ISOTOPE PRODUCTION RATES IN THE LEAD TARGET OF THE “ENERGY PLUS TRANSMUTATION”-SETUP IN THE REACTION D+Pb AT 2,52 GEV

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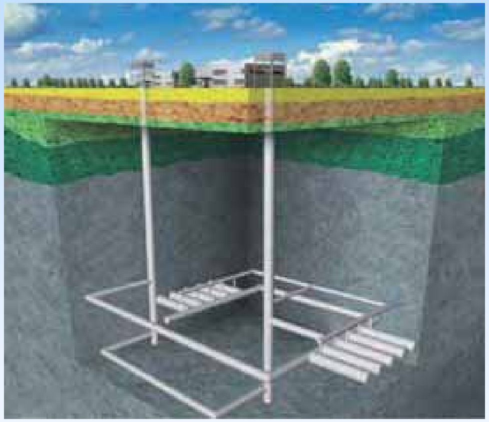
The need of studies for future options of Nuclear power

Contemporary Nuclear Power

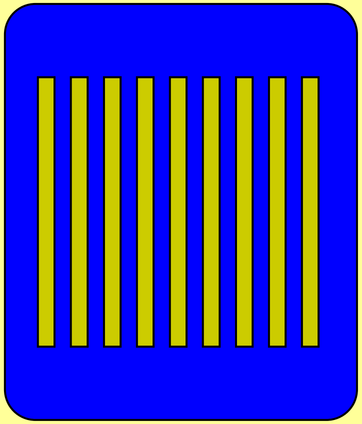
- Favorable price of the produced energy
- clean - limited emission of CO_2 compared to the amount of produced power
- dependable- one of high-tech branches of world's economy
- Environmentaly friendy?: depends on the existence of long-term storage capabilities



Expanding Nuclear Power Production?

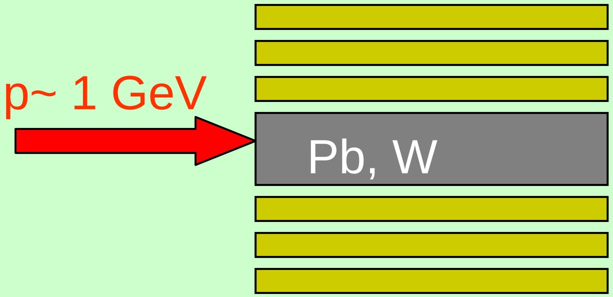
- Fast rising energy demands of growing economies
- Economic growth + reduction of greenhouse gas emissions
- Avoiding of storage needs for large quantities of radioactive wastes
- Need for new approaches for future energy production

A possible approach:
Accellerator Driven Systems (ADS)-



Contemporary technology

- Self sustaining reaction
- Use of enriched fuel
- "Criticality" of the reactor
- Need of long-term storage of the produced radioactive wastes



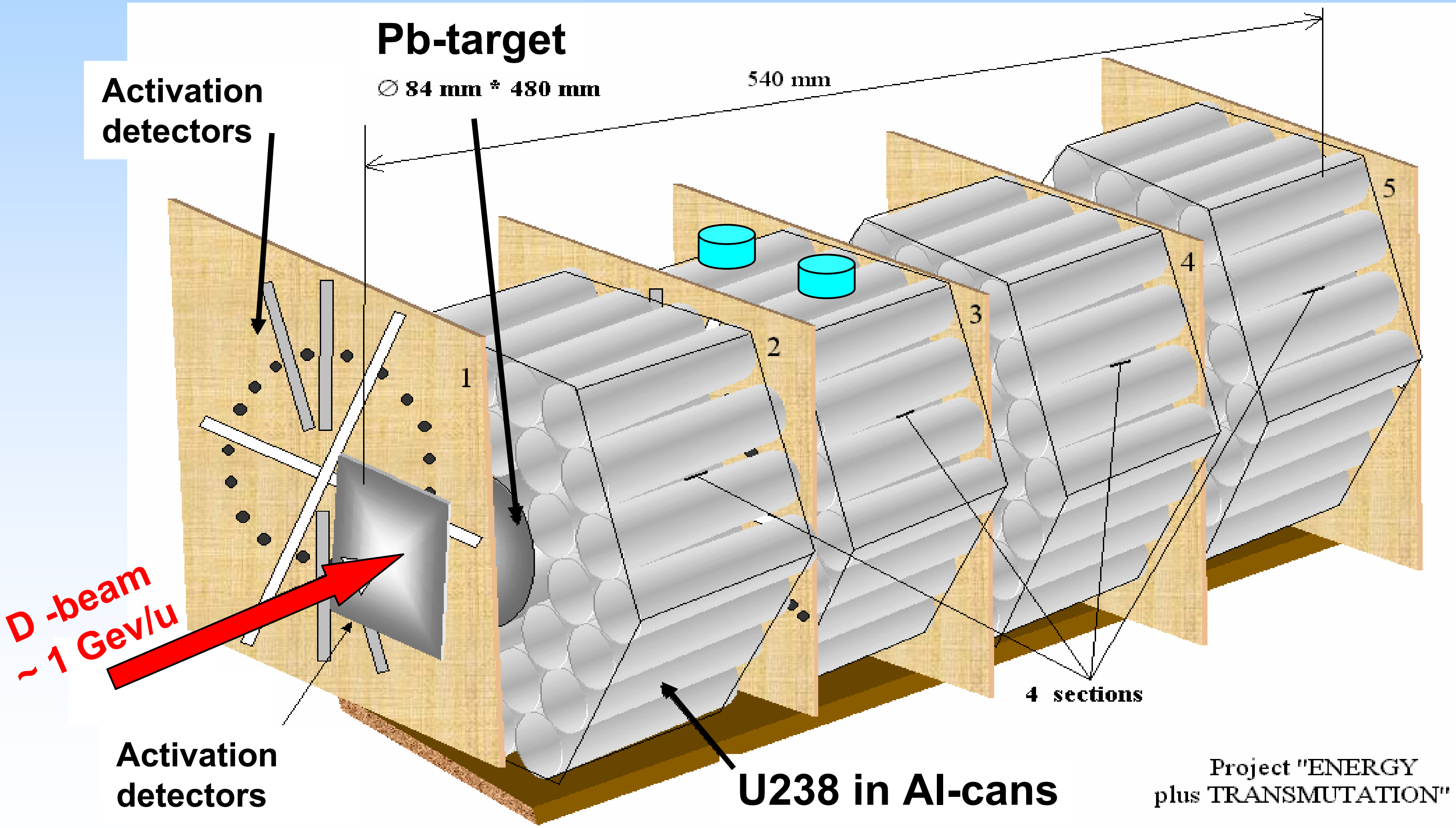
ADS

- No need for fuel enrichment
- Use of an external neutron source
- Sub-critical operation
- Transmutation of long-living and toxic radioactive components
- Stable operating high-current accelerator required

The “Energy plus Transmutation” experiment, JINR Dubna: A sub-critical assembly for transmutation studies following the ADS concept

Studies of (n,γ) , (n,f) , (n,xn) reactions in the neutron field generated in the irradiation of the U/Pb-target-blanket-assembly with relativistic proton/deuteron beams

Samples: Pu238,239, Np237, I129, I127, Bi, Al, Fe, Dy, La, In, Pb, Au

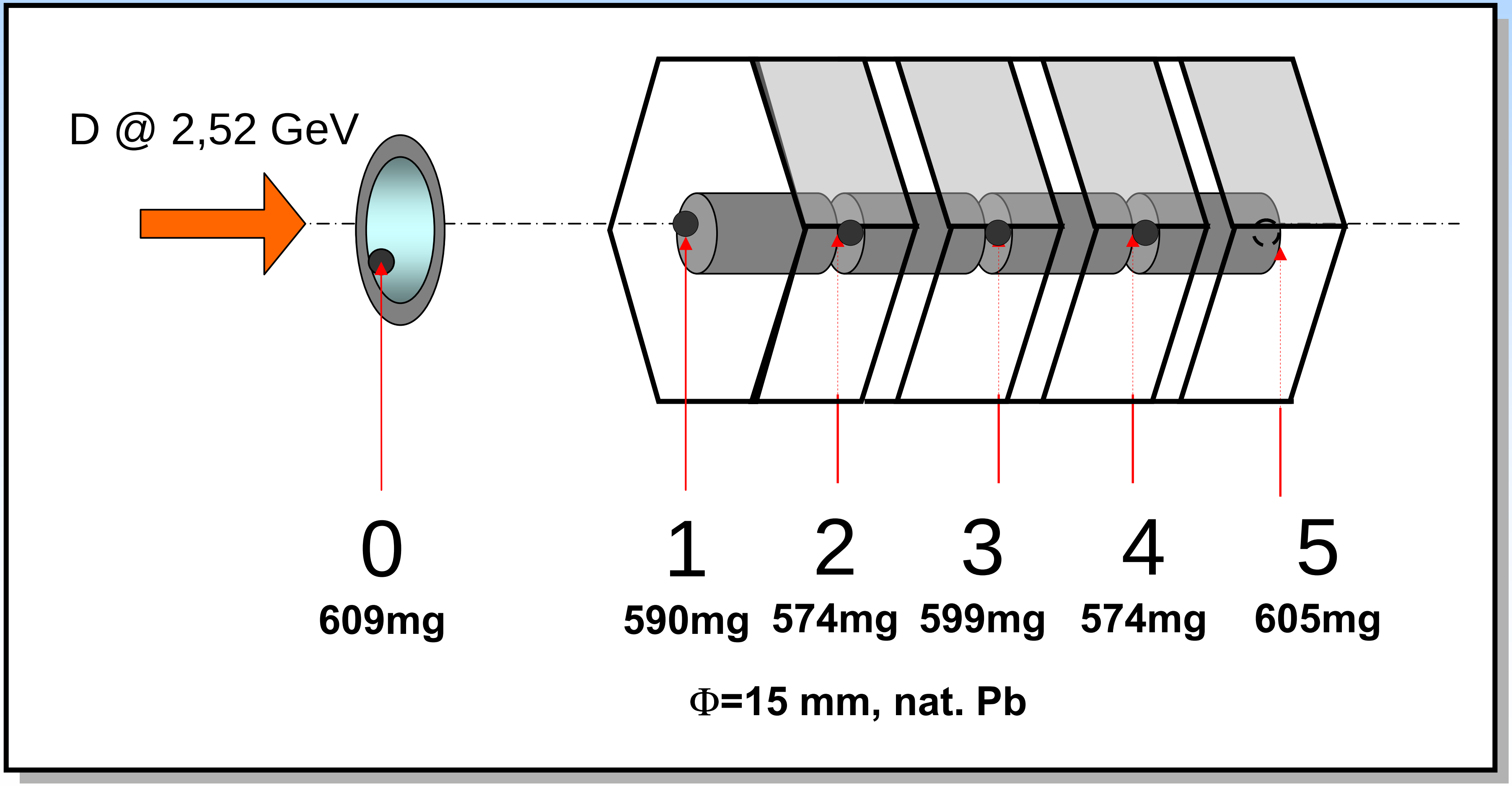


Drawing by M. I. Krivopustov and T. Tumendelger, JINR Dubna

Target-Blanket System “Energy & Transmutation”,
Experiments’ hall of the Nuclotron facility

Experimental studies on nuclide production in the Pb-target

- Six Pb-samples
- Experimental data for the nuclide production in the Pb-target
- Comparison of the experimental data with calculations



•Production of β+ radioactive nuclides
•Identification of the produced nuclides by precision gamma-spectroscopy of the samples using HPGe detectors
•Assignment of the observed gamma-transitions to the corresponding decaying nuclides
•“Off-line” gamma-spectroscopy e.g. after the end of the irradiation
•The determination of the isotope production rates is based on the measurement of the absolute intensity of the assigned gamma-transitions

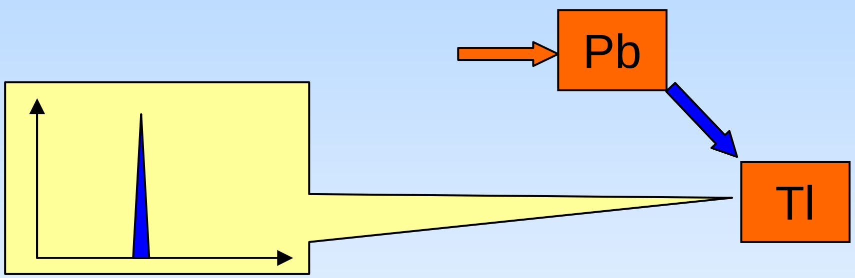
							121					126	
				118	83	203	204	205	**206**	207	208	209	**Bi**
82	197	198	199	200	201	**202m**	**203**	204	205	206	207	208	**Pb**
81	196	197	198	199	200	201	202	203	204	205	206	207	**Tl**
80	195	196	197	198	199	200	201	202	203	204	205	206	**Hg**
	79	195	196	197	198	199	200	201	202	203	204	205	**Au**

The production rate of an isotope (A,Z) is defined as:

$$R_{A,Z} = \frac{N_{A,Z}}{Y_{total}.N_{nat.Pb}}$$

[number of prod. nuclei/incoming deuteron/target atom]

<u>Analysis of the isotopes of Bi and Pb: 1-step decay</u>



$$A(E_\gamma, i)_{A,Z} = N(t_{end.})_{A,Z}.\left(\exp\left(-\lambda_{A,Z}.(t_i - t_{end})\right) - \exp\left(-\lambda_{A,Z}.(t_i + \delta_i - t_{end})\right)\right).I_\gamma.\varepsilon(E_\gamma).P_{esc}(E_\gamma)$$

Area of the gamma-line in spectra "i"

Amount of the decaying isotope

Decay constant

Start of the measurement

End of irradiation

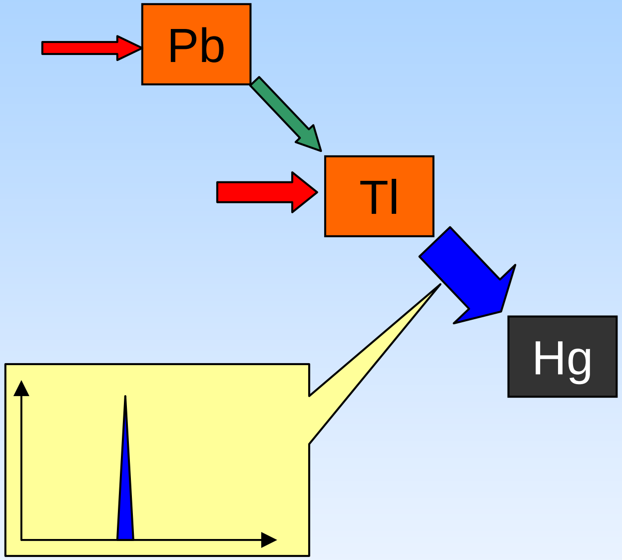
Duration of the measurement

Relative Intensity of the gamma-transition

Absolute detection efficiency

Absorption probability of the outgoing radiation within the volume of the sample

Analysis of isotopes of Tl: 2 feeding and two decay channels



$$\frac{dN_1}{dt} = -\lambda_1.N_1$$

$$\frac{dN_2}{dt} = -\lambda_2.N_2 + \lambda_1 N_1$$

$$N_2(t) = \frac{\lambda_1.N_1^0}{\lambda_2 - \lambda_1}.\exp(-\lambda_1.t) + \left(N_2^0 - \frac{\lambda_1.N_1^0}{\lambda_2 - \lambda_1}\right).\exp(-\lambda_2.t)$$

$$D_2(t_1,t_2) = \frac{\lambda_2.N_1^0}{\lambda_2 - \lambda_1}.\left[\exp(-\lambda_1.t_1) - \exp(-\lambda_1.t_2)\right] + \left(N_2^0 - \frac{\lambda_1.N_1^0}{\lambda_2 - \lambda_1}\right).\left[\exp(-\lambda_2.t_1) - \exp(-\lambda_2.t_2)\right]$$

- Nuclei of Pb and Tl are produced by each spill of the accelerator, the produced amounts are proportional to the R-factors and the number of D-nuclei.
- The number of D-nuclei in each spill are known
- The production rate of the nuclide R(A,Tl) can be calculated if R(A,Pb) is known and a sum over all spills is taken.

Measured number
Of decays of (A,Tl)

known

$$D(t_1,t_2) = R_{A,Pb}.\sum_j \frac{\lambda_2.y(t_j).N_{nat.Pb}}{\lambda_2-\lambda_1}.\left[\exp\left(-\lambda_1.(t_1-t_j)\right)-\exp\left(-\lambda_1.(t_2-t_j)\right)\right]+$$

$$+.R_{A,Tl}.\sum_j y(t_j).N_{nat.Pb}.\left[\exp\left(-\lambda_2.(t_1-t_j)\right)-\exp\left(-\lambda_2.(t_2-t_j)\right)\right]-$$

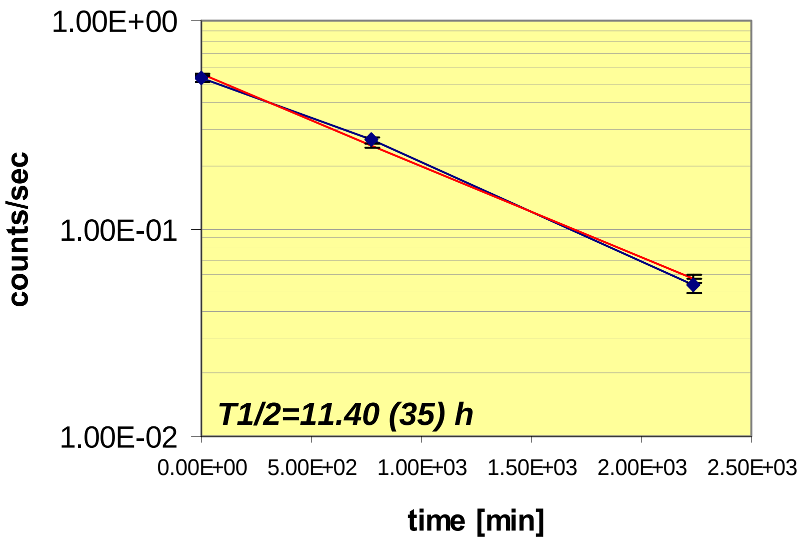
To be determined

$$-R_{A,Pb}\sum_j \frac{\lambda_1.y(t_j).N_{nat.Pb}}{\lambda_2-\lambda_1}.\left[\exp\left(-\lambda_2.(t_1-t_j)\right)-\exp\left(-\lambda_2.(t_2-t_j)\right)\right]$$

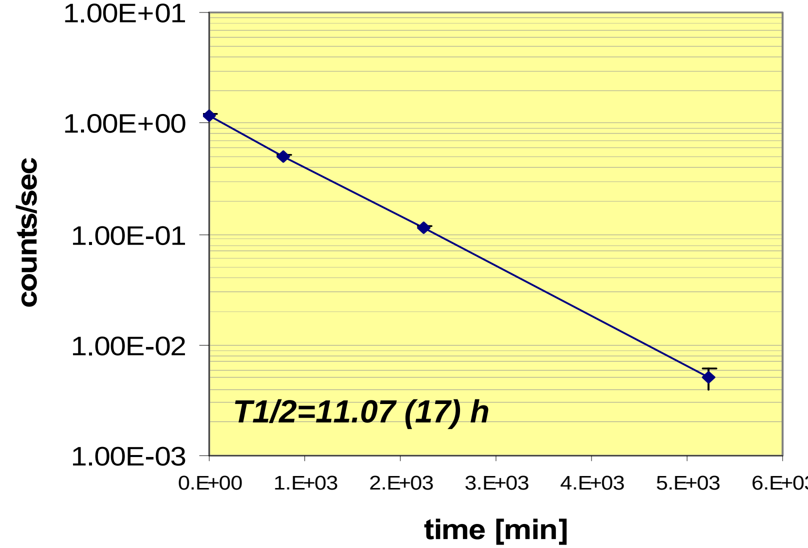
known

Lit.: T1/2=11.22 (10) h

204Bi, 984.02 keV

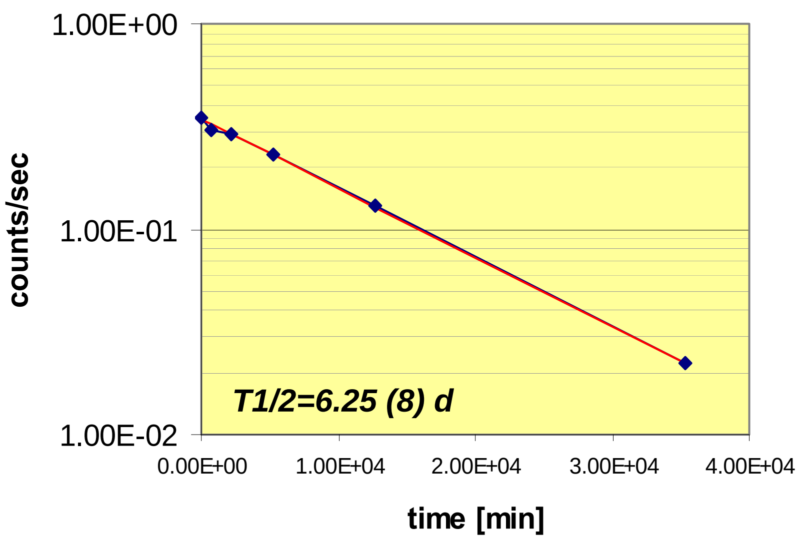


204Bi, 899.15 keV

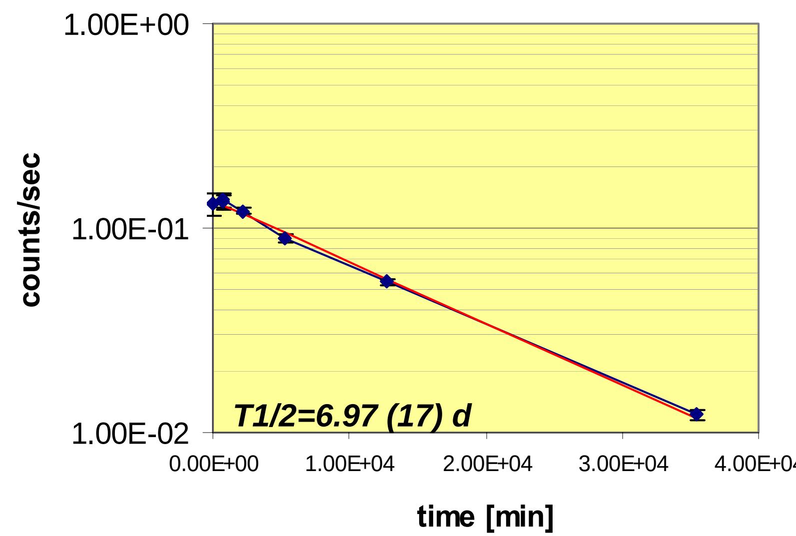


Lit.: T1/2=6,243 (3) d

206Bi, 803.10 keV

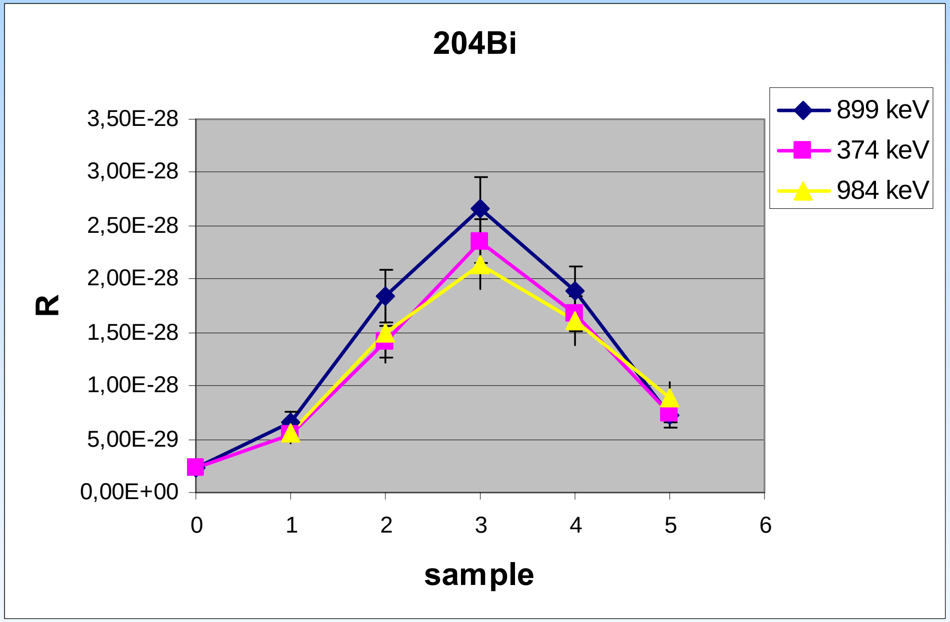


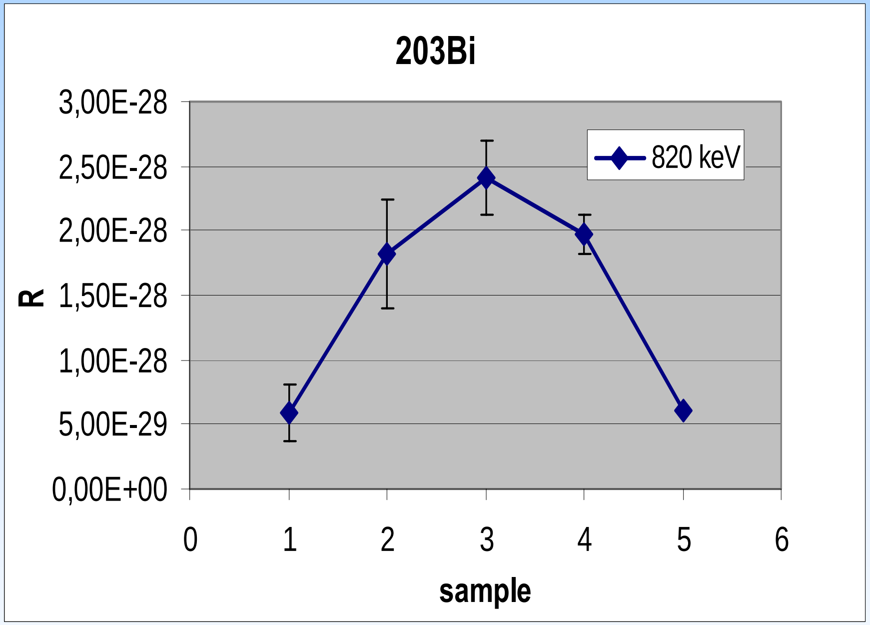
206Bi, 343.51 keV



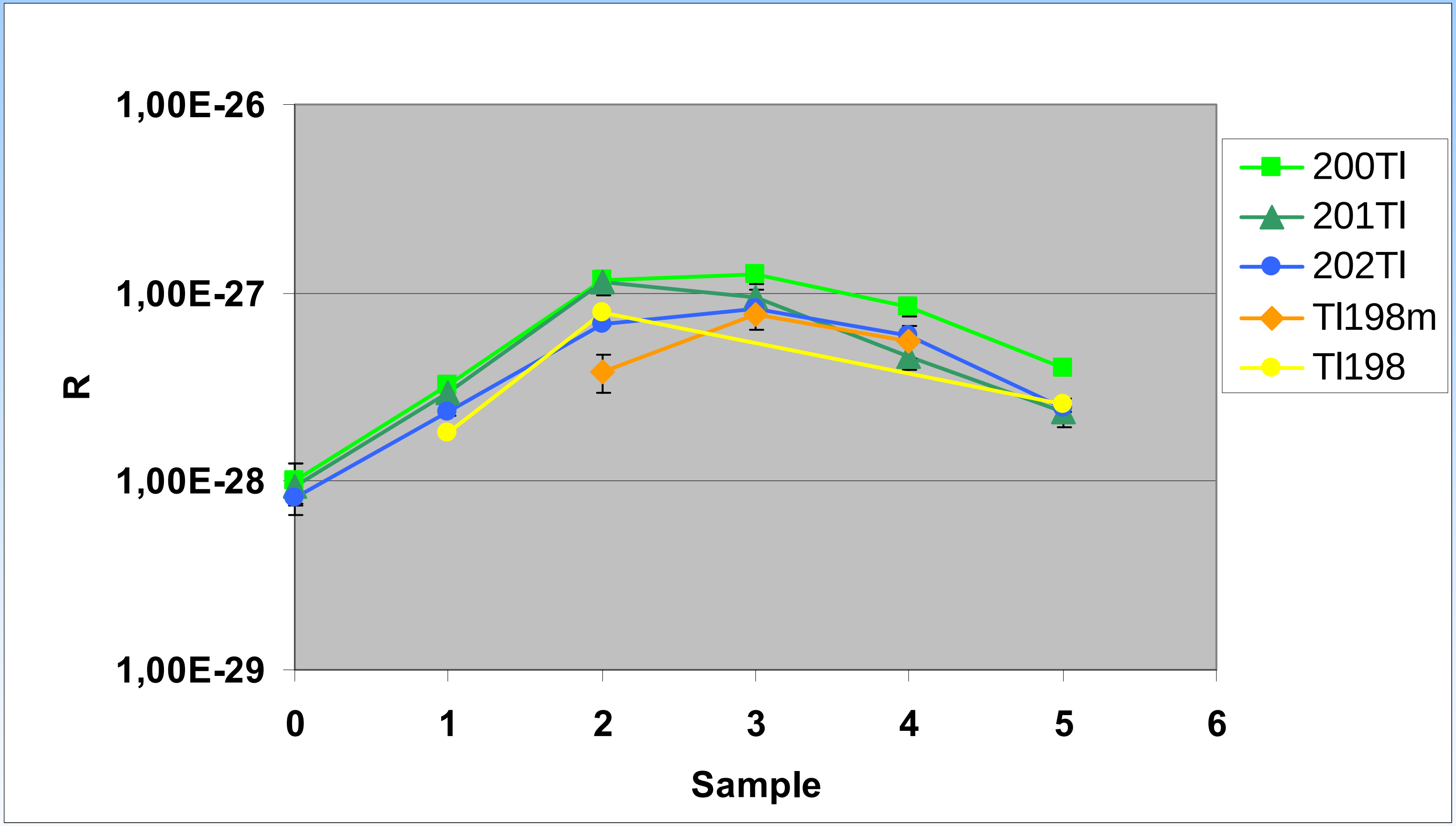
Results

Production rates of Bi-isotopes

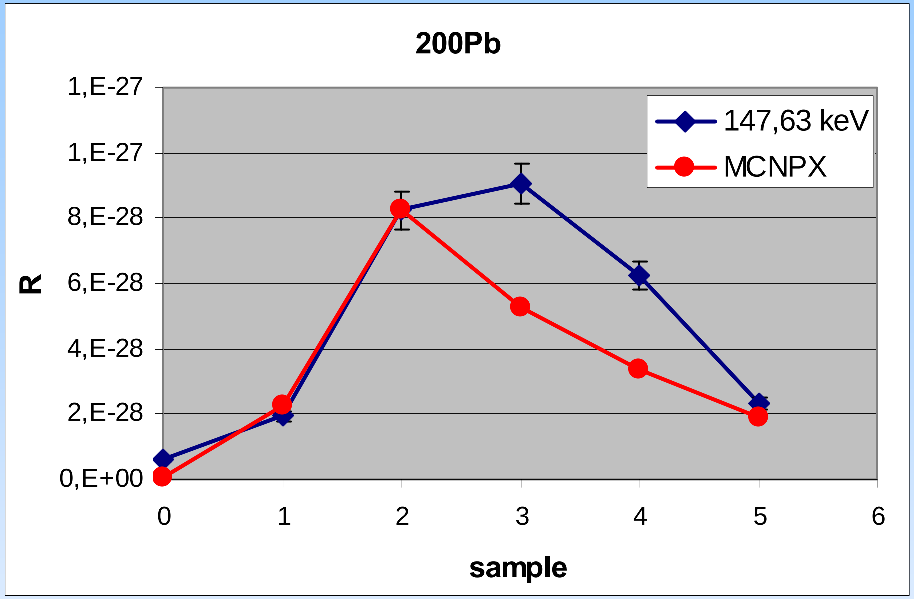


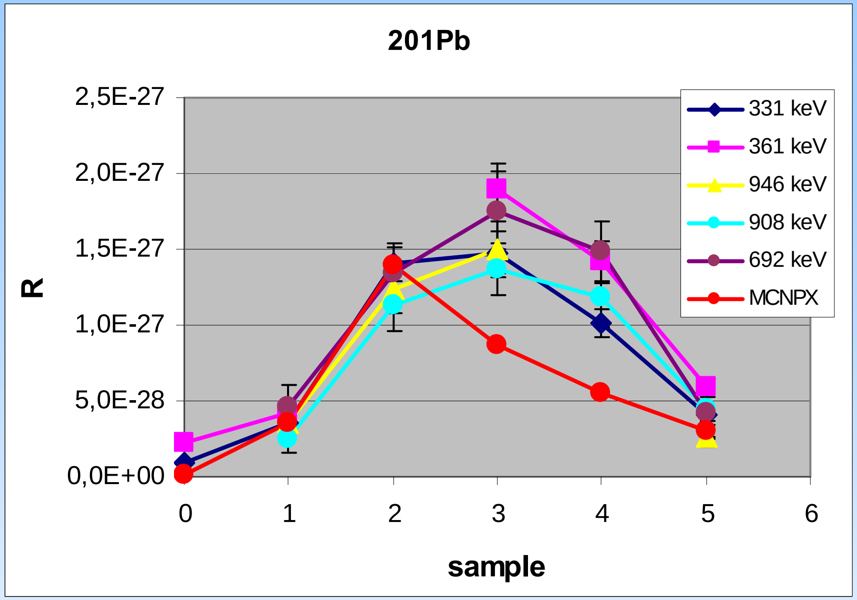


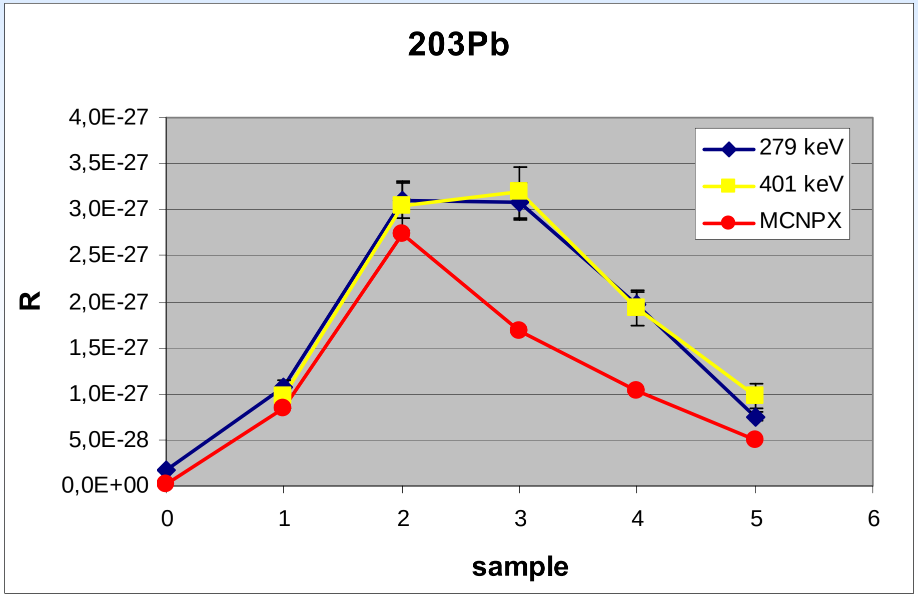
Production rates of Tl-isotopes

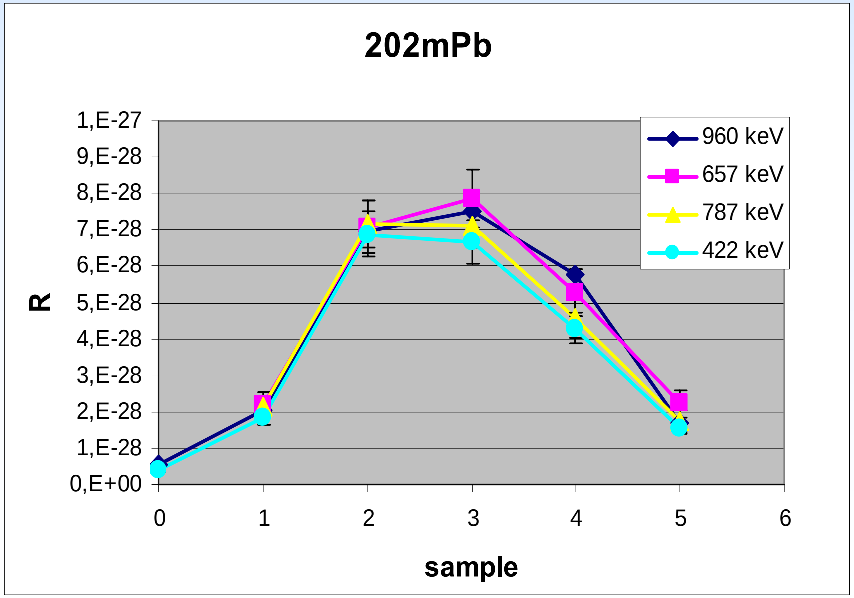


Production rates of Pb-isotopes

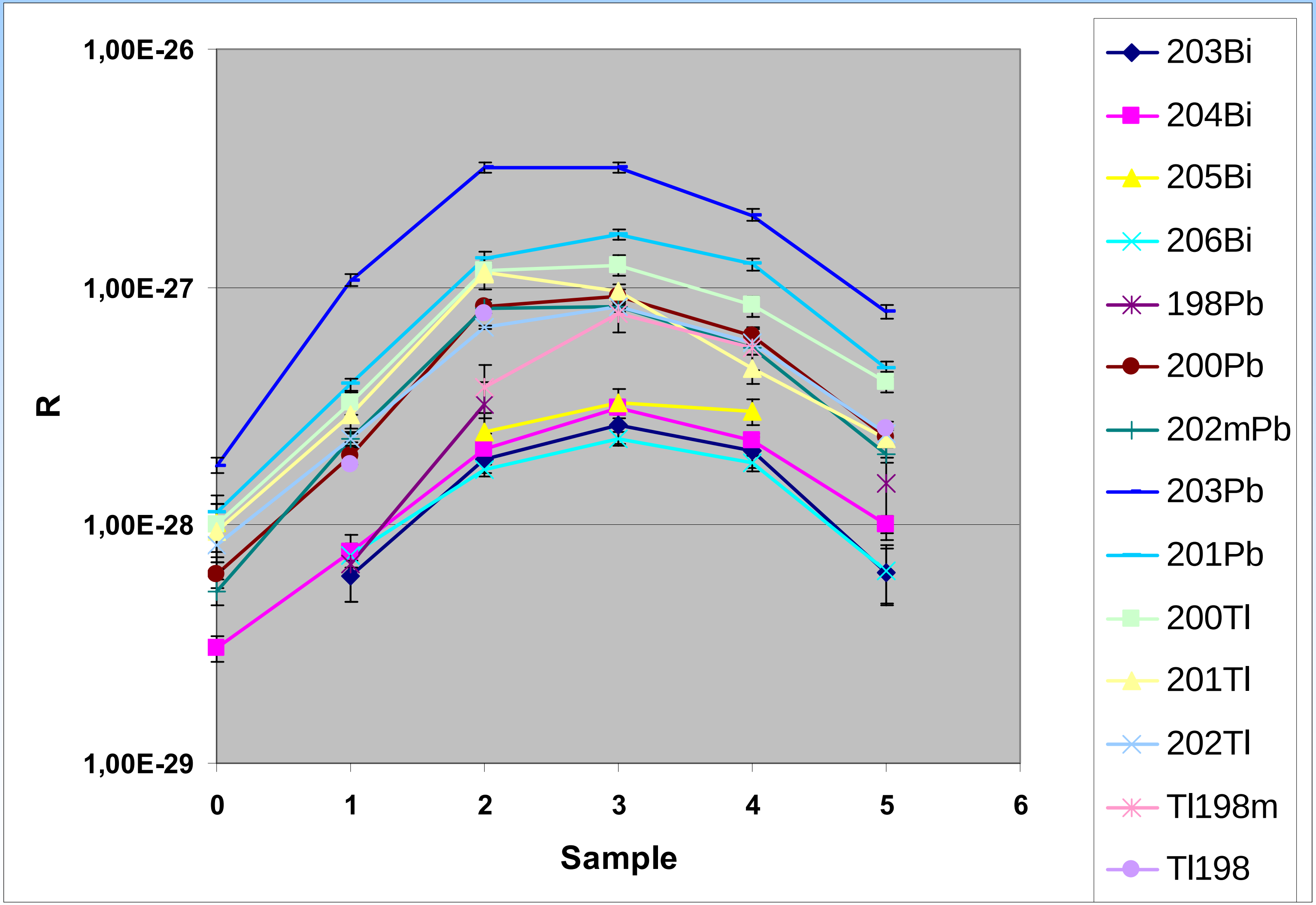








Isotope production rates for the reaction D+Pb @ 2,52 GeV



Calculations: MCNPX , TALYS

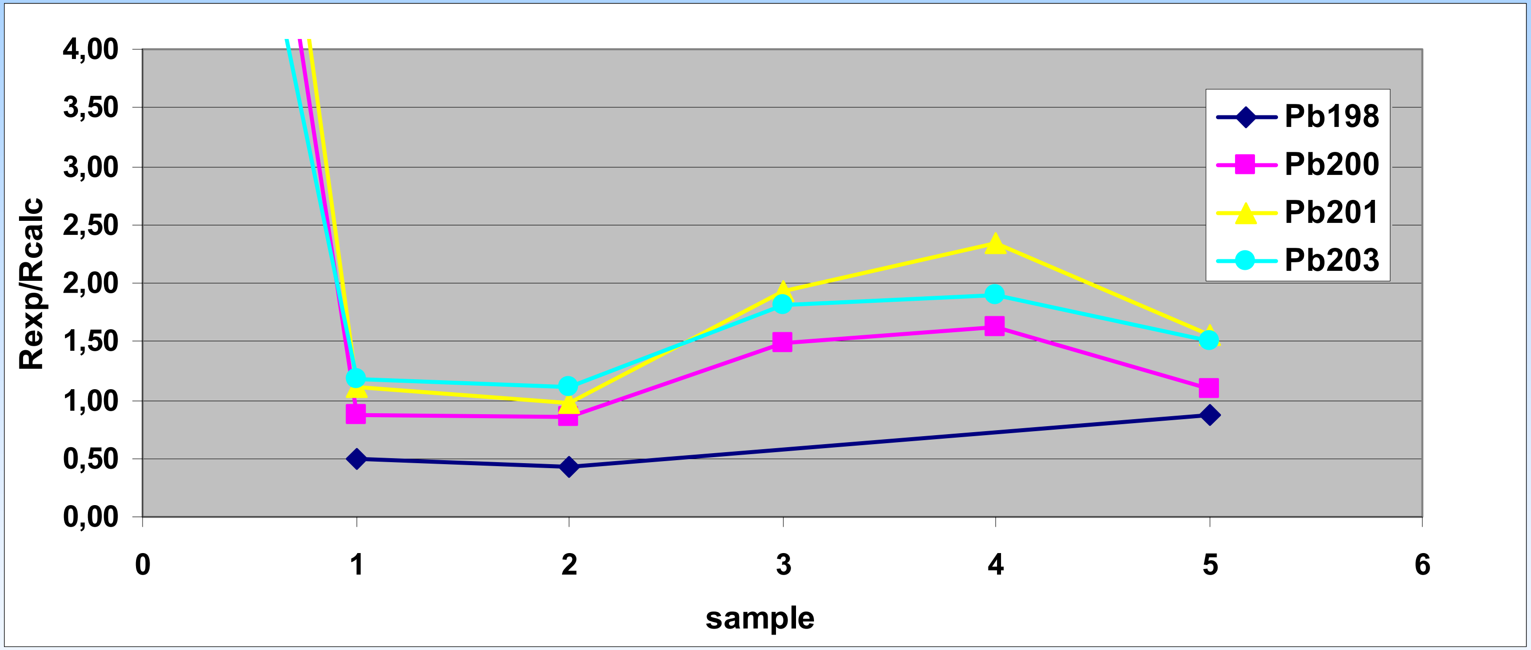
- Goal: Calculation of the isotope production rates R(A,Z)
- MCNPX- provides calculation of the fluxes of neutrons, deuterons and protons at the location points of samples
- Production cross sections: TALYS: particle energies less than 150 MeV , MCNPX – greater than 150 MeV
- Sum over the partial productions with respect to the isotope composition of nat. Pb: 204Pb,206Pb,207Pb,208Pb

$$R_{Calc} = \sum_{i,A(Pb)} p_{A(Pb)} . \left(\phi_n(E_i) . \sigma^{A(Pb)}_{n,X(A,Z)}(E_i) + \phi_p(E_i) . \sigma^{A(Pb)}_{p,X(A,Z)}(E_i) + \phi_d(E_i) . \sigma^{A(Pb)}_{d,X(A,Z)}(E_i) \right) . 0{,}001.1e^{-24}$$

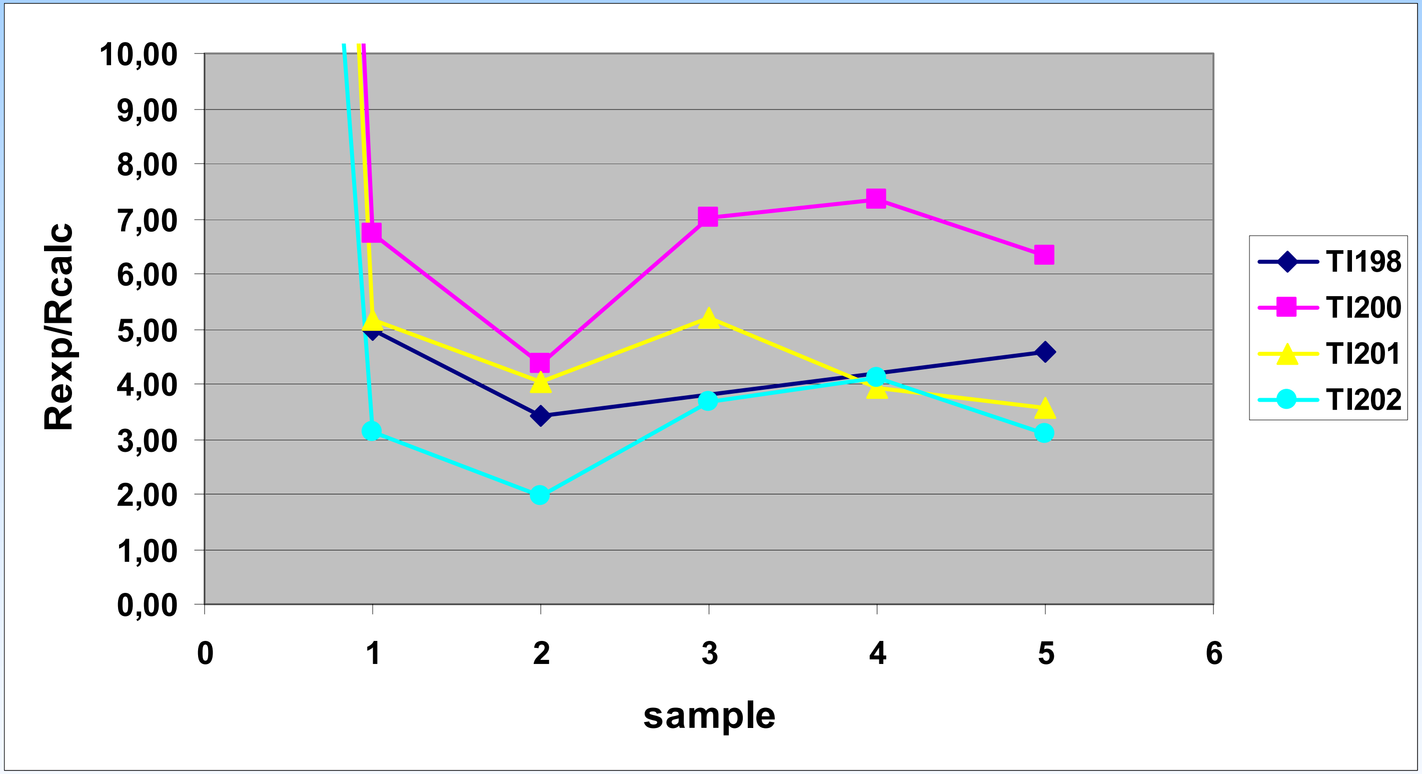
$\phi_n(E_i), \phi_p(E_i), \phi_d(E_i)$: **[particles/cm²/incoming deuteron].**

$\sigma^{A(Pb)}_{n,X(A,Z)}(E_i), \sigma^{A(Pb)}_{p,X(A,Z)}, (E_i), \sigma^{A(Pb)}_{d,X(A,Z)}(E_i)$: **production cross sections [mbarn]**

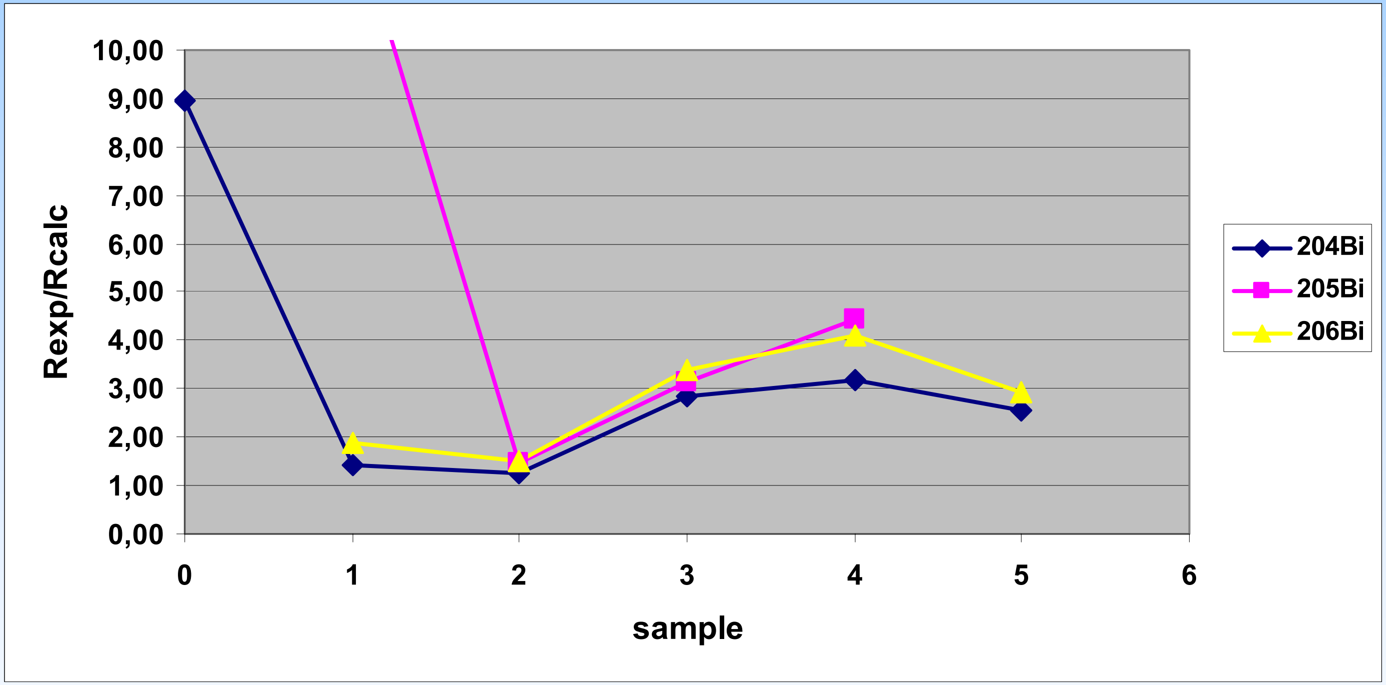
Comparison between calculated and measured isotope production rates: Pb isotopes



Comparison between calculated and measured isotope production rates: Tl isotopes



Comparison between calculated and measured isotope production rates: Bi isotopes



Outlook

•Using Pb-samples placed at different positions along the Pb-target the production rates of isotopes of Bi, Pb and Tl have been measured.

•The results are consistent and show a maximum of the isotope production in the middle part of the target.

•No short-living isotopes with T1/2 below 3h have been observed.

•No significant amount of decays of isotopes with Z<80 have been observed.

•The best agreement between measured and calculated isotope production rates was observed for Pb-isotopes.

•Except the 0^{th} target, all deviations between calculated and measured production rates do not exceed 1 order of magnitude.

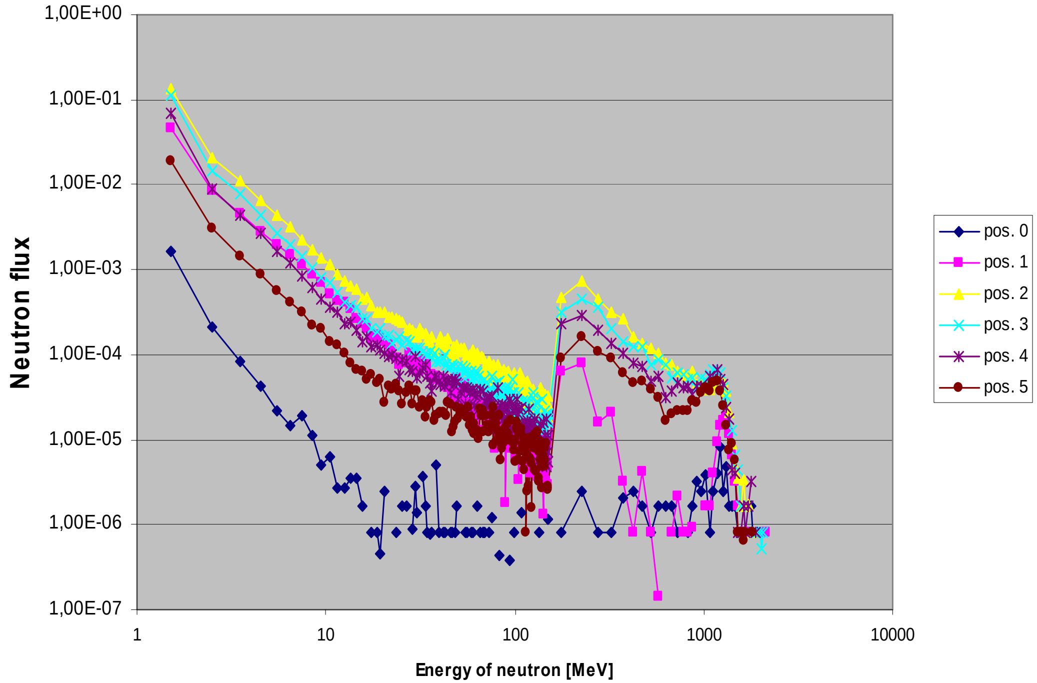
Next experiments

•The use of purified samples of 100%-208Pb is preferred.

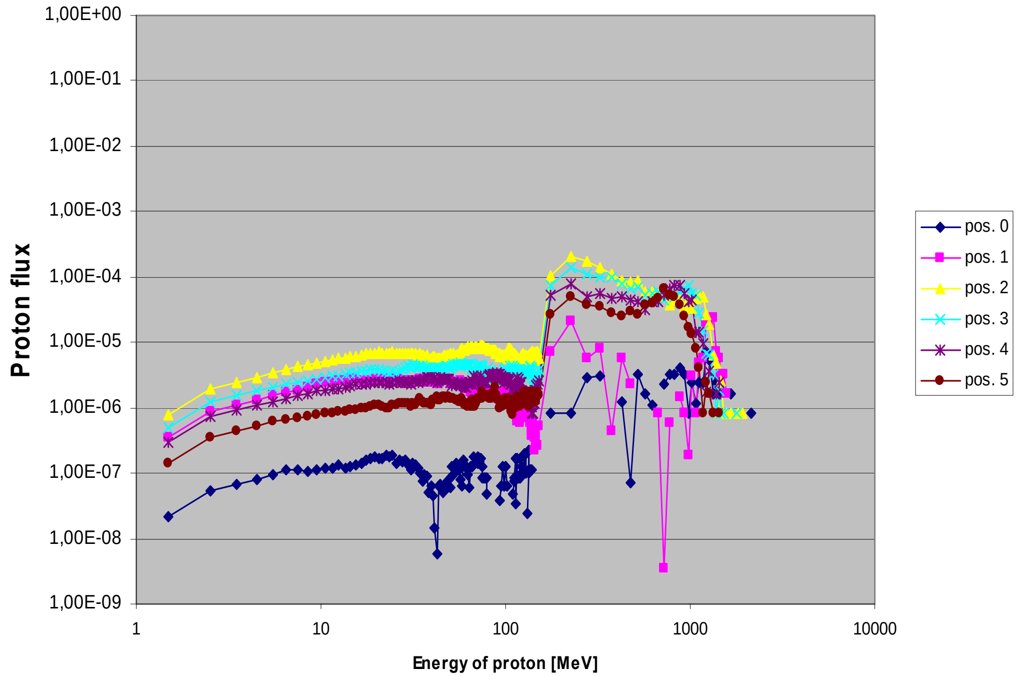
•The gamma-spectroscopy measurements of the samples has to start as soon as possible after the end of the irradiation in order to observe short-living isotopes produced in reactions with the most energetic particles.

• Collecting of isotope production rates at different beam energies.

Thanks to all friends and colleagues from:

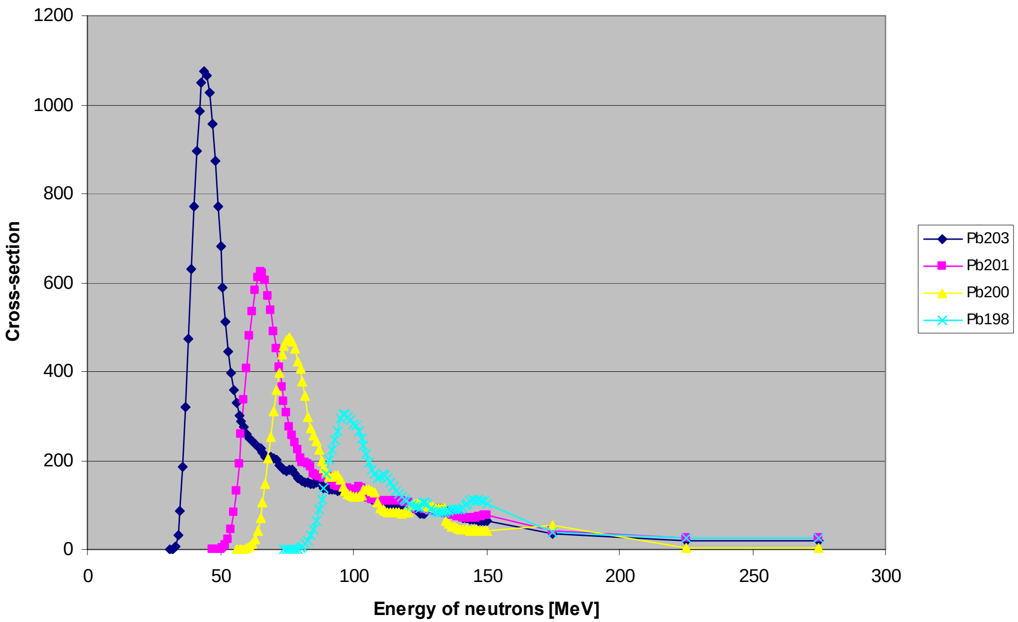


1,00E+00
1,00E-01
1,00E-02
1,00E-03
1,00E-04
1,00E-05
1,00E-06
1,00E-07
Neutron flux
1
10
100
1000
10000
Energy of neutron [MeV]
pos. 0
pos. 1
pos. 2
pos. 3
pos. 4
pos. 5



1,00E+00
1,00E-01
1,00E-02
1,00E-03
1,00E-04
1,00E-05
1,00E-06
1,00E-07
1,00E-08
1,00E-09
Proton flux
1
10
100
1000
10000
Energy of proton [MeV]
pos. 0
pos. 1
pos. 2
pos. 3
pos. 4
pos. 5

Cross-section Pb(n,xn) reaction



Cross-section Pb(p,pxn)