Measurement of neutron yield by 62 MeV proton beam on a thick Beryllium target

$p +^9 Be \rightarrow n + X$

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Accelerator based Neutron Production (ABNP),
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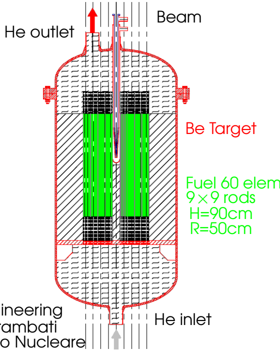
Outline

INFN-E/ADS Project

EPJ Plus Focus Point 2014

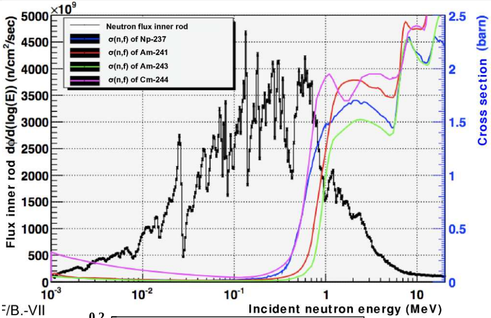
- SPES cyclotron (LNL,2014): protons of 70 MeV, 0.75 mA.
- He gas-cooled ^{9}Be target/converter.
- Fast sub-critical reactor core:
  - solid Pb matrix (94 t.),
  - 20% enriched UO_2 (1.8 t.),
  - gas cooling (He),
  - $k_{eff} = 0.946$, $\phi = 3 \div 6 \times 10^{12}$ n/cm^2/s, $P_{th} \simeq 130$ kW$_{th}$, $T_{vessel} \simeq 200^\circ$ C.
- Main research goals:
  - study of radioactive waste burn-out and transmutation,
  - core kinetics and reactivity dynamics,
  - safety and licensing,
  - training of students and researchers.

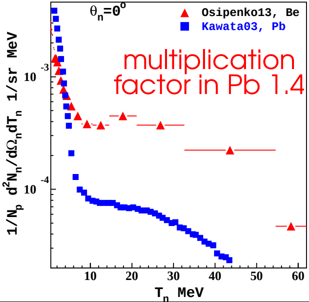


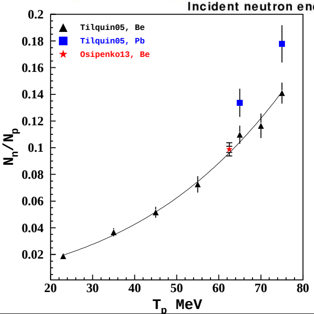
engineering
S.Frambati
Ansaldo Nucleare

Beryllium Converter

- Fast neutrons ($>$ 1 MeV) burn minor actinides,
- ^{9}Be with 70 MeV p - hard, abundant neutron source,
- low γ yield, high melting point and thermal conduc.,
- Pb converter gives 20% higher, but softer, yield.





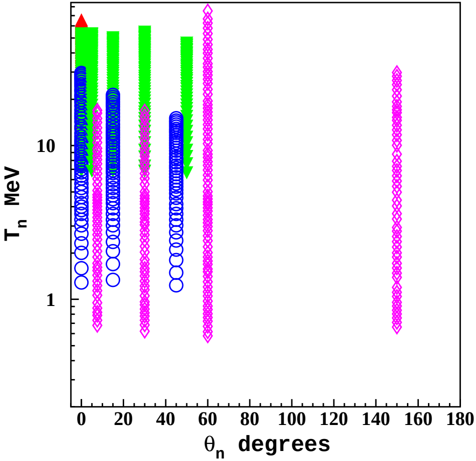


^{9}Be(p,n) Data

- Scarce neutron yield data in 70 MeV proton energy range,
- Low precision and/or missing systematic uncertainties,
- Incomplete neutron spectrum,
- Integrated yield data:

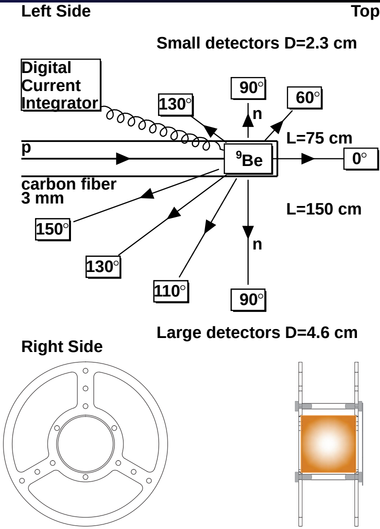
  65 and 70 MeV, I. Tilquin *et al.*,**NIM A545**.
- Differential yield data:

  46 MeV, F. Waterman *et al.*,**Med.Phys.6**, 55 MeV, S. Johnsen,**Med.Phys.4**, 66 MeV, H. Almos *et al.*,**Med.Phys.4**, P. Heintz *et al.*,**Med.Phys.4**, 113 MeV, M. Meier *et al.*,**Nucl.Scien.Eng.102**, R. Madey *et al.*,**Med.Phys.4**, G. Harrison *et al.*,**Med.Phys.7**.



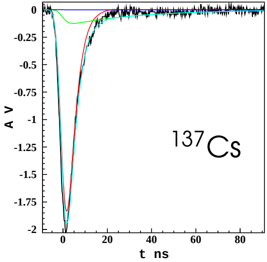
LNS (Catania) Setup

- 62 MeV SCC proton beam, 30-50 pA, RF=40 MHz,
- 125 ns bunch period (1/5 suppression), 1.5 ns bunch width.
- Charge deposited in 3 cm thick ^{9}Be target used for normalization.
- Light carbon fiber beamline and Teflon target holder.
- Neutron ToF was measured with respect to SCC RF.
- 4×2 detectors acquired simultaneously via 2 CAMAC DAQs.



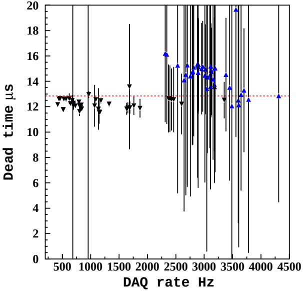
Neutron Detectors

- Al (EJ520 Paint or Teflon) cylindrical cells: H=4 cm, D=4.6 (2.3) cm,
- filled (in Ar/N_2) with EJ301 liquid scintillator (PSD), left 4% expansion volume,
- 4 mm thick borosilicate glass, optical grease coupling to ET9954B PMT (2 ns),
- C649 voltage dividers (up to $I_{peak} = 200$ mA),
- installed on light Al supports at beamline height (168 cm) and at > 4 m from hall walls.



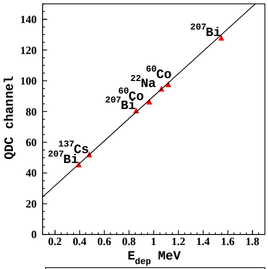
DAQ Scheme

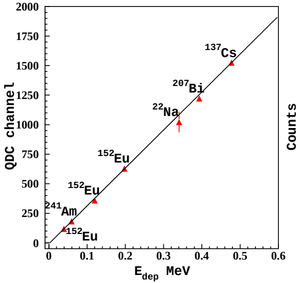
- Passive 3-way splitter: discriminator (2/9,1/9), energy total (1/9,2/9) and slow (2/3),
- Ganelec FCC8 CFDs with 4 ns delay,
- LeCroy TFC with 0.2 ns resolution,
- Double QDC range:
  - small: <0.5 MeVee, integrated ($\tau = 20$ ns) and amplified by Ortec TFA454,
  - large: <50 MeVee, CFD output amplified by P/S 771.
- PSD on tail of the pulse (>30 ns),
- LeCroy FERA DAQ (13 μs dead time) with GPIB interface to Linux PC.

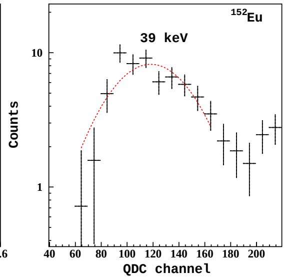


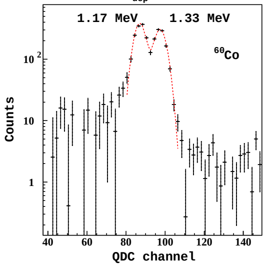
Deposited Energy Calibration

- Backward Compton Scattering coincidences (with BaF_2),
- γ-sources: ^{207}Bi, ^{137}Cs, ^{60}Co, ^{22}Na, ^{152}Eu, ^{241}Am.
- Resolution $\Delta E_{dep}/E_{dep}$<5%/$\sqrt{E_{dep}}$.



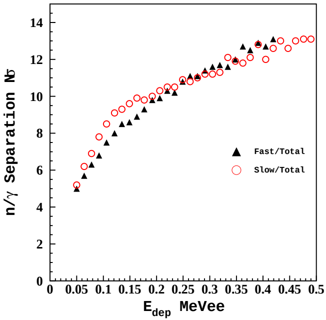


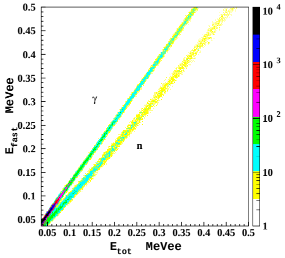


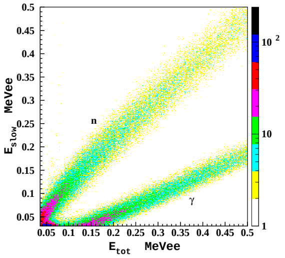


Neutron Identification

- Pulse Shape Discriminations using peak and tail of liquid scintillator signal were compared,
- PSD on the tail allowed better identification for small signals,
- PSD thresholds ($<$ 1% misidentification) of 50 and 200 keVee were achieved.

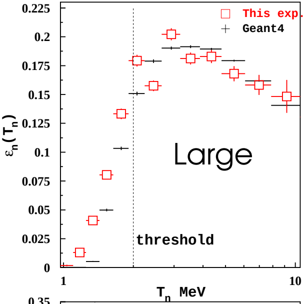


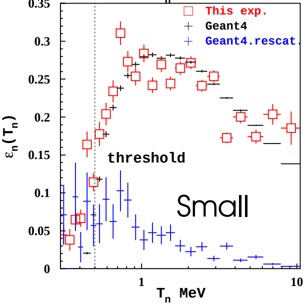




Detector Efficiency

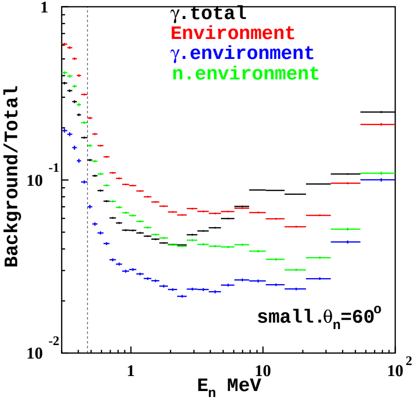
- Efficiency was obtained using a complete GEANT4 simulation of detectors,
- it was validated in a measurement with ^{252}Cf source (γ-n coincidence) according to *N. Colonna et at., NIM416*,
- in the threshold region the measurement was contaminated by the rescattering of neutrons from BaF_2 detector,
- within accepted energy range the overall deviation of GEANT4 simulations from the data is $<$ 10%.

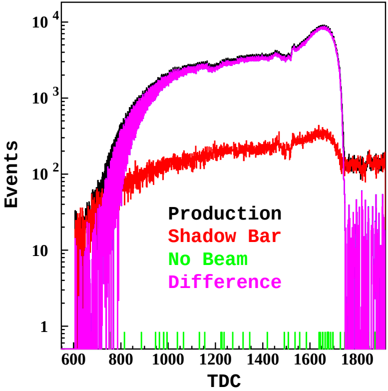




Backgrounds

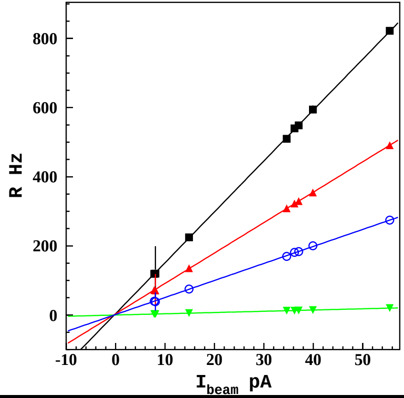
- γ contamination separated by PSD: 10÷15% (thanks to carbon fiber beamline),
- environmental background (n rescattering and γ production from target/detector enclosure) measured using shadow bar: 10÷15%.

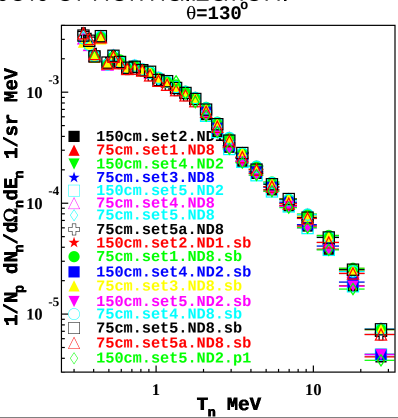




Normalization

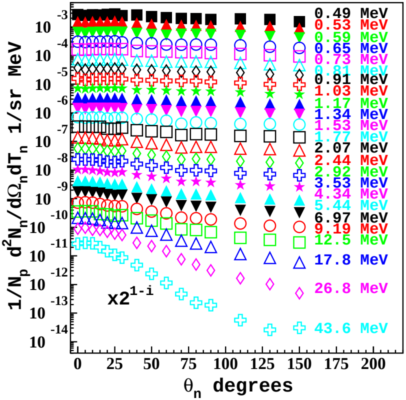
- proton beam charge deposited on ^{9}Be target, protected by guard ring, was measured,
- two different digitizers: Ortec 439 and BIC 1000C with precision < 2 pA were used,
- rate dependence on measured beam current was studied to obtain small offsets of normalization.

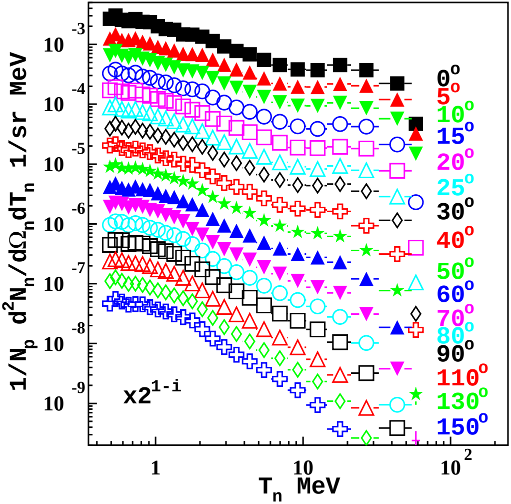




Differential Yield

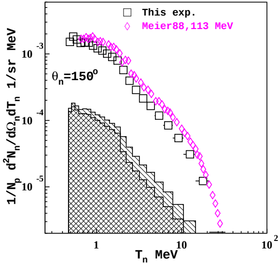
- 16 angular points from 0 to 150 degrees (2° res.),
- wide energy range from 0.5 to 62 MeV (30 bins).

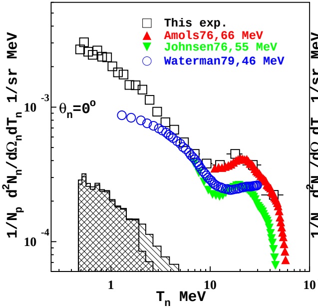


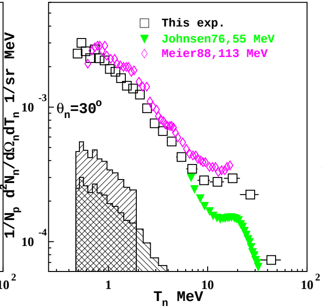


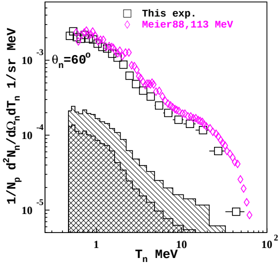
World Data

- Good agreement with existing data,
- lower beam energy data cannot be easily extrapolated (46/62=0.4, 55/62=0.7) due to different neutron energy range,
- Waterman79 used plastic scintillators (no γ/n separation).



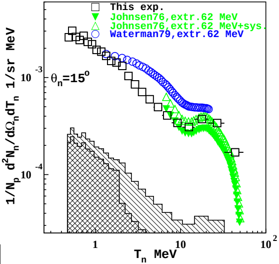


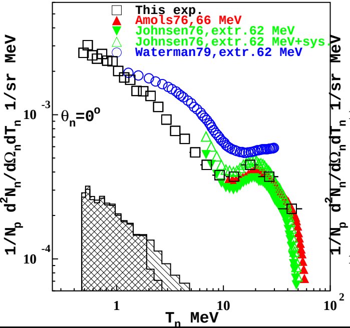


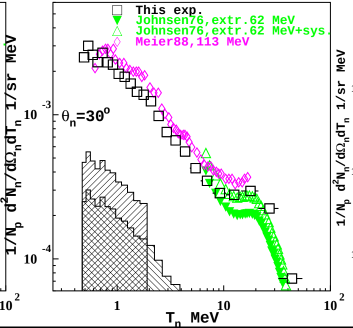


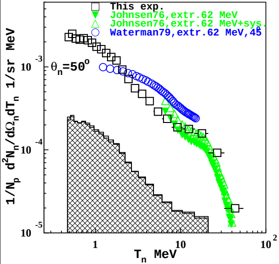
World Data Cont.

- extrapolated world data to beam energy of 62 MeV by the overall beam energy dependence from Johnsen76,
- data from Johnsen76 becomes compatible with ours,
- Waterman79 used plastic scintillators (γ contamination neglected).



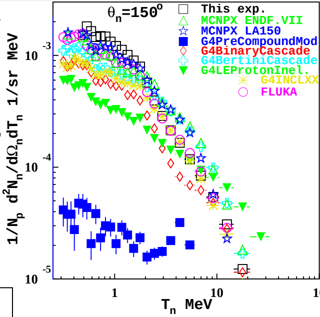


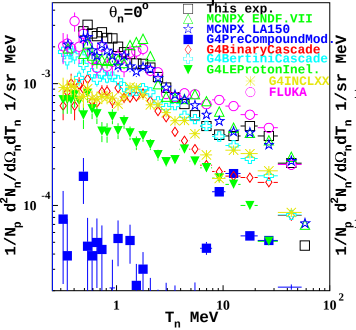


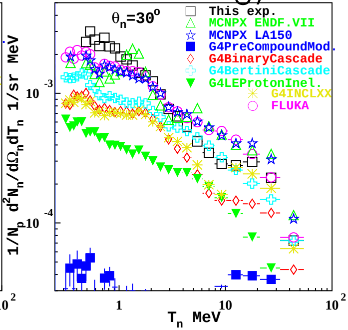


Monte Carlo Packages

- MCNP and FLUKA lie closer to the data, but with different T_n-trend,
- in GEANT4, BertiniCascade - similar to MCNP and FLUKA, BinaryCascade - has 30 MeV ^{8}Be threshold, LEProtonInelastic - has no ^{8}Be or 2α channels, INCLXX - similar to BinaryCascade, PreCompound - zero excess energy.

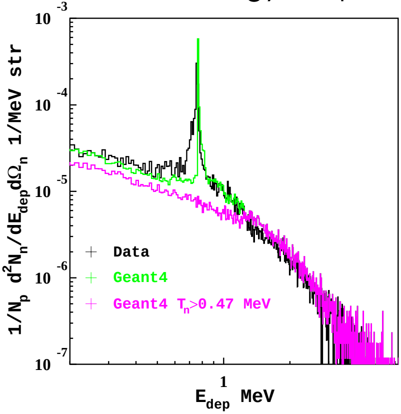


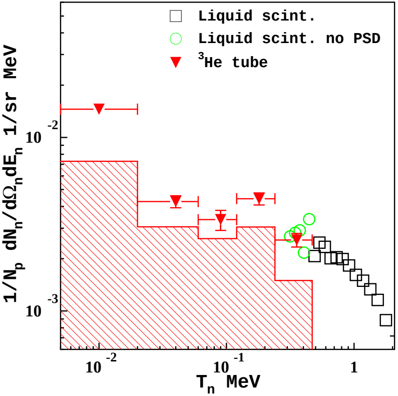




Low Energy Neutrons

- ^{3}He detector was used to measure $T_n < 0.5$ MeV energy range,
- ^{3}He data agree with lowest energy ToF points.

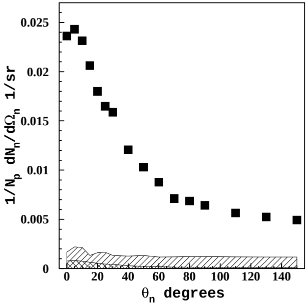


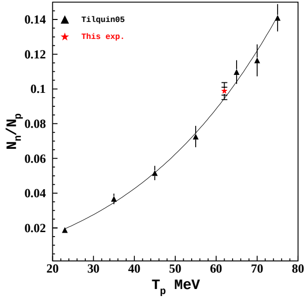


Integrated Yield

- At 62 MeV MCNPX simulations give $N_n/N_p = 0.103$ (ENDF VII) or $N_n/N_p = 0.096$ (LA150),
- at 65 MeV experimental data give $N_n/N_p = 0.110 \pm 0.007$ ($N_n/N_p = 0.098$ at 62 MeV)

  I. Tilquin *et al.*,**NIM A545**,
- this experiment at 62 MeV $N_n/N_p = 0.09875 \pm 0.0003_{stat.} \pm 0.002_{sys.} \pm 0.005_{norm}$.
- Quasi-elastic scattering at small angles and isotropic, evaporative process at large angles.





Summary

- Neutron yield produced by 62 MeV proton beam on full range ^{9}Be target has been measured in complete energy and angular ranges.
- The obtained data are in agreement with previous experiments at similar beam energy and with the total yield measurement.
- Comparison with MCNP and FLUKA shows slightly different energy behavior, various GEANT4 models provide even worse data description (BertiniCascade lies closer than the other models).
- Data are published in M.Osipenko *et al.*, Nucl.Instrum.Meth.**A723**, 8 (2013) and tables are provided in arXiv:1302.7226 sources and at http://www.ge.infn.it/~osipenko/lns2012/.
- These data were used in design of ADS facility and ISODAR experiment A. Bungau et al.,PRL109.

For Further Reading I

M. Ripani et al.
Choice and test of the photomultipliers for the Large Angle electromagnetic shower Calorimeter on the CLAS detector at CEBAF.
Nuclear Instruments and Methods in Physics Research Section A, Volume 406 (3):403-410, 1998.