ESTIMATING THE RADIATION SOURCE TERM FOR PET ISOTOPE TARGETS

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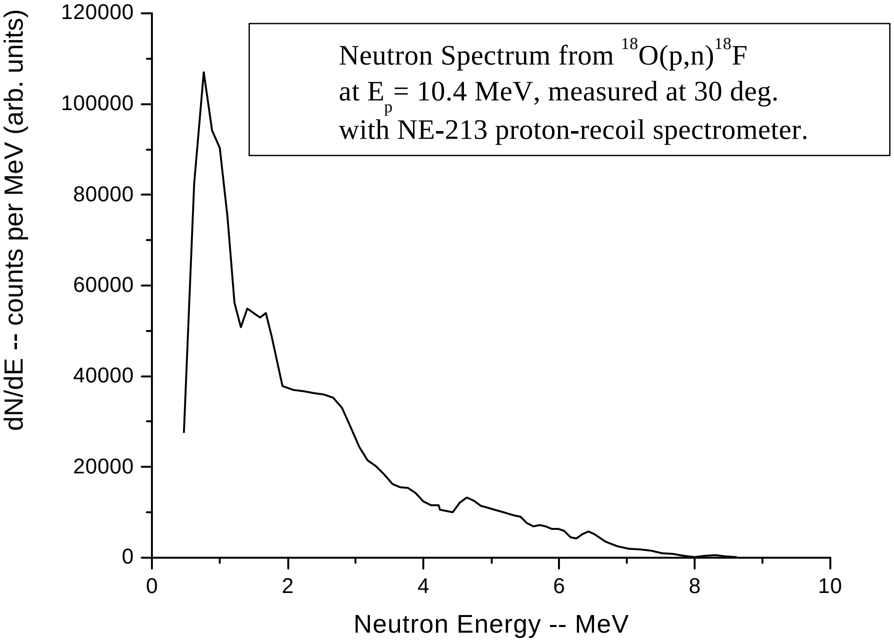
ABSTRACT An estimate of the source term – the neutron fluence and spectra for nuclear reactions commonly used for producing PET isotopes – is required to validate the design of shielding, and to estimate the potential for activation of materials and components in and around the cyclotron.

We present data on neutron fluence and spectra for the most commonly used (p,n) PET isotope nuclear reactions, including $^{18}O(p,n)^{18}F$ for proton energies of 11 MeV and 17 MeV. Data were obtained from our own neutron measurements on bare and partially-shielded targets at 11 MeV. At the higher proton energy we conducted computer simulations utilizing the program ***ALICE-91***.

Neutron spectra at 11 MeV. The Energy spectrum of neutrons from un-shielded RDS-112 Targets (CTI, Inc., Koxville, TN, USA) were measured using an NE-213 Proton-recoil Spectrometer[1]. Pulse-shape discrimination produced separate and distinct energy spectra for gamma-ray events versus neutron-induced proton-recoil events. The raw detector data were 'unfolded' using our own algorithm which incorporates a correction for the intrinsic non-linearity of response of the scintillator at low recoil energies, a correction for the energy-dependent fall-off in detector



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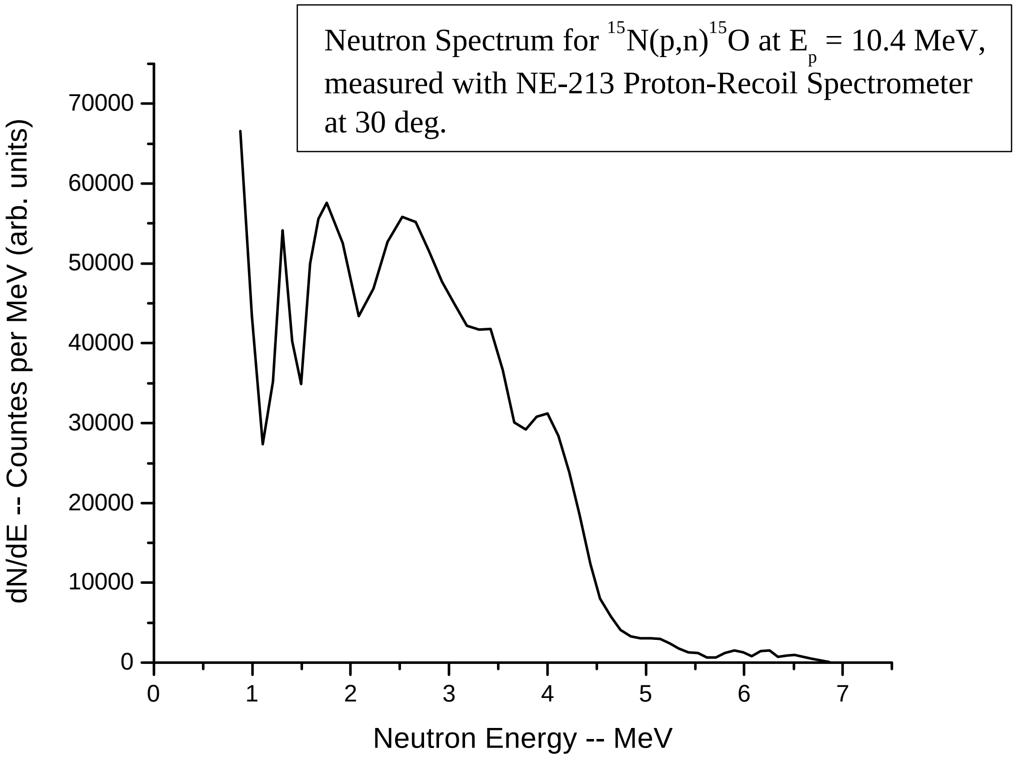
[1] Beam energy on target -- accounting for energy loss in the foils – was 10.4 MeV.

efficiency and, finally, channel-by-channel discrete differentiation to extract spectral information from the (more-or-less) featureless continuum of the raw data. The algorithm was validated by comparing an 'unfolded' AmBe neutron spectrum against examples from the literature[2].



Angular distribution of neutrons This was measured by fast-neutron activation of small material samples placed at several angles around (and close to) bare RDS -112 targets: Small pellets of P_2O_5 were activated via the reaction $^{31}P(n,p)^{31}Si$ to record neutrons above 2 MeV; small iron bolts were activated via the reaction $^{56}Fe(n,p)^{56}Mn$ to record neutrons above 6 MeV. In the figures below, data for respective threshold reactions are normalized – ***not according to relative intensity*** (which is apparent from the above figures) -- but rather for ease of visualization of angular distribution.

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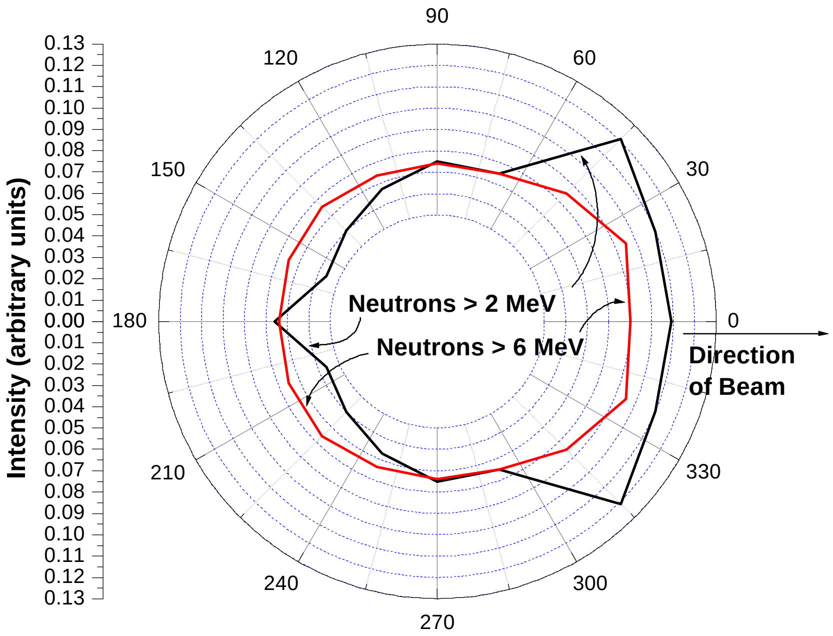
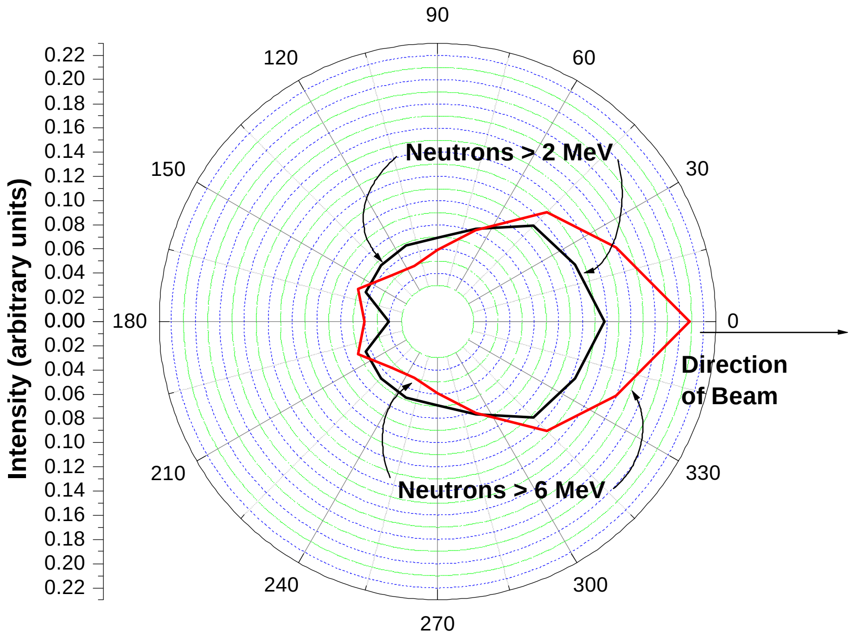
[2] Carroll L.R., Pekrul E.:"Radiation Measurements in the Design and Evaluation of a Self-Shielded Accelerator for PET". Proceedings of the Twentieth Midyear Topical Meeting of the Health Physics Society. Reno, Nevada, Feb., 1987.

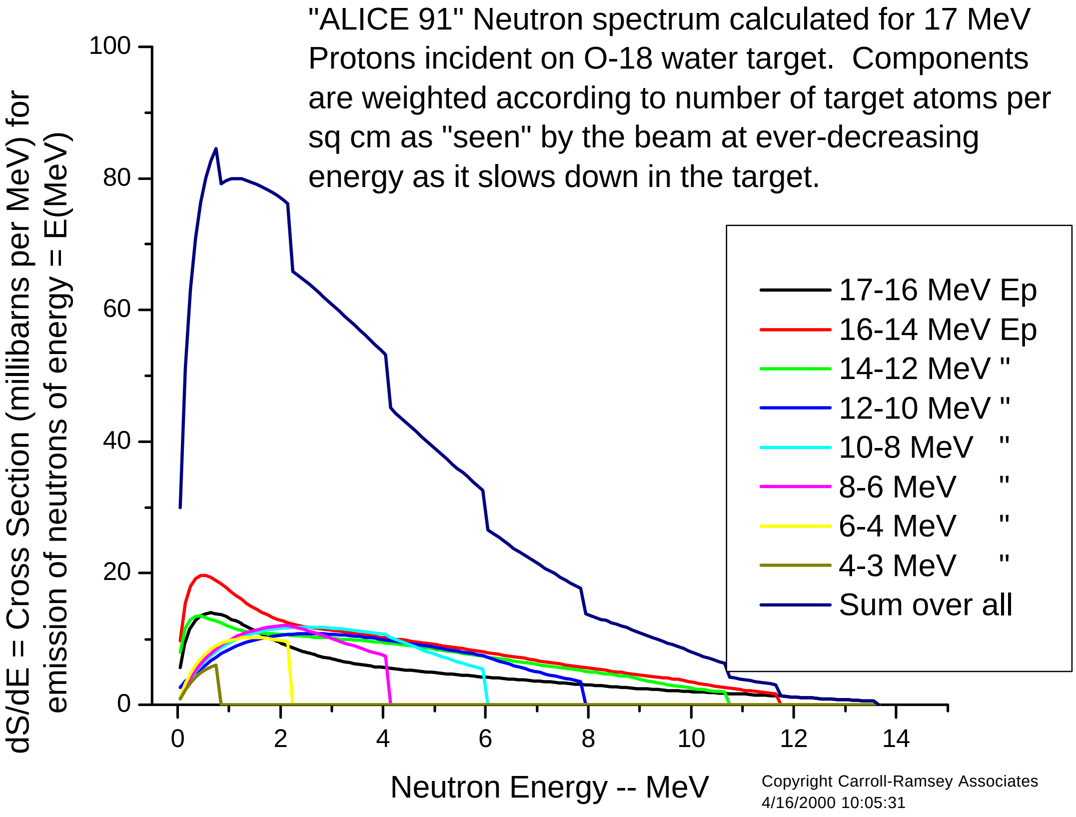


Angular Distribution of Neutrons
from O-18(p,n)F-18 at Ep=10.4 MeV



Angular Distribution of Neutrons
From N-15(p,n)O-15 at Ep = 10.4 MeV

Spectrum and Fluence for Ep = 17 MeV For bombarding energies greater than Ep = 12 MeV, a number of additional neutron-producing reaction channels open up. However, to the best of our knowledge, direct experimental data on total neutron fluence and spectrum for reaction energies higher than ~12 MeV is not available at this time.


"ALICE 91" Neutron spectrum calculated for 17 MeV Protons incident on O-18 water target. Components are weighted according to number of target atoms per sq cm as "seen" by the beam at ever-decreasing energy as it slows down in the target.

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Discussion: The reaction $^{18}O(p,n)^{18}F$ is today -- by far -- the most widely used reaction for PET isotope production. Below E_p = ~12 MeV the rate of neutron production is virtually identical to the ^{18}F saturation yield, i.e., the rate of production of ‘new’ ^{18}F atoms[3].

Above E_p = 11 MeV a number of additional $^{18}O(p,x)$ neutron-emitting reaction channels become energetically possible[4], but experimental cross-section data are not readily available to help us determine rates of ‘excess’ neutron emission. We turn, therefore, to computer codes, such as ***ALICE 91*** to help us make these estimates.

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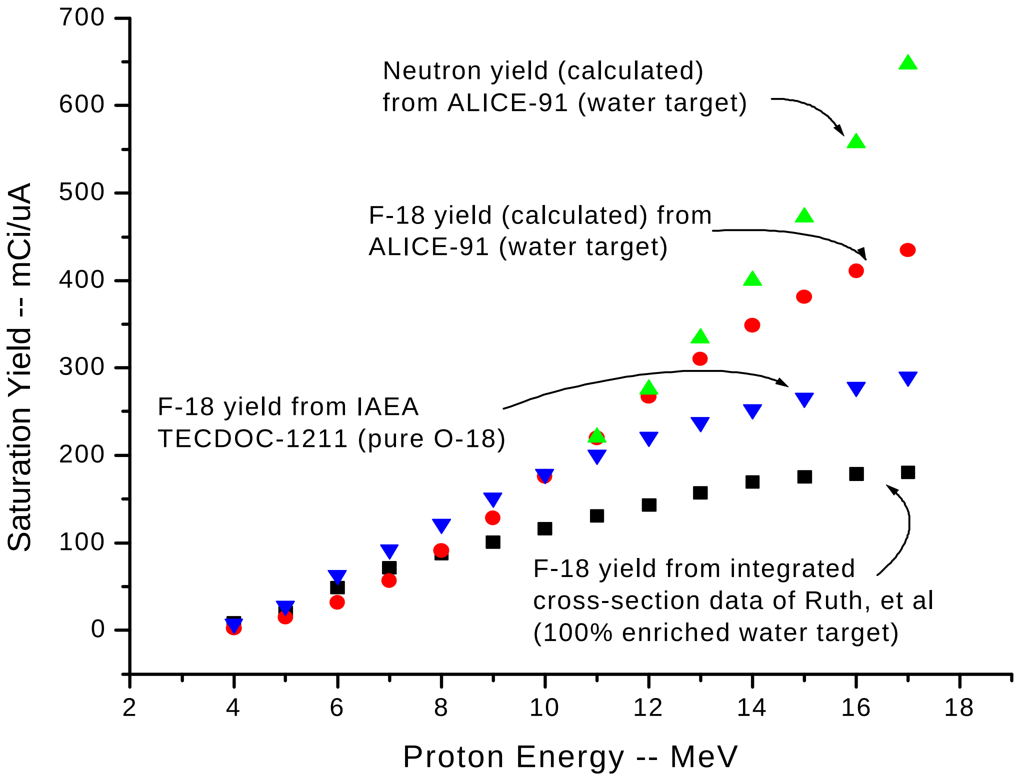
[3] Bair, Miller, and Wieland; **IJARI**, Vol. 32, pp. 389-395, 1981.

[4] Threshold and ‘Q-value’ data base at <http://t2.lanl.gov>



The plots above show that below E_p = ~8 MeV ***ALICE 91*** underestimates ^{18}F saturation yield and – by inference – also underestimates neutron production per uA on an ^{18}O water target.

Above E_p = 8 MeV, ***ALICE 91*** begins to overestimate both ^{18}F saturation yield and neutron yield.

At 17 MeV ***ALICE 91*** plausibly predicts approximately 1.5 times as many neutrons per second relative to its own internal model calculation for ^{18}F saturation yield, but this is almost 4 times as many neutrons per second relative to experimentally-measured -- and widely accepted -- ^{18}F yield data [5] scaled for a 100% enriched water target.

Thus, between 11 MeV and 17 MeV ***ALICE 91*** provides a credible – albeit highly conservative – upper bound for neutron yield per uA from this reaction, offering a wide safety margin relative to enriched water targets as well as higher-performance $^{18}O_2$ gas targets for use in shielding and activation calculations.

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[5] T. Ruth, *et al;* ***EXFOR*** charged-particle nuclear reaction data base at <www.nndc.bnl.gov>