Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

Laboratory of Fast Neutron Generators

New detection systems at U-120M cyclotron

Jan Novák
Nuclear Physics Institute
of the Czech Academy of Sciences

EUROPEAN UNION
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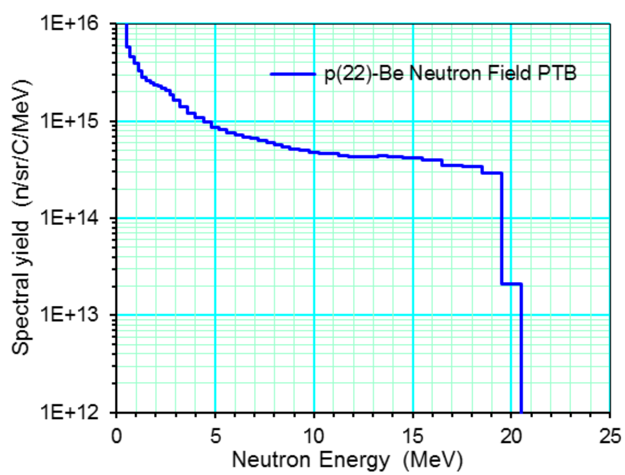
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

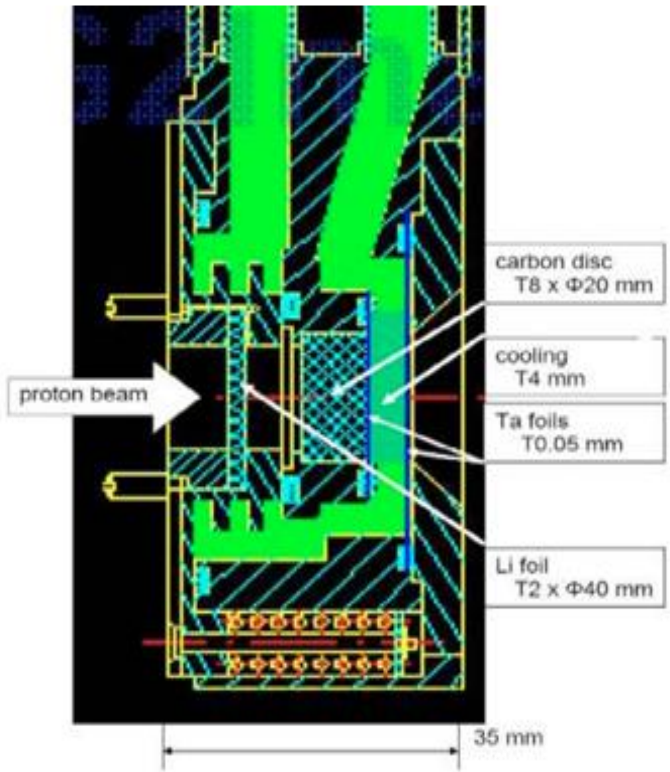
Variable-energy broad-spectrum neutron generator

- Neutron production: p+Be, d+Be
- E_{proton}= 17 – 35 MeV
- $E_{deuteron}$= 11 – 20 MeV
- Mean energy: 4 - 12 MeV
- Integral flux: up to 10^{11} $n/cm^2/s$



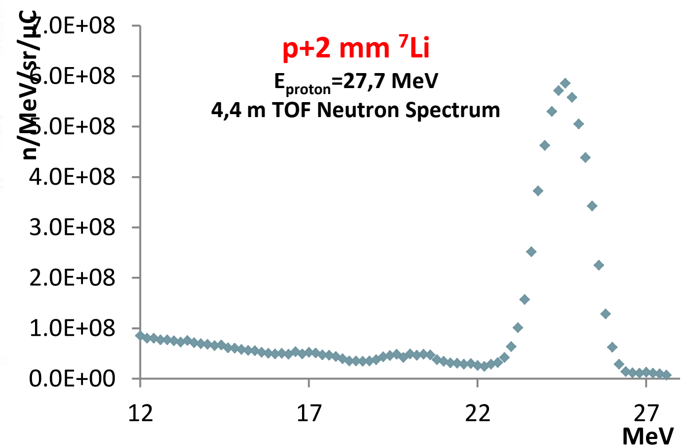
The shape of spectrum valid for p(22 MeV)+Be neutron source at NPI. The reference neutron field data from PTB Braunschweig are used.

Variable-energy quasi-monoenergetic neutron generator

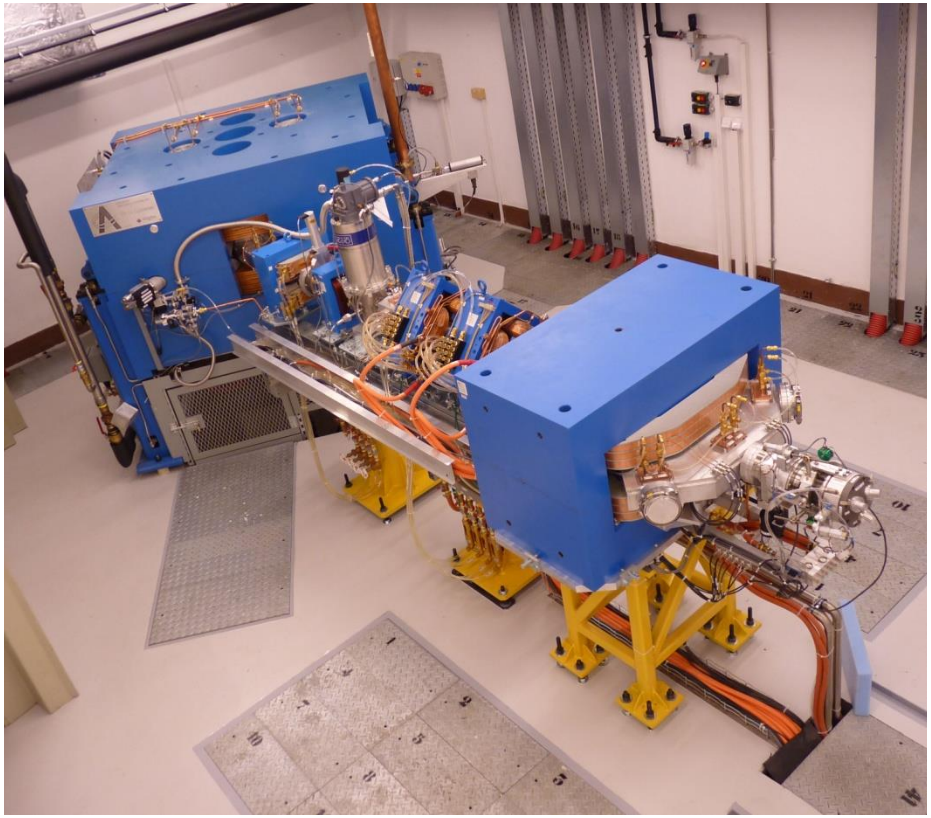


- Neutron production: $p + {}^{7}Li$
- E_{proton} = 17 – 35 MeV
- Peak energy: up to 33 MeV
- Neutron flux density in the QMN peak:

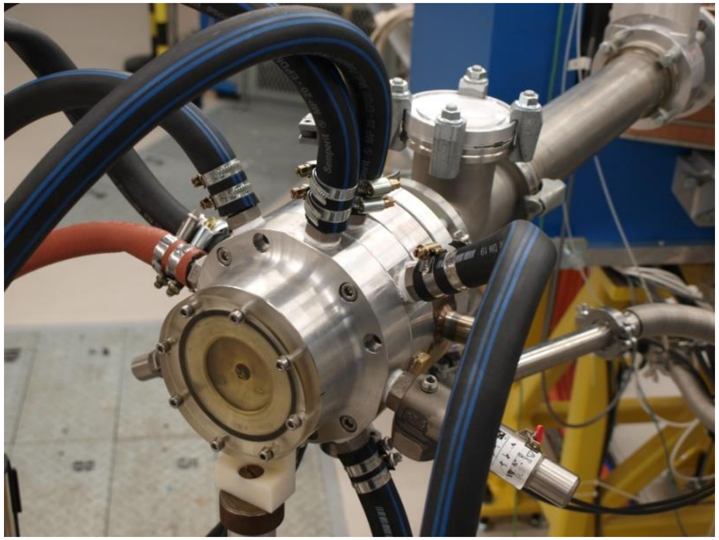
  up to 10^{9} $n/cm^{2}/s$



High-flux broad-spectrum neutron generator (theoretical possibility)

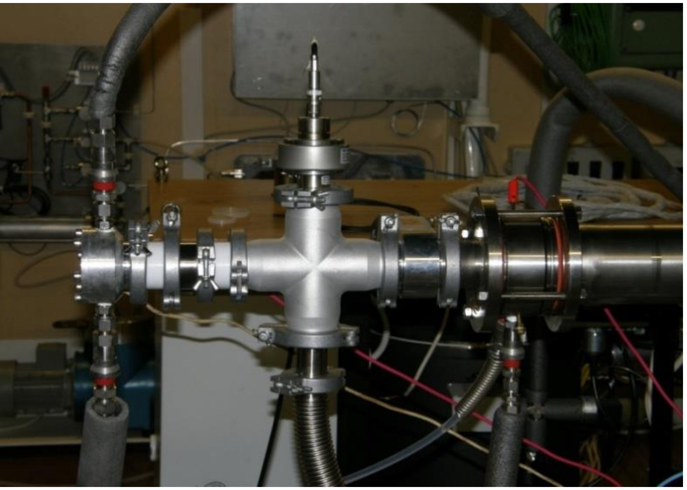


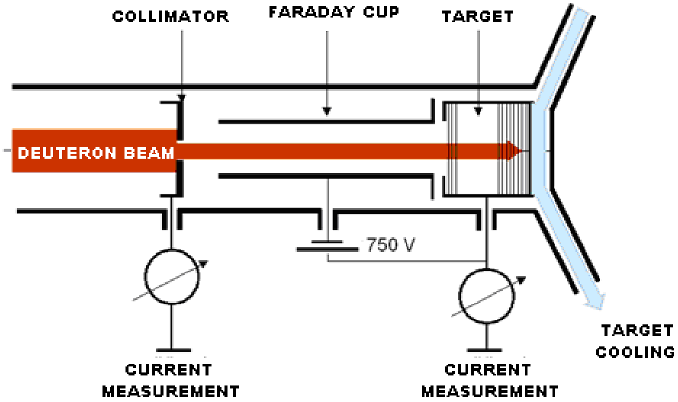
- Protons accelerated by TR 24
- Neutron production: p+Be
- E_{proton}= 24 MeV (fixed)
- Integral flux: 10^{12} $n/cm^2/s$



Unofficial

Nuclear data measurements with ion beams





- Proton and deuteron production
- E_{proton}= 17 – 35 MeV
- $E_{deuteron}$= 11 – 20 MeV

- ❑ Equipment is developed for irradiation of different materials with protons and deuterons and investigation of activation cross-sections using the stacked-foils method.
- ❑ The irradiation chamber is equipped by Farraday-cup
- ❑ The cooling of stacked foils is possible.
- ❑ The HPGe-detector technique is used for the off-line investigation of activated samples.

Cross section measurement

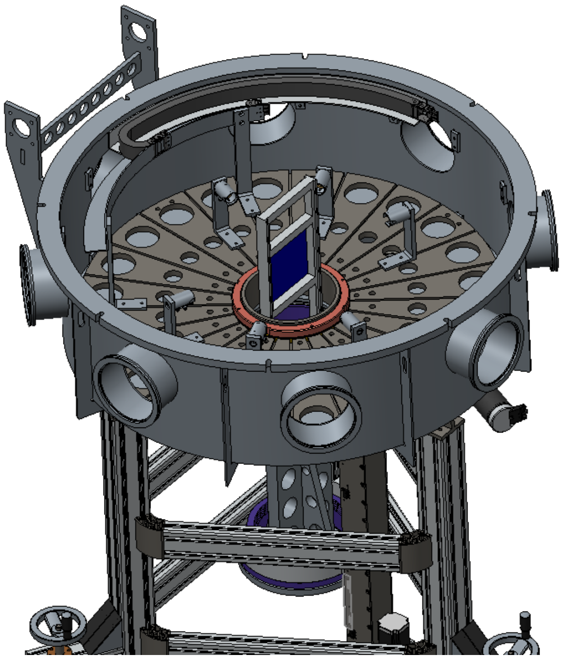
Projectiles

- neutrons
- charged particles

→

Reaction products detection

- γ spectrometry after irradiation
- on beam γ spectrometry (in construction)
- charged particle spectrometry (in construction)



Neutron beam treatment

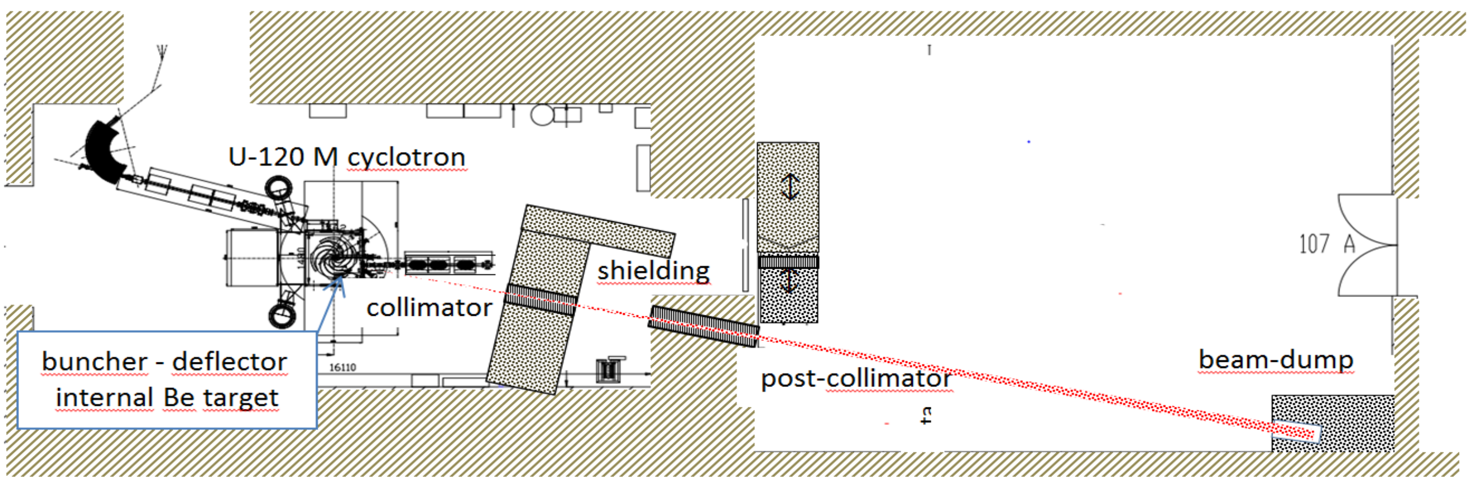
Beam collimation

- Collimation system (will be developed)
- Placement of the neutron generator in front of the collimator is possible

Beam dump (will be developed)

Neutron beam spectrum estimation

- measurement of the charged particle beam current + simulation
- measurement of the Li target γ activation after irradiation
- TOF



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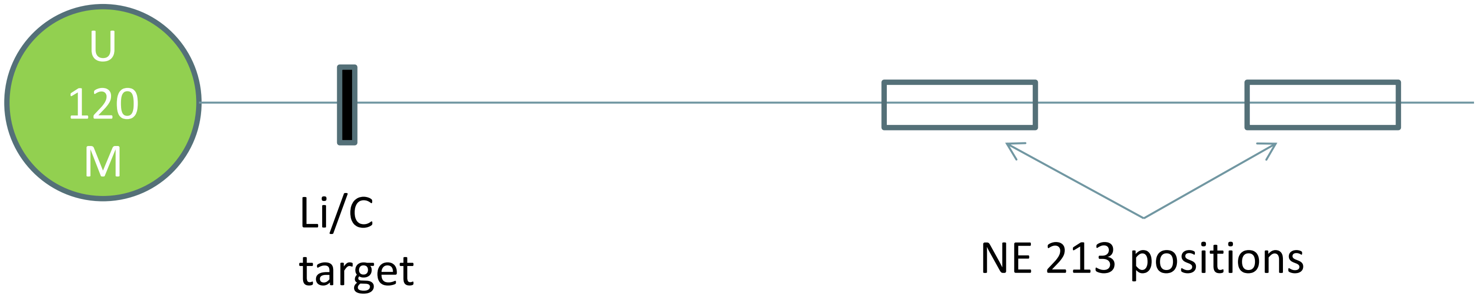
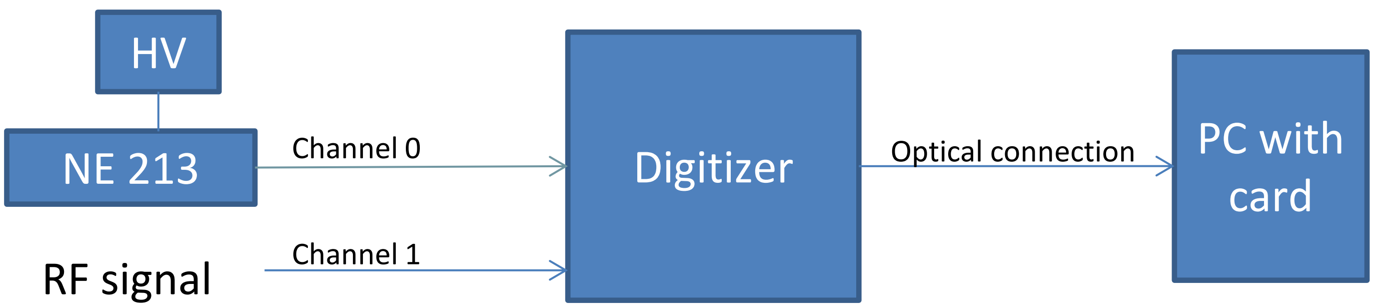
TOF measurement

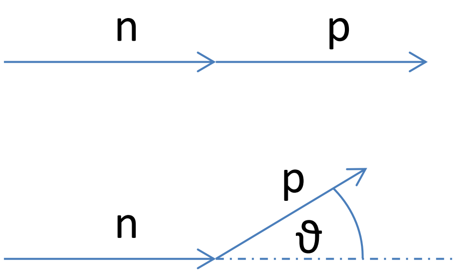




- CAEN V1751 digitizer: 1GHz sampling rate, 10 bits resolution
- Simultaneous sampling of the anode signal from the scintillation probe and the cyclotron accelerating frequency (RF)

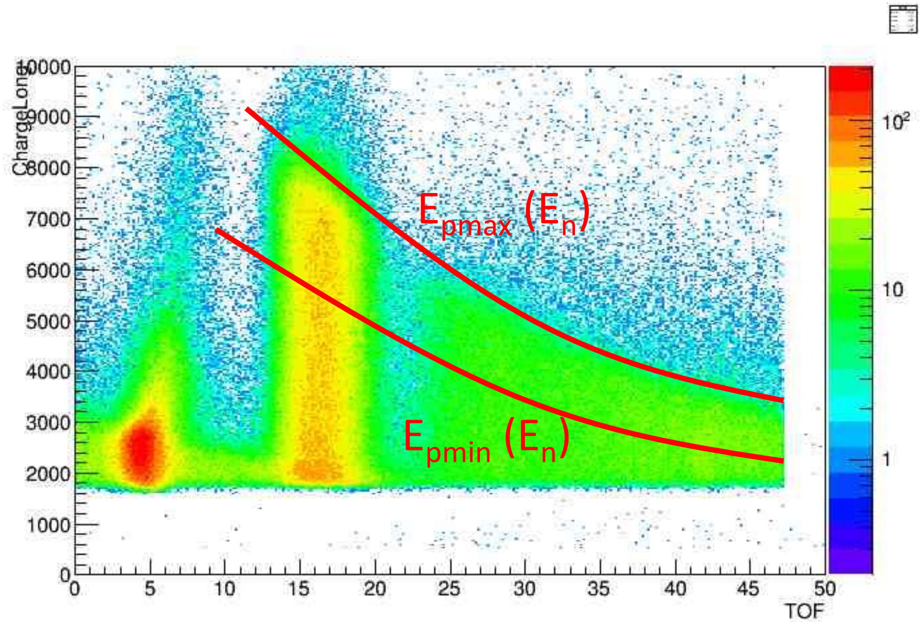
TOF measurement

Dynamic threshold method



$E_{pmax}(E_n) = E_p(E_n, 0) = E_n$

$E_{pmin}(E_n) = E_p(E_n, \vartheta_{max})$



$$\frac{dN_n}{dE_n}(E_n) = \frac{\frac{dN}{dE_n}(E_p > E_{p\min}(E_n), E_n)}{\eta(E_p > E_{p\min}(E_n), E_n)}$$

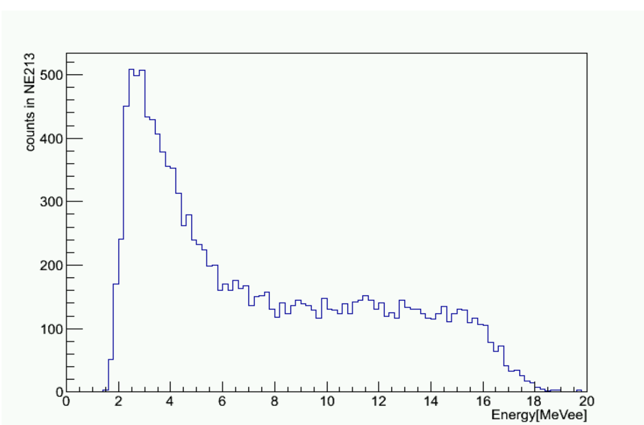
$$\eta(E_p > E_{p\min}(E_n), E_n) = 2\pi\rho_S \int_0^{\vartheta_{\max}} \frac{d\sigma}{d\Omega}\sin(\vartheta)\, d\vartheta$$

+ boundary effects

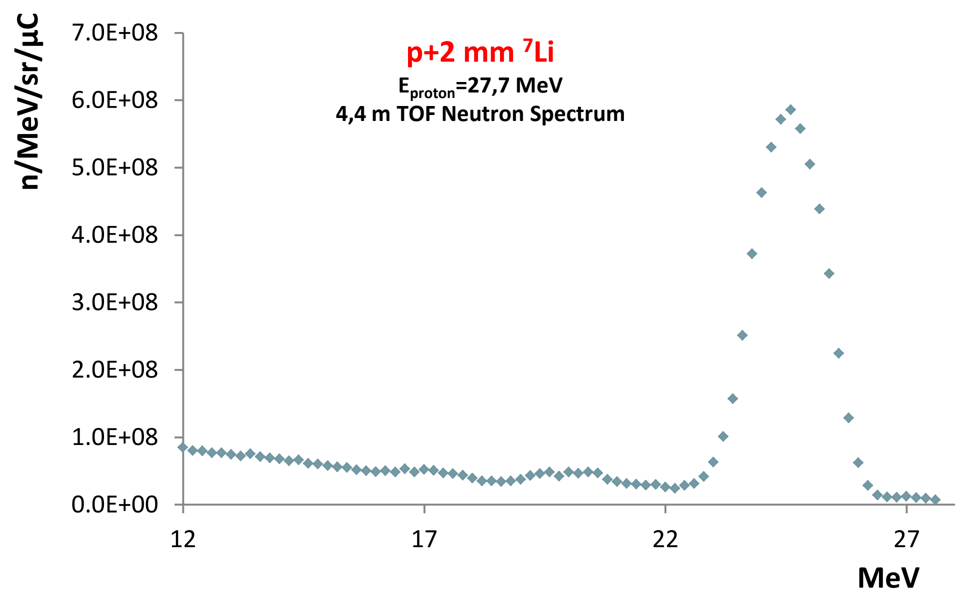
This approach removes the necessity to know the whole response function of the scintillator, the results are based only on the number of hydrogen atoms in the scintillator and on the cross-section of elastic scattering of neutrons on hydrogen, which are both accurately known.

TOF measurement

- Feasible for the direct neutron spectra measurement.
- The multichannel coincidence set up can give the input neutron energy as one of the reaction parameters.
- From the two channel graph of the scintillator response vs. TOF, the scintillator response at given time/energy can be extracted.



Currently, the LC&FNG prepares a new TOF set up for the significantly longer base and the significantly longer time range.
The bunching system for the U 120 M cyclotron is in construction.



Detection systems at U-120M cyclotron

Measurement of γ activation after irradiation

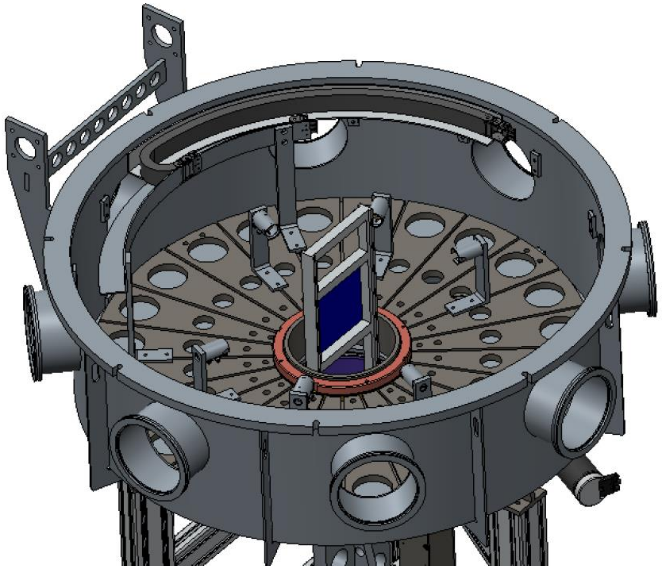
- The targets from target stations, as well as irradiated samples, are transported by pneumatic transport system to the HPGe detector station in tens of seconds after irradiation.
- The residual products are also measureable after irradiation with charged particles.

Pneumatic post system is used for fast transport of the irradiated samples to the detectors.

Detection systems at U-120M cyclotron

System for the direct detection of charged particles, which are produced in reaction with neutrons

- Large vacuum chamber
- Target in the center
- dE-E telescopes at different angles, outside the reach of the neutron beam, on a rotating table.
- Ready in 2019



Detection systems at U-120M cyclotron

System for the direct detection of charged particles, which are produced in reaction with neutrons

- The bunching system will make the detection system usable for the direct cross-section measurement of the (n, cp) reactions.
- Charged particle angular distribution will be measured.
- Extension of the laboratory know-how from measurements to modeling will be possible.

Detection systems at U-120M cyclotron

System for the direct detection of γ photons, which are produced in reaction with neutrons

- System consists of several HPGe detectors.
- Sample is placed in the neutron beam.
- HPGe detectors are mounted at different angles in respect to the beam direction.
- System is usable also on the beams of charged particles.
- Ready in 2019.

Detection systems at U-120M cyclotron

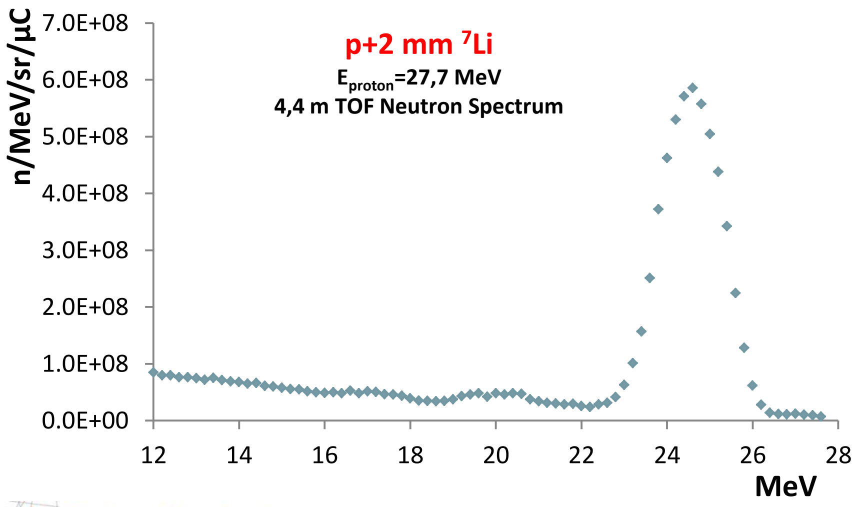
System for the direct detection of γ photons, which are produced in reaction with neutrons

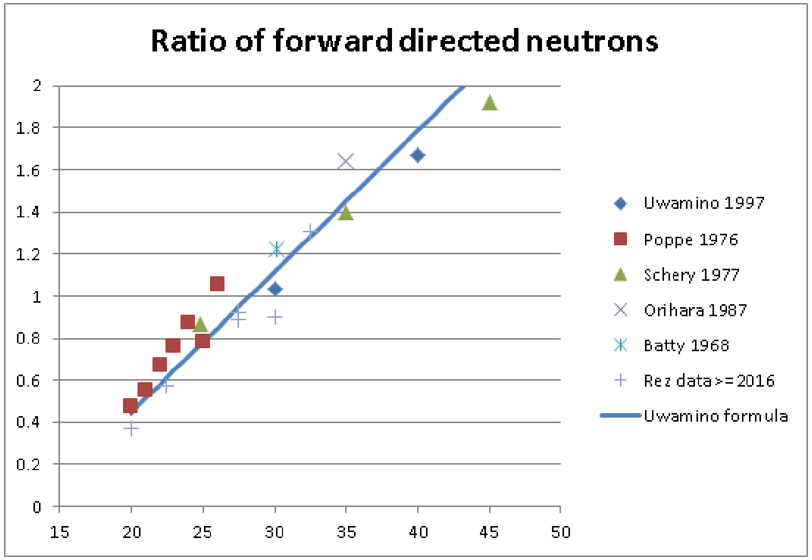
- Measurement of the residuals with decay times down to ms will be possible.
- The bunching system will make the online gamma spectrometer usable for the direct cross-section measurement of the (n, xγ) reactions.
- In combination with the neutron generators, the detection system will be most efficient in the neutron energy range of 10-33 MeV.

Measurement of nuclear reactions relevant to technological applications

$^{7}Li(p,n)^{7}Be$ reaction cross-section

The neutron cross-sections above 20 MeV are commonly measured with the quasi-monoenergetic (QM) neutrons from the p+Li reaction.
In general, the uncertainty of the neutron spectra from neutron sources such as p+Li and p+Be above 20 MeV is considered to be 10% and higher. The designed fusion and ADS facilities need better accuracy of the neutron cross-sections measured at these neutron sources, therefore knowledge of the neutron spectra needs to be improved.





Measurement of nuclear reactions relevant to technological applications

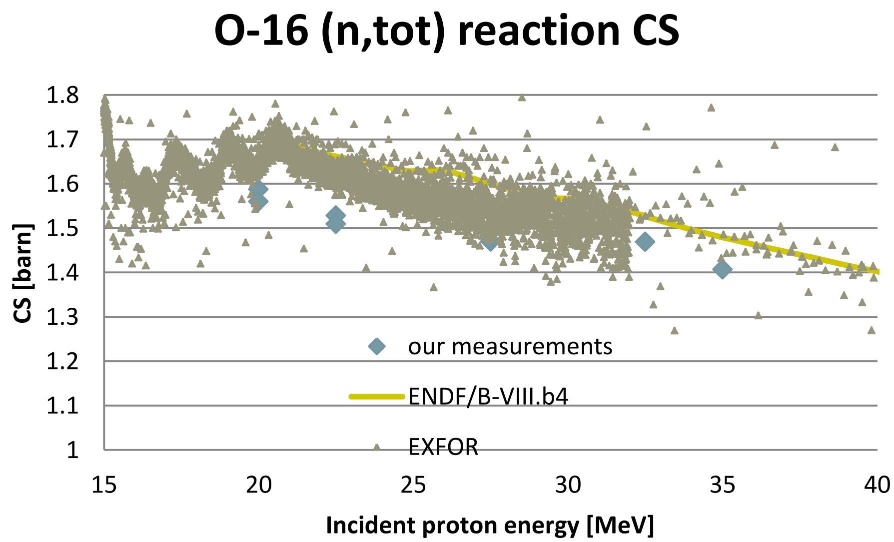
$^{209}Bi(n,2n)^{208m}Bi$ reaction

- The lead-bismuth eutectic alloy is the prospective coolant for future fast reactors and Accelerator Driven Systems (e.g., MYRRHA).
- The residual radioactivity of the coolant has to be studied.
- Using the standard activation method, it is difficult to determine the amount of residuals from the (n,2n) and (n,3n) reactions in Bi due to their long decay times ($T_{½}$ (^{208}Bi) = 3.68×105 y, $T_{½}$ (^{207}Bi) = 31.55 y).
- However, after the (n,2n) reaction, part of the residual is left in the first excited state with the $T_{½}$ (^{208m}Bi) = 2.5 ms, which could be measured using online γ-spectrometry methods.
- The experimental data on this reaction above 24 MeV neutrons does not exist.

Measurement of nuclear reactions relevant to technological applications

^{16}O(n,tot) reaction

- ADS require the extension of the cross-section upper energy limit above 20 MeV.
- One commonly present element in today‘s reactors is oxygen (in water), for which the experimental data on the (n,tot) reaction in the energy range 20-35 MeV does not exist.
- Transition measured by TOF measurement with and without liquid oxygen box.



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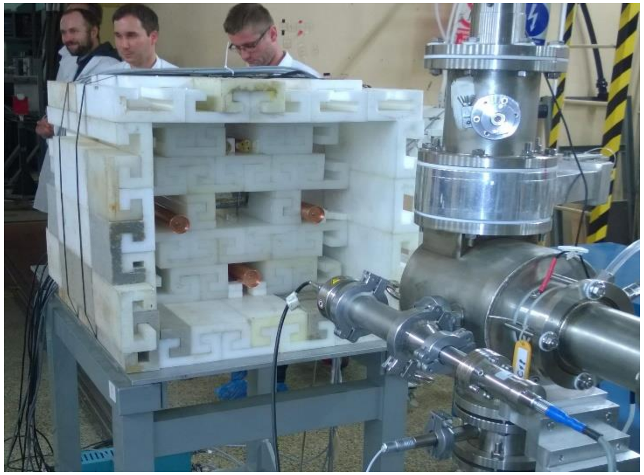
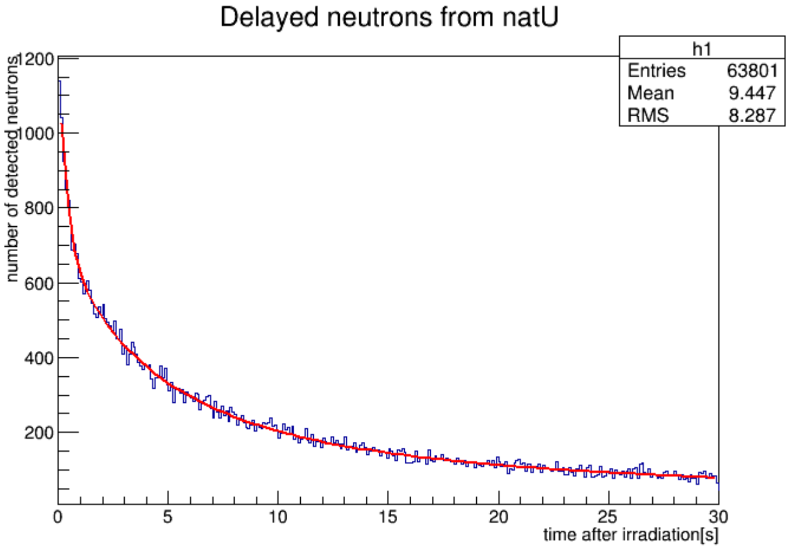
Measurement of nuclear reactions relevant to technological applications

Measurement of delayed neutrons

- BF_3 detectors
- Cyclotron is driven in suitable time periods (0.5 min/0.5min)
- In May 2017 experiment with 50g ^{nat}U was performed, continuous neutrons 33 MeV.
- Delayed neutron curve are measured and fitted to 6 energy groups.
- U foil was measured with HPGe, yields of some fission products can be obtained from spectra.





- Group 1: t_1/2=55.9s. Ratio 0.0535626
- Group 2: t_1/2=22.72s. Ratio 0.0492551
- Group 3: t_1/2=6.222s. Ratio 0.214534
- Group 4: t_1/2=2.3s. Ratio 0.250806
- Group 5: t_1/2=0.61s. Ratio 0.051267
- Group 6: t_1/2=0.23s. Ratio 0.380576

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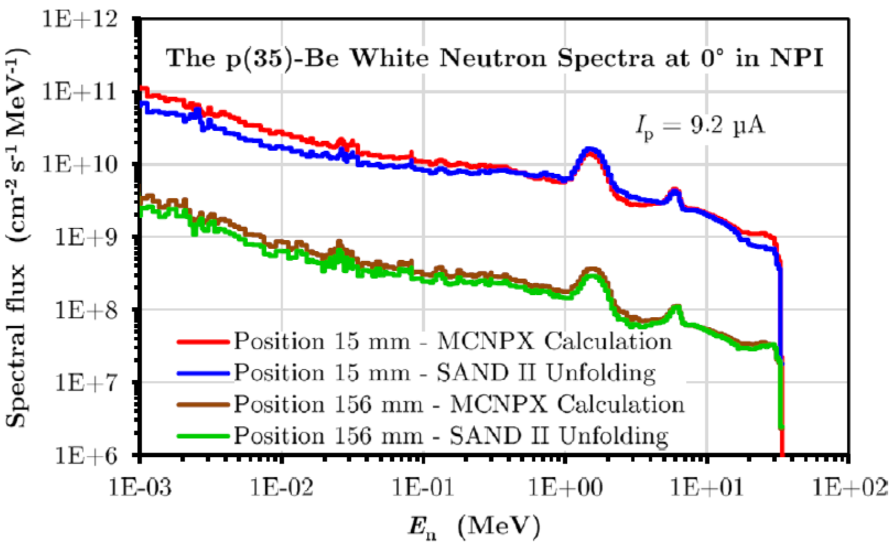
Measurement of nuclear reactions relevant to technological applications

Determining radiation damage using positron annihilation spectrometry

- Fusion devices D+T -> α+n(14 MeV)
- Worse mechanical properties due to radiation damage.
- DPA – unit to describe the damage by different sorts of irradiation
- PALS detect size < 1 nm
- 30 hours on p+Be (Running in parallel with other experiments)
- Only cumulative neutron flux is important, $10^{16} n/cm^2$ is sufficient.



Thank you

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