Determination and Monte Carlo Simulations of Neutron Flux Inside Spallation Target QUINTA

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Subcritical setup QUINTA

- Accelerator Driven Systems research
- Testing of quality of simulation programs
- The QUINTA dimensions are 700 x 350 x 350 mm and the weight is about 540 kg
- 5 sections (composed of natural uranium rods)
- 6 aluminium plates (holders) for placement of activation samples
- Irradiation by relativistic proton or deuteron beams from Phasotron or Nuclotron accelerators
- Production of huge neutron field inside the setup by spallation and fission reactions
- Neutron flux is measured by activation detectors and evaluated by activation techniques
Subcritical setup BURAN

- Experiments with a new subcritical setup called BURAN should start soon in the Joint Institute for Nuclear Research.
- Basic part of the Buran setup is a huge cylinder made from 20 tons of depleted uranium (0.3 % 235U) with longitudinal distance of 1000 mm and 1200 mm in diameter.
- The cylinder is surrounded by 100 mm steel covering.
- In the blanket there are 72 channels for placement of samples.
- BURAN is considered as quasi-infinite target with almost no neutron leakage (neutron leakage from QUINTA is more than 80 %).
Positions of aluminium and lead detectors

• Irradiation by 4GeV and 8GeV deuteron beam on Nuclotron in November 2013 and December 2013 and by 660MeV proton beam on Phasotron in November 2015
• Marking of aluminium plates: the first one = 0, the last one = 5
• Aluminium, cobalt and lead activation samples placed on x-axis edges of each aluminium plate
• Reaction rates of Na-24, Co-57, Co-58, Bi-205 and Bi-206 were investigated (evaluated by neutron activation techniques) and compared to Monte Carlo simulations
• Reaction rate = total number of nuclei created in an activation sample normalised to one source particle and one atom of the sample
• It is expected that reactions on aluminium and cobalt samples provide us with an information about sum of neutron +proton+deuteron flux $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$, $^{27}\text{Al}(p,3\text{n})^{24}\text{Na}$, $^{27}\text{Al}(d,2\text{n}3\text{p})^{24}\text{Na}$, $^{59}\text{Co}(n,3\text{n})^{57}\text{Co}$, $^{59}\text{Co}(p,2\text{n})^{57}\text{Co}$, $^{59}\text{Co}(d,\text{p}3\text{n})^{57}\text{Co}$
• Reactions on lead samples -> proton+deuteron flux $^{\text{nat}}\text{Pb}(p,x)^{206}\text{Bi}$, $^{\text{nat}}\text{Pb}(d,x)^{206}\text{Bi}$
Simulations

- Simulations were performed in Monte Carlo code MCNPX 2.7 (physical models used INCL4+ABLA)
- Flux of neutrons, protons and deuterons were simulated
- Cross sections of Na-24, Co-57, Co-58, Bi-205 and Bi-206 production were calculated in TALYS 1.6
- Reaction rates were calculated by convolution of the simulated flux and the calculated cross sections
Cross sections

• Comparison of cross sections calculated by TALYS 1.6 with data from cross section database EXFOR

• Good agreement for reactions with protons
Simulations of neutron (blue line), proton (red) and deuteron (green) fluxes on 2nd Al-plate (upper figures for d4GeV, lower for p660MeV)

*Figures on the left = left side of Quinta*
*Figures on the right = right side of Quinta*

- Values on the left and right side are supposed to slightly differ because of incident beam inclination (about 2 degrees)
Reaction rates of Na-24 November 2013. 4GeV deuteron

- Statistical uncertainties of experimental reaction rates visible in the graphs
- Experiment – greater values of reaction rates on left side
- Simulated reaction rates of Na-24 = neutrons+protons+deuterons
- Dominant contribution from neutrons (for protons < 5%, for deuterons < 0.1%)
- Good agreement of experiment and simulation
Reaction rates of Bi-206 and Bi-205
November 2013, 4GeV deuteron

- Simulated reaction rates are underestimated compared to experimental reaction rates on the left side
- The biggest discrepancy is on aluminium plate 2 where the greatest particle flux was reached
- The discrepancy decreases with decreasing flux
- Contributions to reaction rates from deuterons were usually < 5%
Rea(on rates of Na-24  
December 2013, 8GeV deuteron

• Simulation does not fit conveniently the experiment – greater values on the left side

• The discrepancies on the left side does not seem to have the decreasing tendency with decreasing flux (aluminium plates 2, 3, 4) opposite to the right side

• Contributions to simulated reaction rates from protons and deuterons were similar to the 4GeV deuteron experiment
Reaction rates of Bi-206 and Bi-205
December 2013, 8GeV deuteron

• Good agreement between experimental and simulated values on the left side

• Contributions to simulated reaction rates from deuterons were similar to the 4GeV deuteron experiment
The agreement between experiment and simulations is sufficient except for values on the 2nd aluminium plate for Co-58 production where the disagreement is a little over 50%.

Contribution to reaction rates of Co-57 and Co-58 production from reactions with protons are high compared to the proton contributions to Na-24 reaction rates at Nuclotron experiments (< 5%).

Deuteron contributions are not more than 0.2%.
Reaction rates of Bi-206 and Bi-205

November 2015, 660MeV proton

- On the left side the differences between experimental and simulated values are not small - at aluminium plates 4 and 5 the experimental and simulated values are in a good agreement
- On the right side the agreement is a little better than on the left side
- The greatest discrepancies can be found at aluminium plate 3
- However, the simulations follow the increasing and decreasing tendency of the experimental results (except for the values at aluminium plate 3 on the left side)
- The deuteron contributions to reaction rates of Bi-205 and Bi-206 production were less than 1.3 %
Reaction rates comparison and left/right side ratios of the experiments
Conclusions

- Reaction rates of Na-24, Co-57, Co-58, Bi-205 and Bi-206 from QUINTA experiments on Nuclotron and Phasotron were evaluated.
- Simulations in MCNPX 2.7 were performed and compared to the experimental data.
- The best agreement between experimental and simulated reaction rates was for Na-24 production for the 4GeV Nuclotron experiment and for Co-57 and Co-58 production for the Phasotron experiment.
- Contribution to reaction rates of Co-57 and Co-58 production from reactions with protons are high compared to the proton contributions to Na-24 reaction rates.
Thank you for attention

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