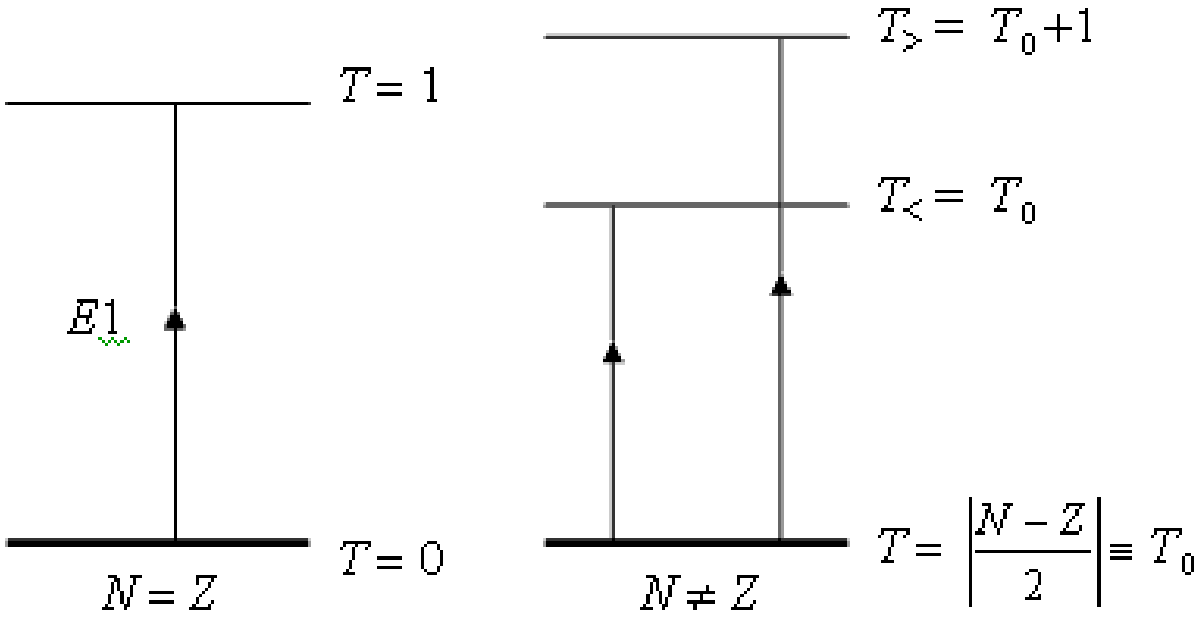
№	A	Reaction	E_{th}, MeV	Yields, 1/*e*	
				TALYS-1.6	Experiment
1	^{81}Rb	^{nat}Sr(γ,in1p) =		$1.12\cdot10^{-9}$	$(1.44 \pm 0.11)\cdot10^{-9}$
		0.0056·^{84}Sr(γ,2n1p) +	28.71	$5.85\cdot10^{-10}$	
		0.0986·^{86}Sr(γ,4n1p)	48.73	$5.39\cdot10^{-10}$	
2	^{82m}Rb	^{nat}Sr(γ,in1p) =		$6.34\cdot10^{-10}$	$(5.01 \pm 0.59)\cdot10^{-10}$
		0.0056·^{84}Sr(γ,1n1p) +	19.81	$3.95\cdot10^{-10}$	
		0.0986·^{86}Sr(γ,3n1p)	39.91	$2.37\cdot10^{-10}$	
3	^{83}Rb	^{nat}Sr(γ,in1p) =		$0.99\cdot10^{-8}$	$(3.34 \pm 0.26)\cdot10^{-8}$
		0.0056·^{84}Sr(γ,1p) +	8.86	$9.63\cdot10^{-9}$	
		0.0986·^{86}Sr(γ,2n1p) +	28.88	$2.58\cdot10^{-10}$	
		0.07·^{87}Sr(γ,3n1p)	36.92	$2.24\cdot10^{-10}$	
4	^{84}Rb	^{nat}Sr(γ,in1p) =		$1.45\cdot10^{-8}$	$(1.22 \pm 0.39)\cdot10^{-8}$
		0.0986·^{86}Sr(γ,1n1p) +	20.13	$9.48\cdot10^{-9}$	
		0.07·^{87}Sr(γ,2n1p) +	28.64	$1.24\cdot10^{-9}$	
		0.8258·^{88}Sr(γ,3n1p) +	40.14	$3.79\cdot10^{-9}$	
5	^{86}Rb	^{nat}Sr(γ,in1p) =		$1.07\cdot10^{-7}$	$(3.56 \pm 0.04)\cdot10^{-8}$
		0.07·^{87}Sr(γ,1p) +	18.07	$1.00\cdot10^{-8}$	
		0.8258·^{88}Sr(γ,1n1p)	29.19	$9.67\cdot10^{-8}$	

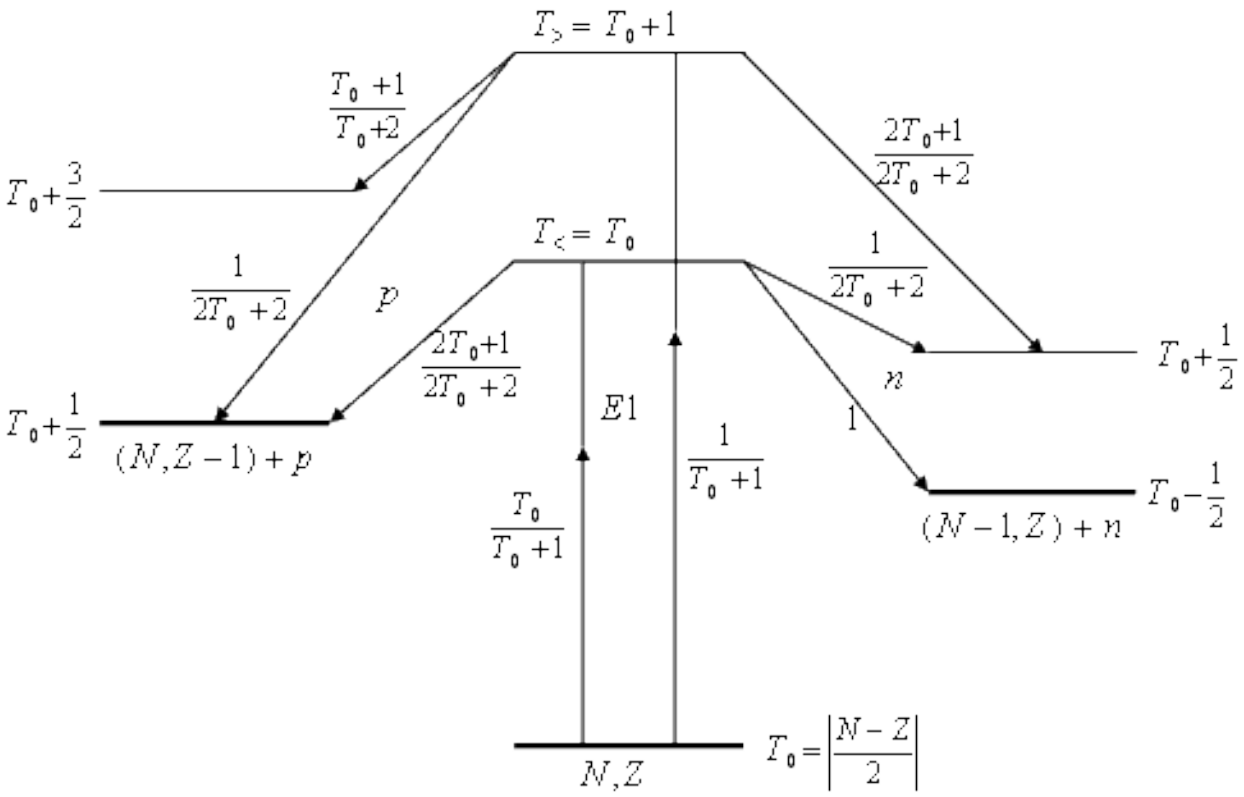
Conclusions

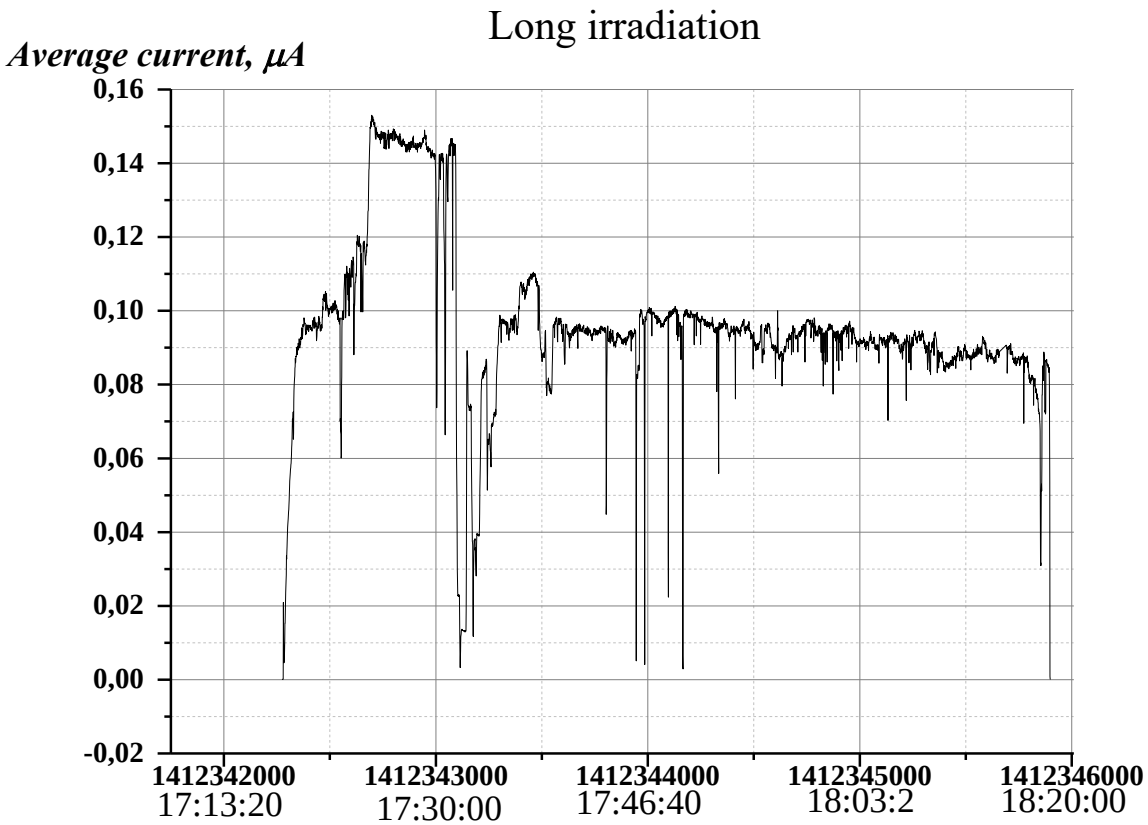
The method of induced activity was used to study photonuclear reactions with a natural mixture of strontium isotopes. The experiment was carried out on the bremsstrahlung of the RM-55 electron accelerator at an electron energy of 55 MeV. The study studied the possibility of obtaining the ^{82}Sr isotope in photonuclear reactions on a natural mixture of strontium isotopes.

There are no experimental data on the cross sections for photoproton reactions on Sr isotopes in the literature. The formation yields of rubidium isotopes ^{81,82m,83,84,86,86m}Rb as a result of ^{nat}Sr(γ,i*n*1*p*) reactions were measured. The experimentally obtained yields of photonuclear reactions are compared with the yields calculated using the theoretical cross sections for photonuclear reactions in TALYS-1.6. The difference in the experimental yields and the theoretical calculations values can be due to two main factors: TALYS uses default photoabsorption cross-sections, and also does not take into account the isospin splitting of the giant dipole resonance, which has a significant effect on the yields of photoproton reactions.

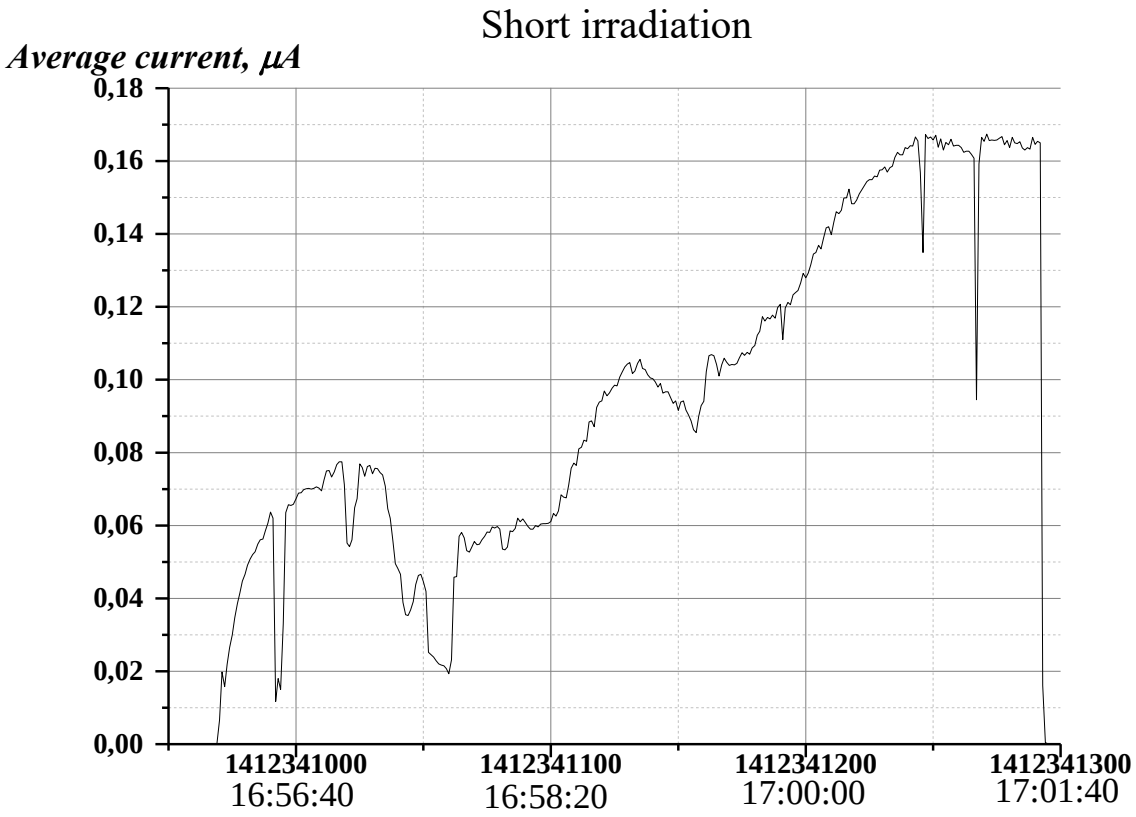
THANK YOU FOR ATTENTION!


$T = 1$
$E1$
$T = 0$
$N = Z$
$T_> = T_0 + 1$
$T_< = T_0$
$T = \left|\frac{N-Z}{2}\right| \equiv T_0$
$N \neq Z$


$T_> = T_0 + 1$
$\frac{T_0+1}{T_0+2}$
$T_0 + \frac{3}{2}$
$\frac{2T_0+1}{2T_0+2}$
$T_< = T_0$
$\frac{1}{2T_0+2}$
p
$\frac{1}{2T_0+2}$
$\frac{2T_0+1}{2T_0+2}$
$T_0 + \frac{1}{2}$
n
$T_0 + \frac{1}{2}$
$(N, Z-1) + p$
$E1$
1
$\frac{1}{T_0+1}$
$T_0 - \frac{1}{2}$
$(N-1, Z) + n$
$\frac{T_0}{T_0+1}$
$T_0 = \left|\frac{N-Z}{2}\right|$
N, Z



a)



b)

Figure 4. Change in the average current of the electron beam of the accelerator:
a) long irradiation; b) short irradiation