Experimental Measurement of the Level of Transmutation and Neutron Flux Density in Subcritical Nuclear Reactors ADS

JOINT INSTITUTE FOR NUCLEAR RESEARCH
LABORATORYOF HIGH ENERGY PHYSICS

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Summer Student Practices
3.07.2018, Dubna , Russia

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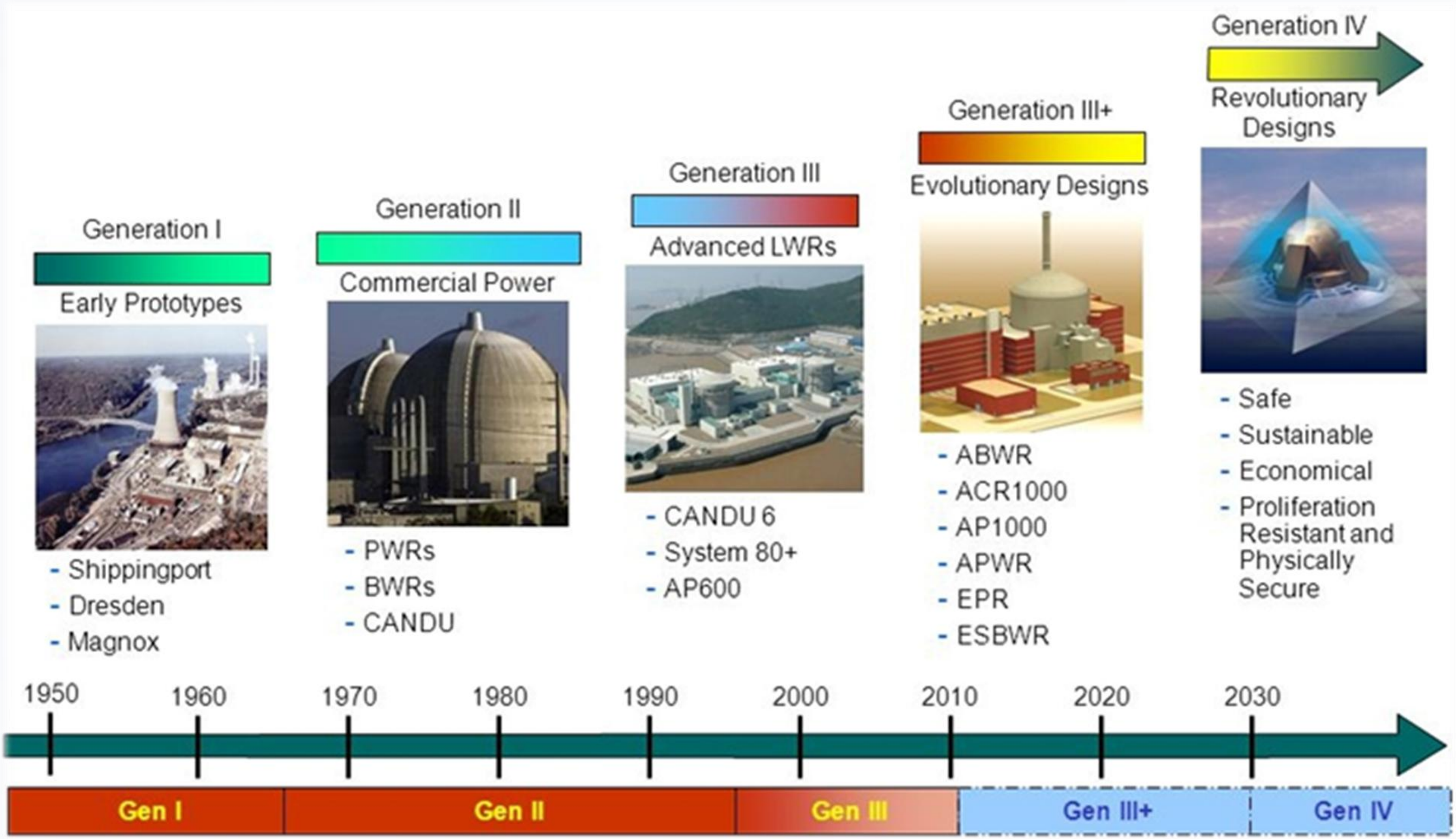
Outline

1. Motivation
2. Experiment
3. Data analysis
4. Conclusions

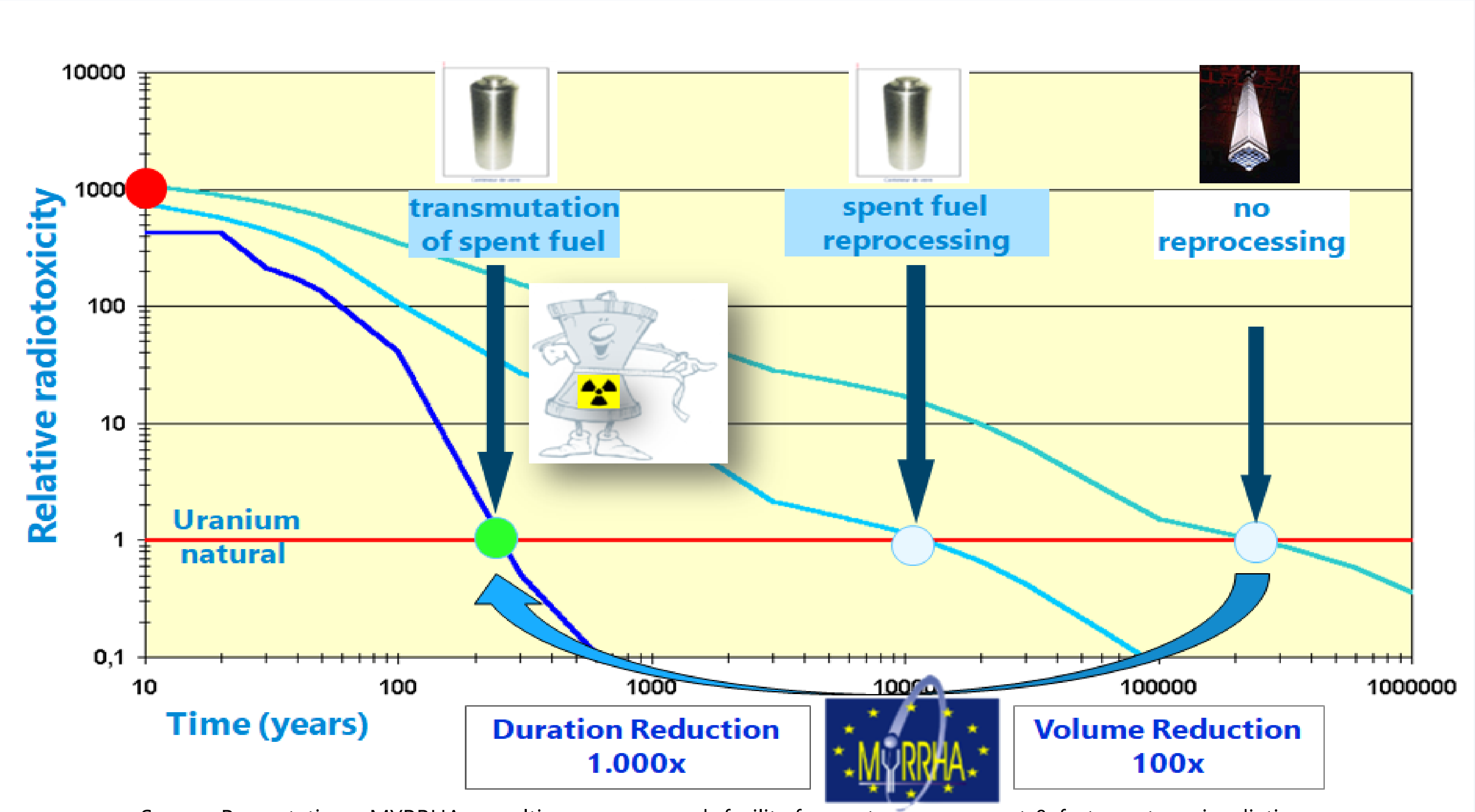
Main goal was to determine the neutron flux inside the QUINTA assembly using the neutron activation method

Evolution of Nuclear Power



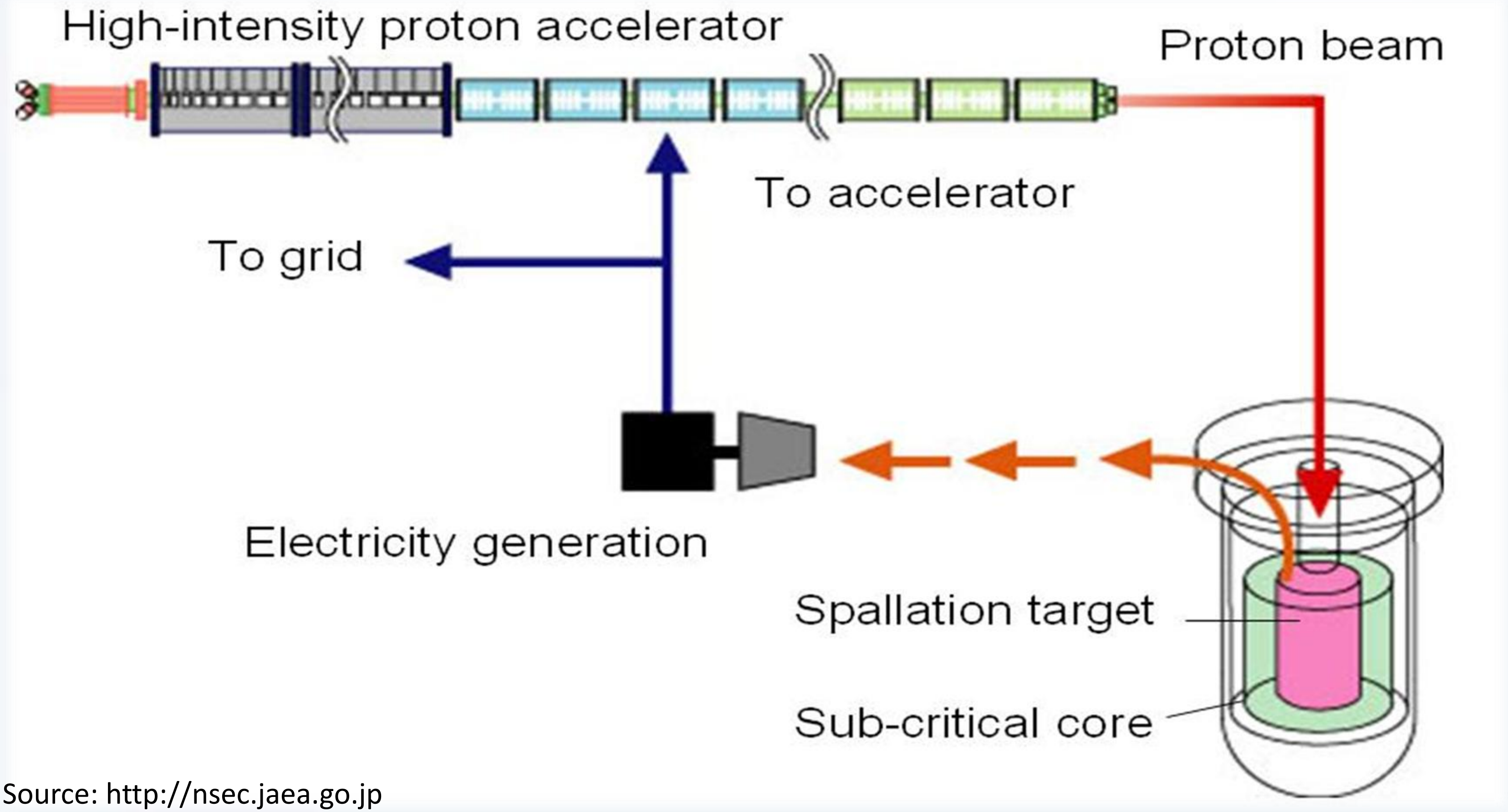
Source: https://www.nuclic.nl/

Radioactivity of Spent Fuel



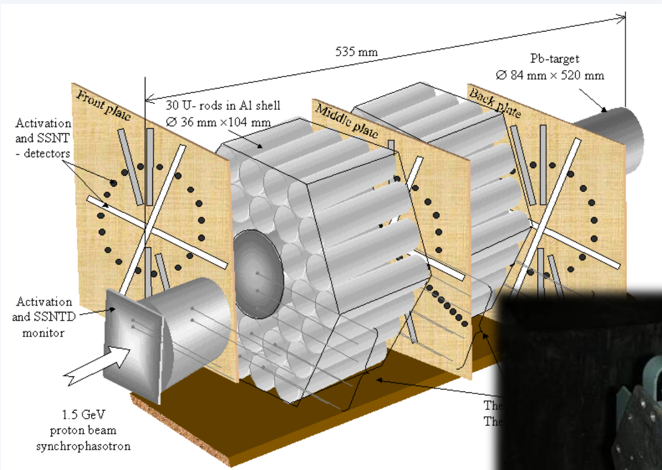
Source: Presentation - MYRRHA: a multipurpose research facility for waste management & fast spectrum irradiation.
Importance of Nuclear Data for MYRRHA project - Alexey Stankovskiy, Hamid Aït Abderrahim

Accelerator Driven System



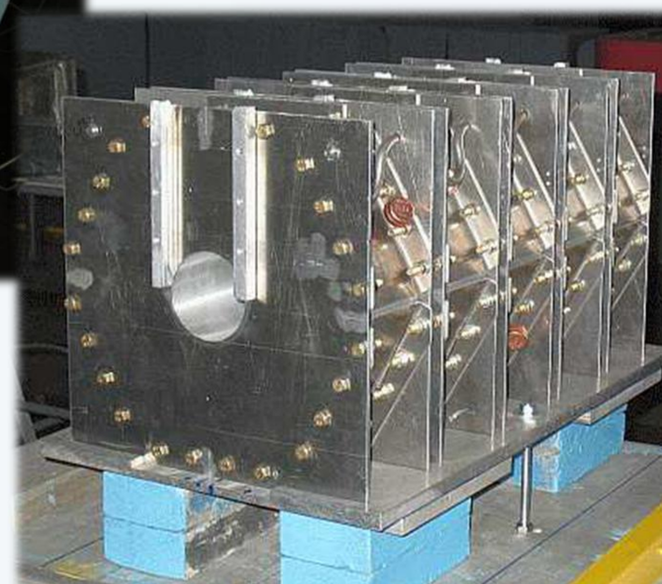
Source: http://nsec.jaea.go.jp

Experiment Quinta



Energy plus Transmutation
(2000-2003)

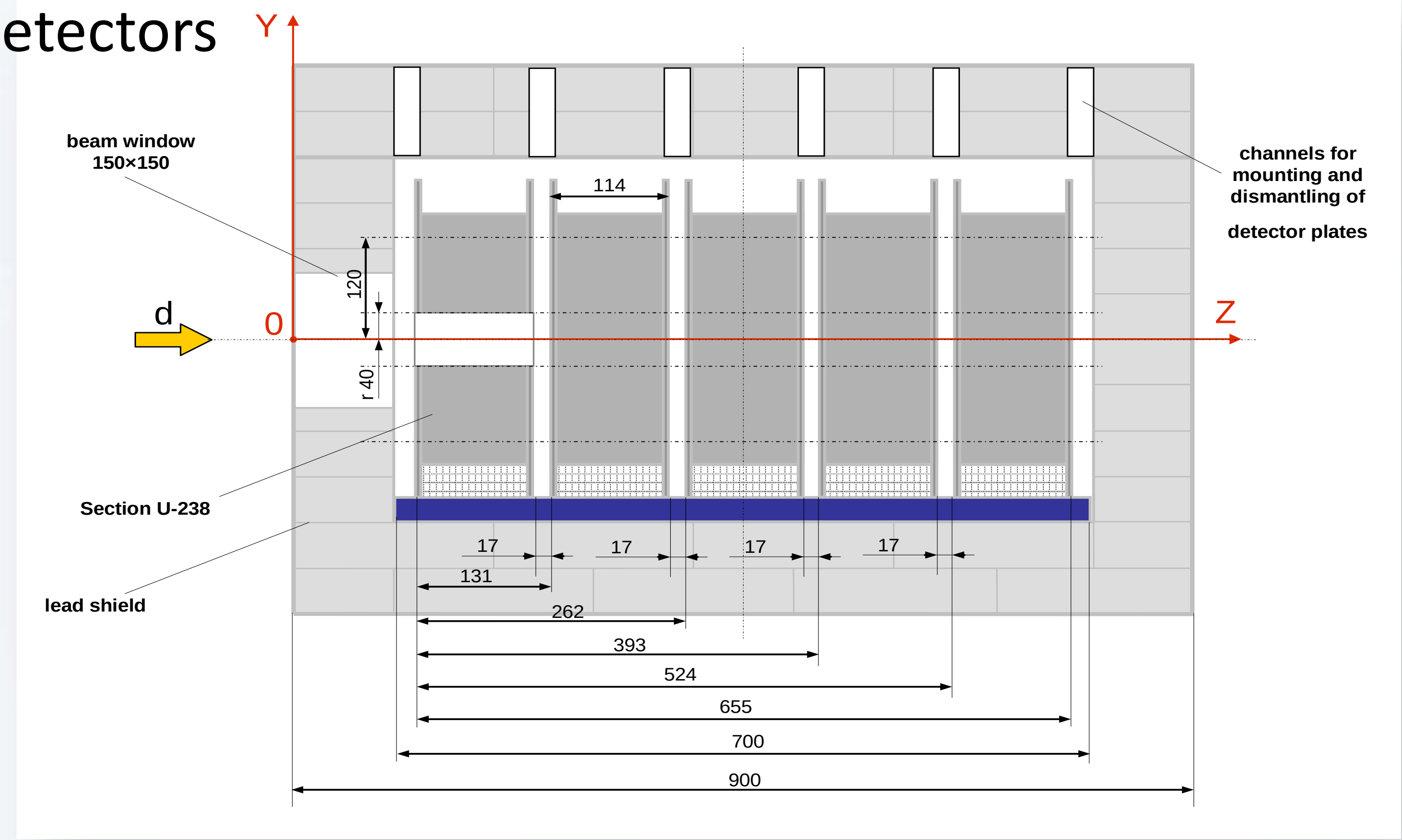
Energy plus Transmutation
(2004-2009)



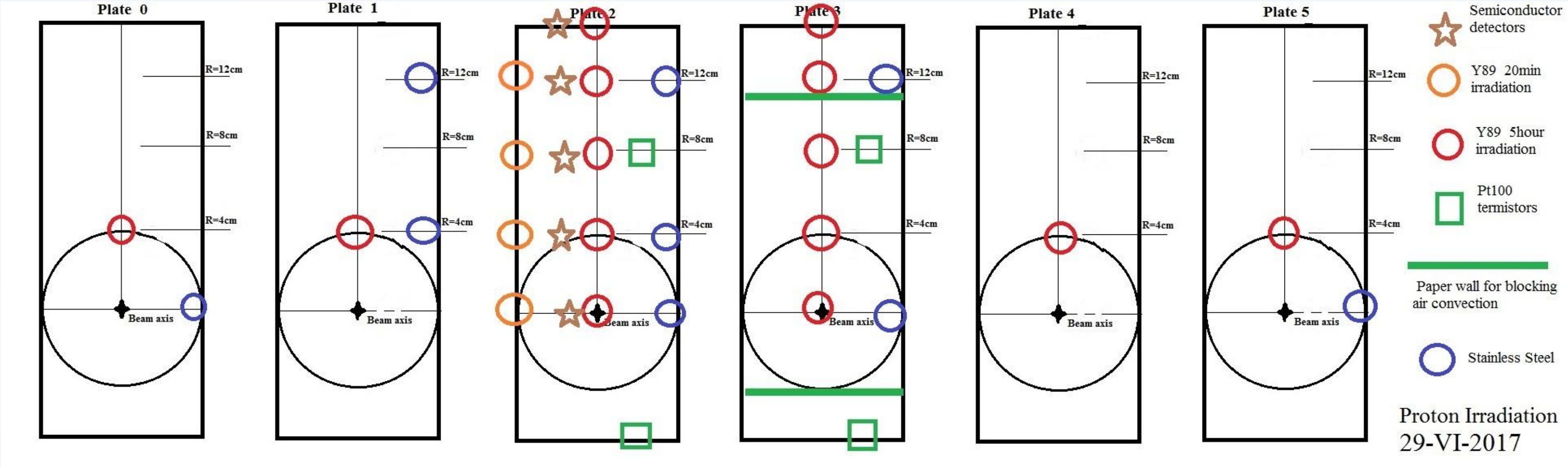
QUINTA (2011-2017)

Experiment Quinta

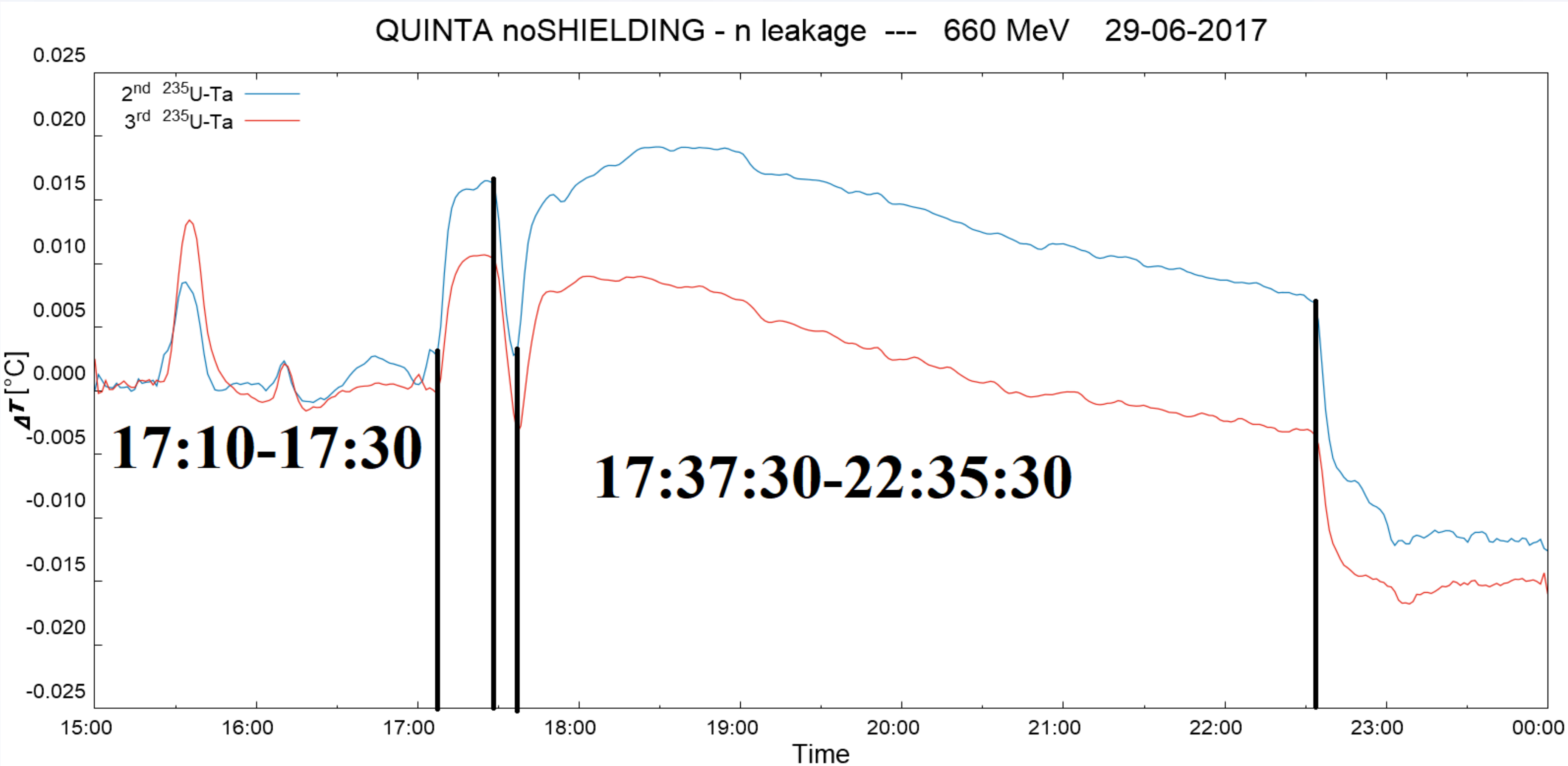
- 512 kg of natural uranium in five sections
- six 17 mm air gap for detectors
- beam window created by removal of 7 rods
- No Pb shielding



Experiment Quinta -
- Iradiation of Y-89 samples



Experiment Quinta



The short and long irraidation process

Yttrium

- Abundance of only one isotope Y^{89}
- Silvery - metallic transition metal
- Chemically stable
- Sufficient half-life to measure products of Y^{89}(n, xn) reactions
- Not sufficient knowledge of cross sections experimental values

Source: https://assets2.sharewise.com/attachment/file/120406/open-uri20180110-7613-1np8kqm

Data analysis – gamma spectroscopy

Samples were examined using gamma spectroscopy with High Purity Germanium (HPGe) Radiation detector

Fig. 1. Samples of yttrium

Fig. 2. Gamma spectroscopy detecor

Data analysis – energy calibration

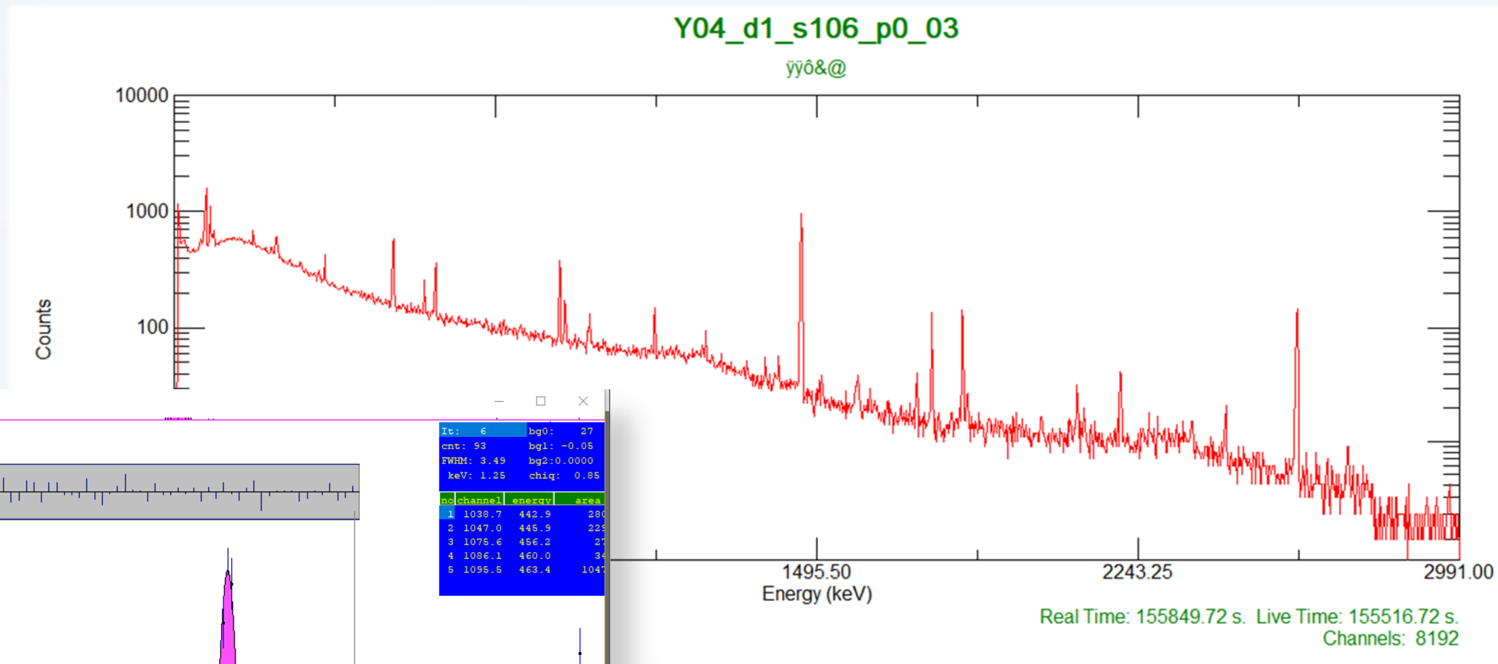


Fig. 3. Gamma spectrum from HPGe detector

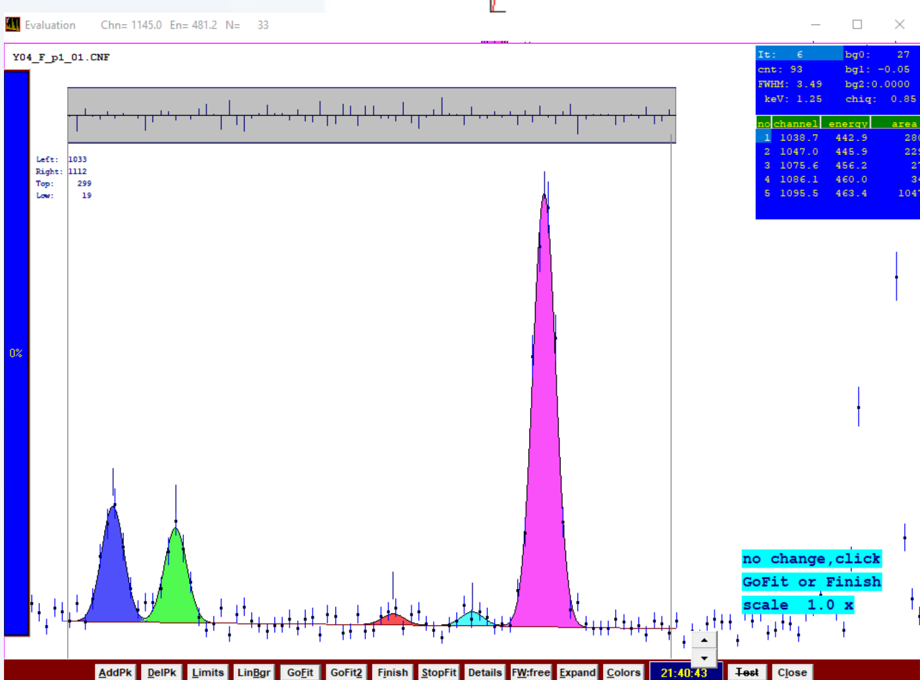


Fig. 4. Gamma spectrum – DEIMOS program

Data analysis – B parameter

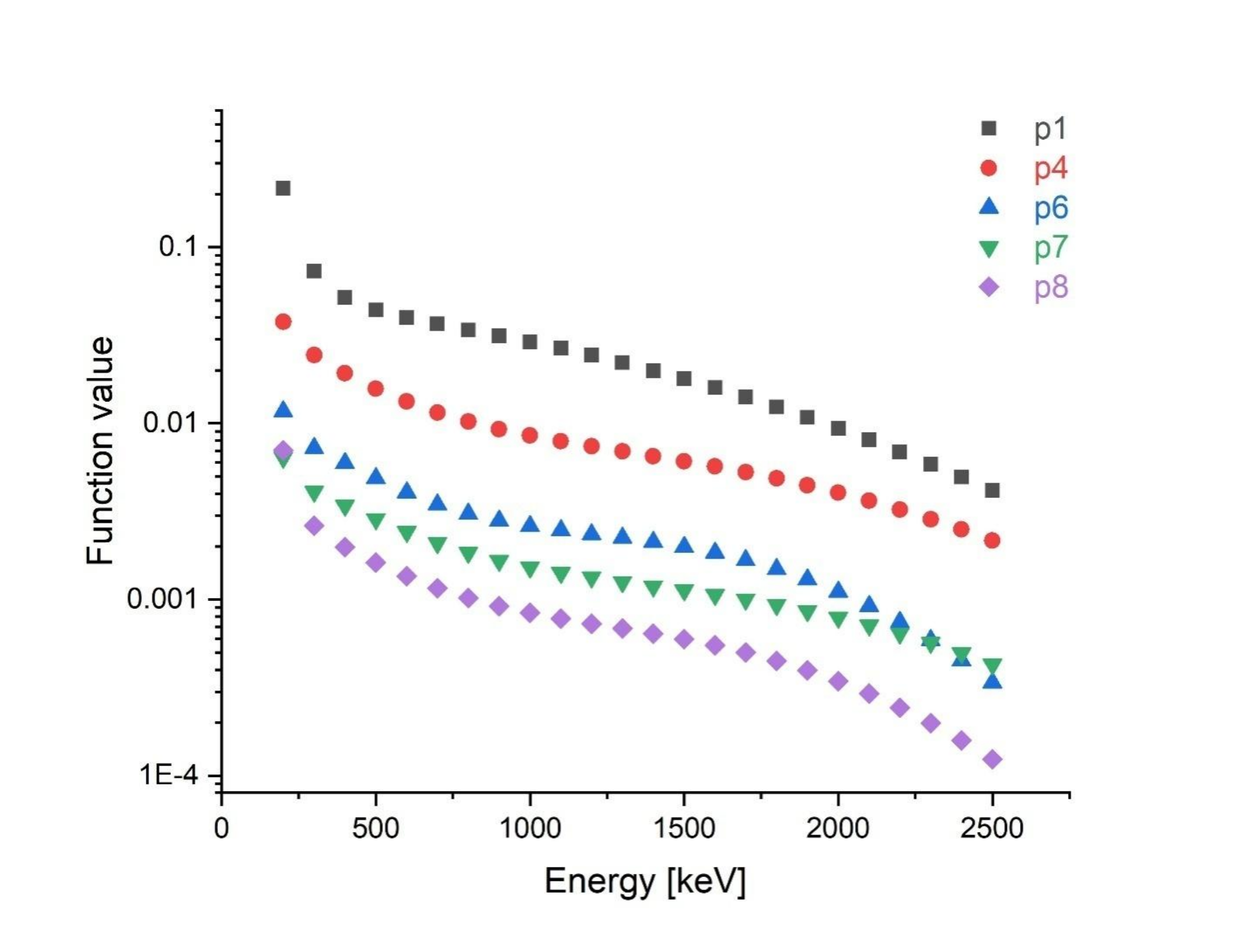
$$B = N_1 \frac{1}{m * I} \frac{\Delta S(G) * \Delta D(E)}{\frac{N_{abs}}{100} * \varepsilon_p(E) * COI(E,G)} \frac{\lambda * t_{ira}}{1 - \exp(-\lambda * t_{ira})} \times$$

$$\times \exp(\lambda * t_+) \frac{\frac{t_{real}}{t_{live}}}{1 - \exp(-\lambda * t_{real})}$$

B - number of produced specific isotopes per 1 g of the sample and per 1 proton from the accelerator

- Efficiency detector calibration
- Time correction
- Cascade effects
- Normalization of the results

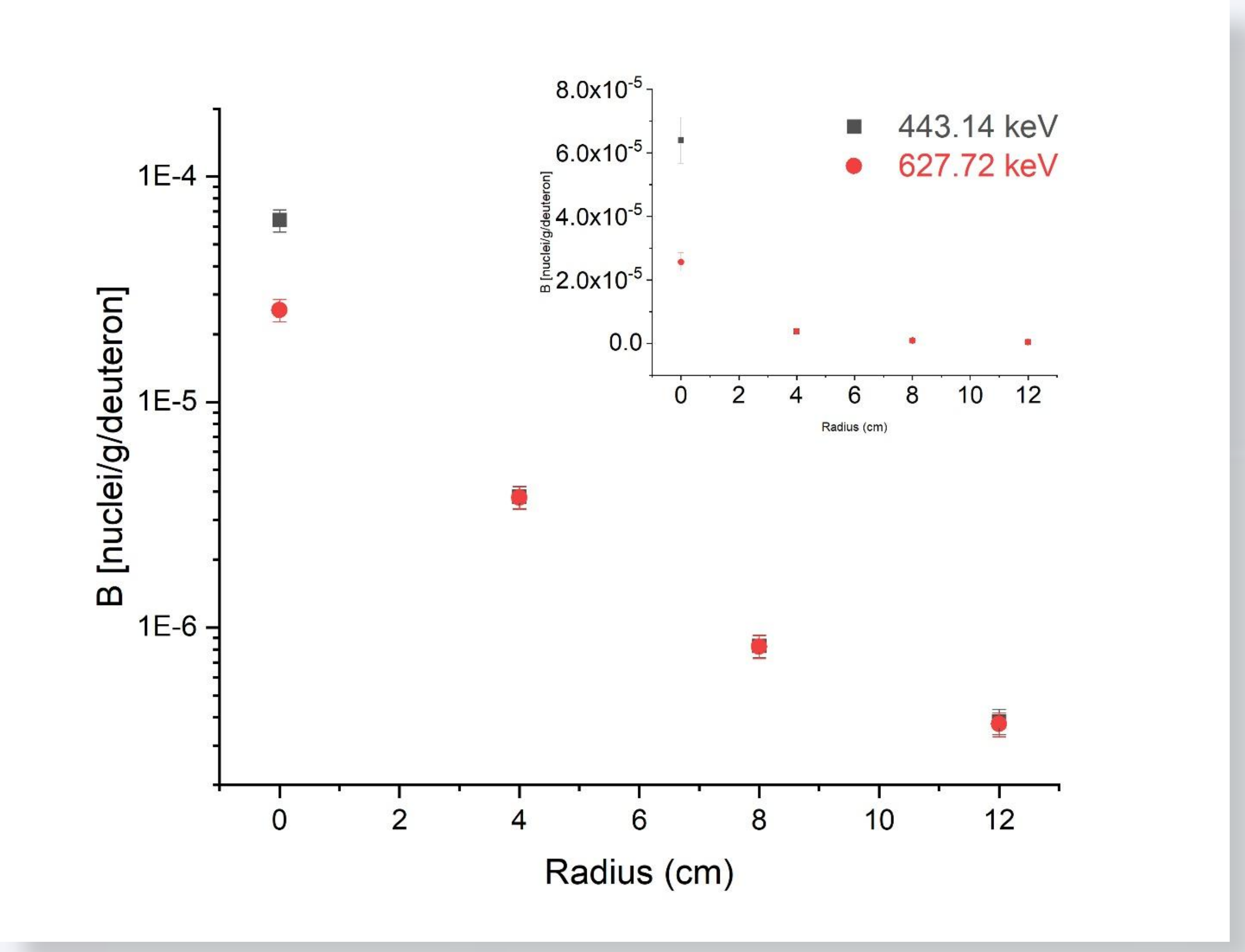
Data analysis – efficiency detector calibration



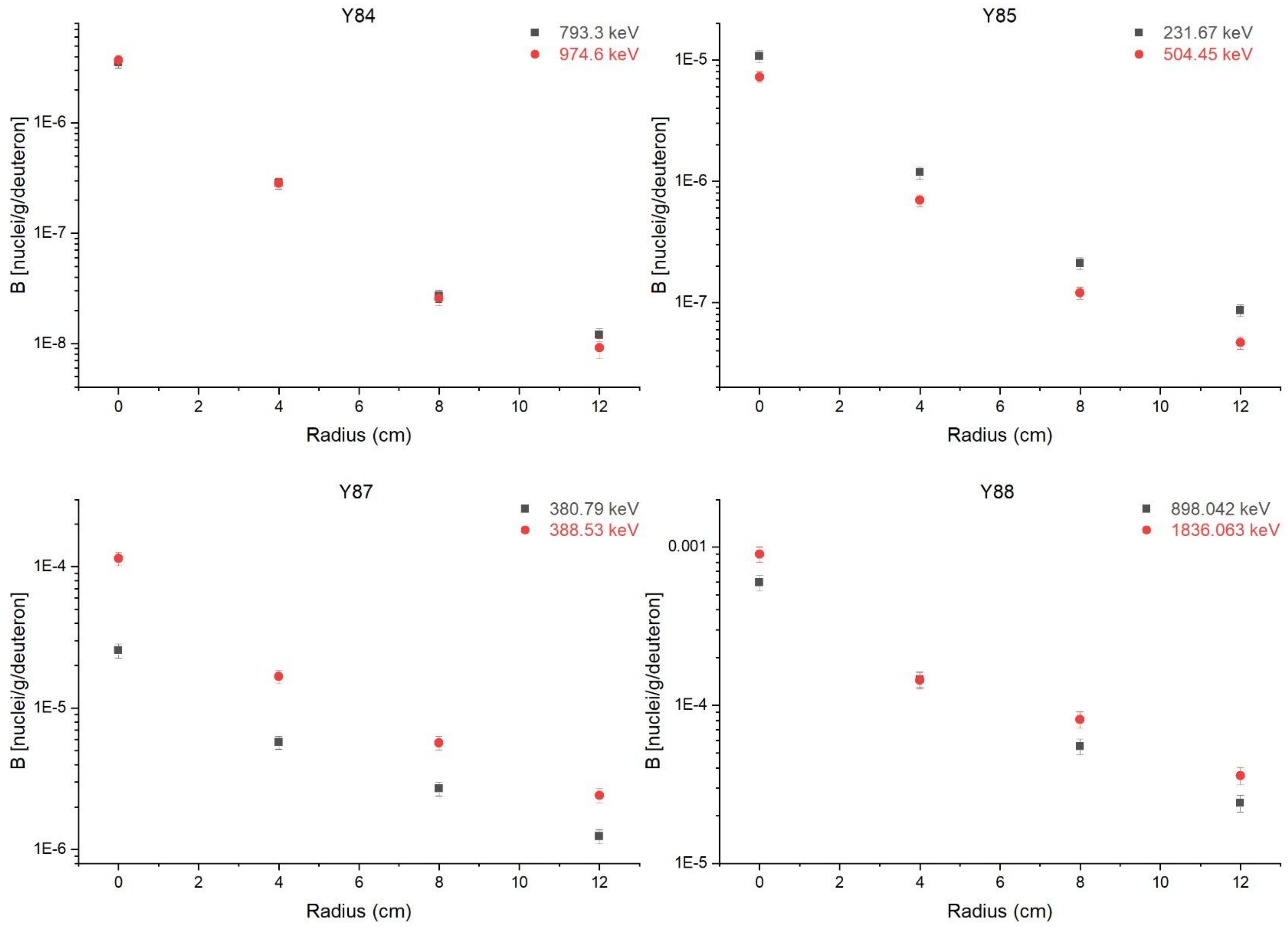
Standard samples used to create the HPGe detector efficiency curve:

- Co-60
- Ba-133
- Eu-152
- Cs-137
- Th-228

Production of Y-86



Production of yttrium



Neutron flux calculation

To evaluate the high energy neutron field we need to know the microscope cross section for the (n,xn) reactions of ^{89}Y. The available experimental data of microscopic cross section for the reaction $^{89}Y(n, 2n)^{88}Y$ and the small part for reaction $^{89}Y(n, 3n)^{87}Y$ are going from EXFOR database. For the reactions $^{89}Y(n, 4n)^{86}Y$, $^{89}Y(n, 5n)^{85}Y$, $^{89}Y(n, 6n)^{84}Y$ we had to use cross sections provided by TALYS programme.

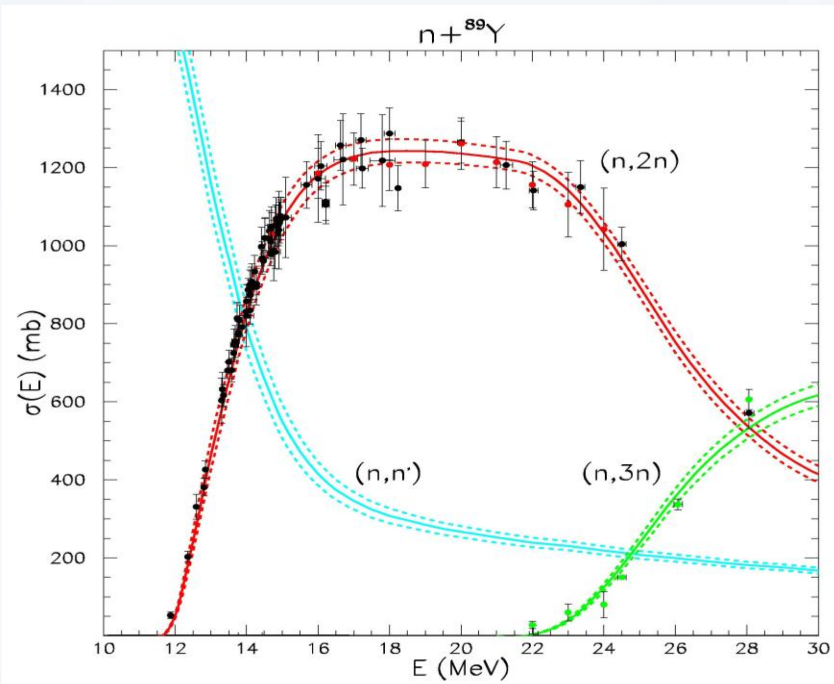


Fig. 5. Cross section for certain yttrium isotopes using EXFOR database

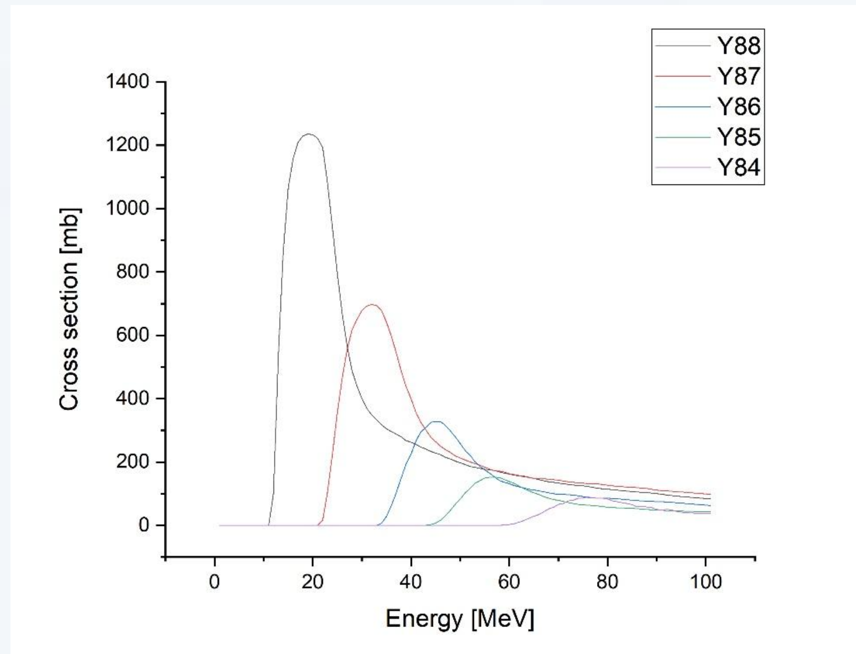


Fig. 6. Cross section for certain yttrium isotopes using TALYS programme

Neutron flux calculation

Y-89 (n,2n) Y-88 E_{th}=11,5 MeV
Y-89 (n,3n) Y-87 E_{th}= 20,8 MeV
Y-89 (n,4n) Y-86 E_{th}= 32,7 MeV
Y-89 (n,5n) Y-85 E_{th}= 42,1 MeV
Y-89 (n,6n) Y-84 E_{th}= 54,4 MeV

- Solution of the system of five algebraic equations let us evaluate the average neutron fluxes in the five energy ranges expressed in [n/cm2·s]:

$$\begin{cases} B^{88}C = \overline{\phi_1}\,\overline{\sigma_{11}}+\overline{\phi_2}\,\overline{\sigma_{12}}+\overline{\phi_3}\,\overline{\sigma_{13}}+\overline{\phi_4}\,\overline{\sigma_{14}}+\overline{\phi_5}\,\overline{\sigma_{15}} \\ B^{87}C = 0+\overline{\phi_2}\,\overline{\sigma_{22}}+\overline{\phi_3}\,\overline{\sigma_{23}}+\overline{\phi_4}\,\overline{\sigma_{24}}+\overline{\phi_5}\,\overline{\sigma_{25}} \\ B^{86}C = 0+0+\overline{\phi_3}\,\overline{\sigma_{33}}+\overline{\phi_4}\,\overline{\sigma_{34}}+\overline{\phi_5}\,\overline{\sigma_{35}} \\ B^{85}C = 0+0+0+\overline{\phi_4}\,\overline{\sigma_{44}}+\overline{\phi_5}\,\overline{\sigma_{45}} \\ B^{84}C = 0+0+0+0+\overline{\phi_5}\,\overline{\sigma_{55}} \end{cases}$$

$$C = \frac{S\,G^{89}}{A\,t}$$

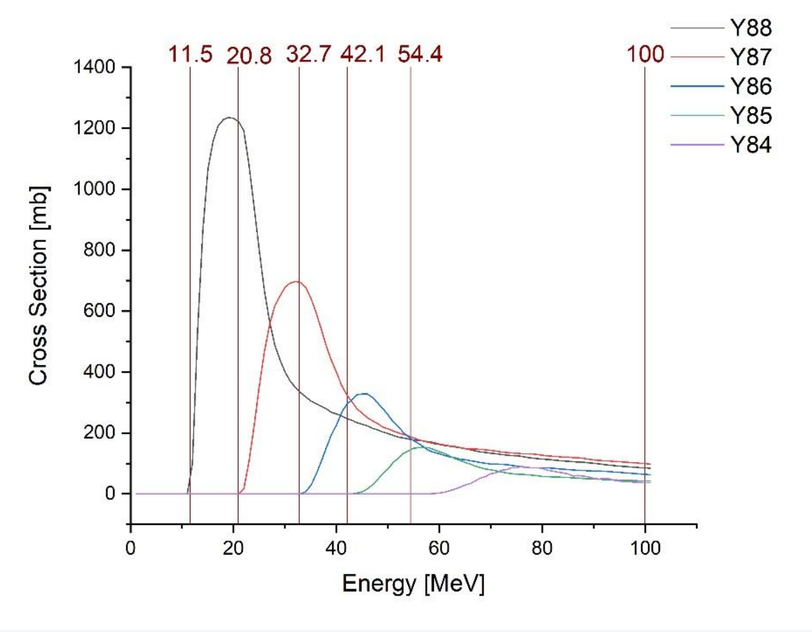
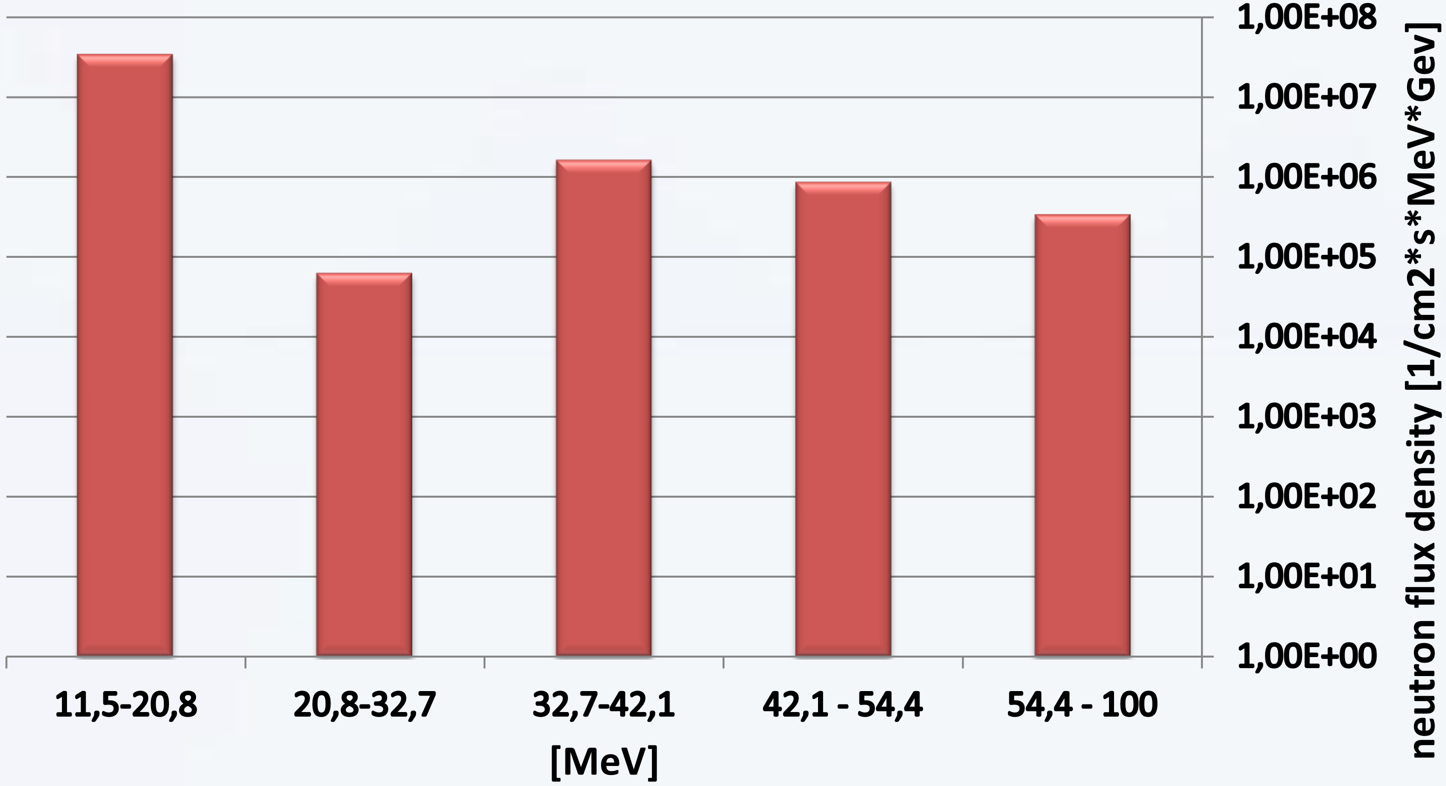


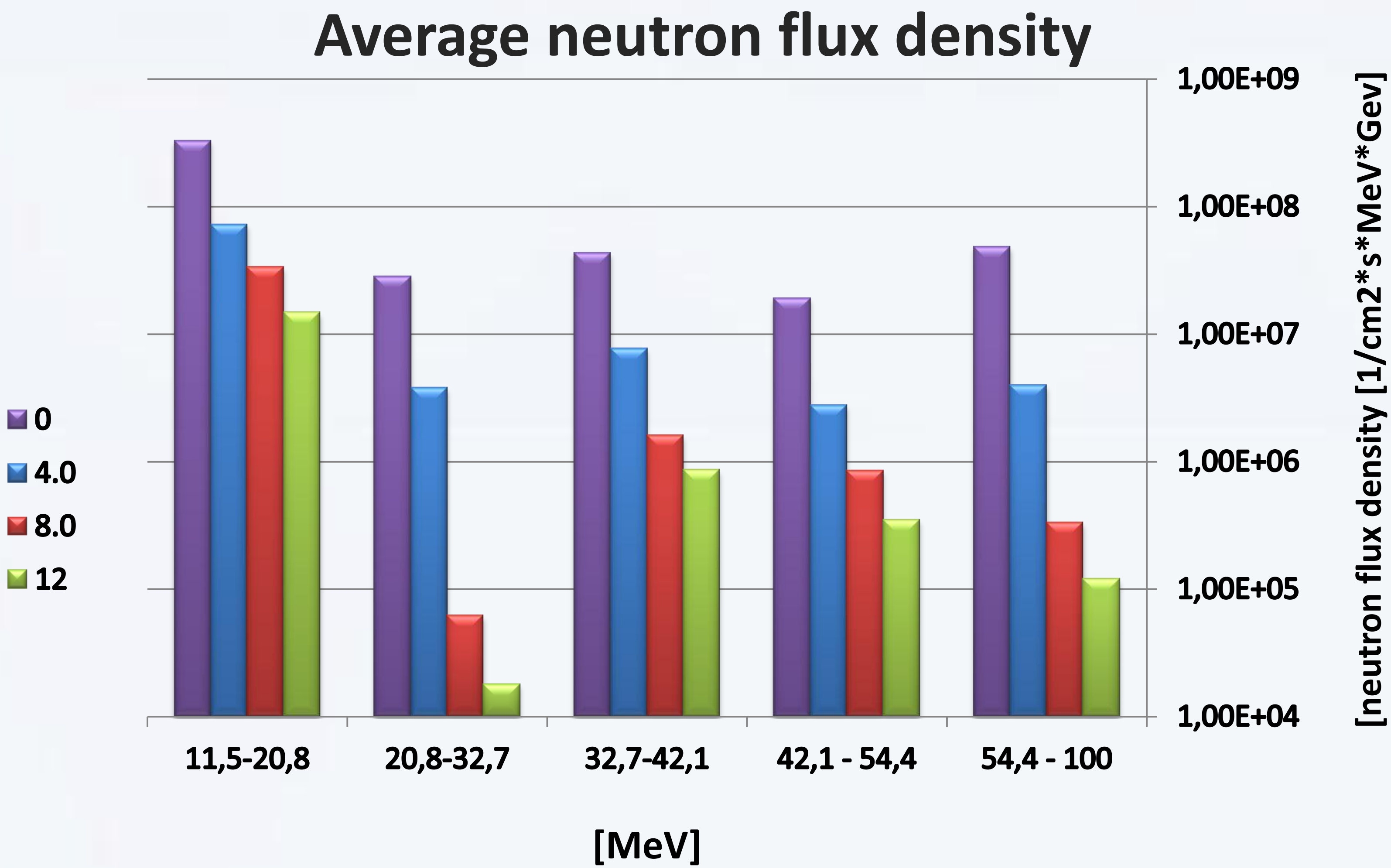
Fig. 7. Cross section for certain yttrium isotopes using TALYS programme with energy ranges

Results

Average neutron flux density 8 cm from beam axis



Results



Average neutron flux density
0
4.0
8.0
12
1,00E+09
1,00E+08
1,00E+07
1,00E+06
1,00E+05
1,00E+04
[neutron flux density [1/cm2*s*MeV*Gev]
11,5-20,8
20,8-32,7
32,7-42,1
42,1 - 54,4
54,4 - 100
[MeV]

Conclusions

- Fast neutron flux is used to plan further ADS subcritical experiments and future nuclear power plants
- Errors or calculated points vary from about 5% to 20% thus further experiments are needed
- Production of yttrium isotopes decreases in higher energies what meets theoretical expectations concerning cross sections and neutron spectrum
- Cross sections of (n,xn) reactions need to be studied more thorough
- Neutron flux is decreasing in higher energy ranges and in increasing distance from the beam axis
- The measurement of high neutron flux density and explanation of the results are still needed to be developed by additional experiments and calculation.

References

1. M.Bielewicz , E.Strugalska-Gola , S.Kilim, M.Szuta, S. Tyutyunnikov, W. I. Furman, *Measurements of fast neutron spectrum in QUINTA assembly irradiated with 2,4 and 8 GeV deuterons*
2. E. Strugalska-Gola, M. Bielewicz, S. Kilim, M. Szuta, S. Tyutyunnikov, *Average fast neutron flux in three energy ranges in the Quinta assembly irradiated by two types of beams*
3. M. Bielewicz, E. Strugalska-Gola, S. Kilim, M. Szuta, *Experimental Study of the Physical Properties of ADS Systems – Measurement of High Energy Neutron Flux Density by Using the* ^{89}Y *Threshold Detectors*
4. M. Bielewicz, T. Hanusek, A. Jaskulak, M.Peryt, S.Tiutiunnikov, *Determining the fast neutron flux density and transmutation level measurements in ADS bythe use of athreshold nuclear reaction*

Thank you for you attention

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