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Corrections for neutron source cross section data measured by proton-recoil counter telescopes in the presence of water-spray cooling of the source

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Due to the low neutron detection efficiency of proton-recoil counter telescopes which is typically much less than 10^{-4} only highly intense monoenergetic neutron fluxes can be measured, preferably straight from neutron sources. If monoenergetic neutrons are produced by a charged particle beam with a beam stop, comparatively high beam currents require the cooling of the neutron target. If cooling by an air jet does not suffice, water-spray cooling is applied. However, water-spray cooling produces extraneous protons which can (and often did) mess up the result. It is shown how it can be dealt with such extraneous protons.

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Abstract

Due to the low neutron detection efficiency of proton-recoil counter telescopes which is typically much less than 10^{-4} only highly intense monoenergetic neutron fluxes can be measured, preferably straight from neutron sources. If monoenergetic neutrons are produced by a charged particle beam with a beam stop, comparatively high beam currents require the cooling of the neutron target. If cooling by an air jet does not suffice, water-spray cooling is applied. However, water-spray cooling produces extraneous protons which can (and often did) mess up the result. It is shown how it can be dealt with such extraneous protons.

Principle of measurement

Protons recoiling from a thin polyethylene radiator into a reasonable small forward cone are a measure of the neutron flux impinging on the radiator. The identification of the protons is done by means of a dE detector in front of and in coincidence with a total energy detector. For a sufficiently small forward cone (and radiator) the proton yield is proportional to the incoming neutron flux and the 180° cross section of $^{1}H(n,n)^{1}H$1-3), the co-called n-p cross section. At higher neutron energies a relativistic approach becomes necessary4). A background measurement with no radiator in place can be used to subtract extraneous counts (counts not originating from the radiator). This scheme may fail when the neutron field to be measured contains (extraneous) protons. In the foreground run such protons are energy-degraded by the radiator and will therefore not be recorded by the full energy detector if they start out with the same energy as the neutrons. However, in the background run (no radiator) no energy is lost and the full energy is recorded in the main detector. Thus, if in such cases the proton energy is close to the neutron energy the net count number is reduced, resulting in an apparently smaller neutron flux measurement.

Sources of extraneous protons

From above it is clear that extraneous protons disturb when they have about the same energy as the neutrons to be measured. Therefore, break-up protons from, e.g., a deuteron beam used by the neutron source would not disturb, as their energy is off, due to the separation energy of the deuteron and the Q-value of the neutron source reaction. These protons do not only have a wrong energy but should not be present if the beam-stop was dimensioned correctly to retain all of the beam-charge. However, there exists frequently a source of disturbing extraneous protons because it is not unusual to cool the neutron target with a water-spray.

Improving the background measurement

Extraneous protons must be measured as equal as possible in the foreground and the background run so that their effect is minimized in the net result. Thus, the protons must be energy degraded in a similar way in the background run as by the radiator in the foreground run. In an experiment in summer 19785) done at the Ion Beam Facility of LANL (measuring p-T at 13.6MeV) the radiator foil of 39.75 mg/cm2 polyethylene was simulated by a sandwich of two background foils: 17.6 mg/cm2 beryllium + 37.3 mg/cm2 carbon. The amount of carbon equals about that in the radiator, the beryllium foil degrades the proton energy without generating disturbing protons. Thus, the electronic stopping of extraneous protons in the radiator was sufficiently well simulated in the background run, making the experiment independent of the intensity of the water-spray cooling.

Source reaction measurements with water-spray cooling

Unfortunately, usually no information on the kind of target cooling can be found in the papers on cross section measurements done with proton-recoil counter telescopes. It is known for sure only in experiments in which the author himself was involved. It can be assumed that in Table 1 data which are low were measured using water-spray cooling (too much background).

TABLE 1. Comparison of Present Scale8) with Scales of other Absolute Differential Cross Sections for Zero Degree Neutron Production by the Hydrogen Isotopes Measured with Proton-Recoil Counter Telescopes (Adopted from Ref. 6)

Author	Year	Corr.Fact a).	Scale Unc. b)
^{3}H(p,n)^{3}He			
Bogdanov 9)	1959	0.996	10%
Perry10)	1960	1.056	7%
McDaniels11)	1972	1.075	3%
Drosg c)	1978	1.000	2%
^{2}H(d,n)^{3}He			
Smith12)	1957	1.062	5%
Cochran13)	1959	0.999	5%
Goldberg14)	1960	0.990	4%
Wilson15)	1960	1.000	5%
^{3}H(d,n)^{4}He			
Brolley16)	1951	1.043	11%
Bame17)	1957	1.067	5%
Simmons18)	1968	1.130	8%
McDaniels19) <11.5 MeV	1973	1.069	3%
McDanlels19) >11.5 MeV	1973	1.112	3%
Drosg d)	1976	1.051	2.5%

a) data must be multiplied by this factor to coincide in scale with the cross section predictions of DROSG-20008)

b) uncertainties given are either the original values (if available), or some estimate. In both cases adjustment uncertainties were added if their contribution was not negligible

c) measurement5) at 13.6 MeV with equal proton energy loss in the background run

d) measurements7) from 6 to 11 MeV

Correction of data taken with water-spray cooling

In the case of a 0-degree excitation function which is the most common case, it seems justified to take these data as relative data, just as done by McDaniels11),19) (raising in both cases the data by 1.10) and by Drosg6) raising Simmons' data18) by 1.13. These excitation functions are relative under the condition that the water-spray intensity stays (in average) the same during all of the experiment forming an effective constant water-film between neutron target and detector. Under such circumstances the areal density of hydrogen in the radiator is effectively reduced by the effective areal density of hydrogen in the water-spray (taking into account the difference in the neutron flux at the position of the spray-water and the radiator), resulting in an *energy-independent* correction factor (>1). Observe that this is true for the specific experimental set-up and independent of the kind (and energy) of neutron flux to be measured. Of course, the correction factor stays constant only as long as the intensity of the spray stays constant which, usually, is not known. A good example for that are the p-T (Table

2) and d-T data (Table 3) by McDaniels11),19). Both require the same correction factor, suggesting that they were measured under the same conditions (actually, one after the other!). Actually, the original experimental log-book shows that the experiment was interrupted and set-up anew after the 11 MeV measurement of d-T which surely is the reason for the increased correction factor above 11 MeV in Table 1. From the above it is clear that excitation functions measured with water-cooled targets can be relative; however, one cannot be sure.

TABLE 2. Zero-Degree Absolute Laboratory Cross Sections of the Reaction ^{3}H(p,n)^{3}He (Data are given in mb/sr, differential uncertainties in %, scale unc. ± 1.5%). From Ref. 11, with scale adjustment of 1.075 instead of 1.100.

MeV	McDaniels	DROSG-20008)
10.00	27.2 ±2%	27.4
11 .00	30.2 ±2%	29.6
12.00	32.4 ±2%	32.7
13.00	36.8 ±2%	36.0
14.00	39.0 ±2%	39.2
15.00	41.5 ±2%	42.0

TABLE 3. Zero-Degree Absolute Laboratory Cross Sections of the Reaction ^{3}H(d,n)^{4}He. (Data are given in mb/sr, differential uncertainties in %; scale uncertainty is ± 1.5%)

MeV	McDanielsa)	Simmonsb)	DROSG-20008)
6.00	25.9 + 2%		26.5
7.00		27.2	26.9
8.00	26.7 ± 2%	25.4	26.4
9.00	25.9 ± 2%	25.8	25.7
10.00	25.4 + 2%	251.	25.3
11.00	24.8 ± 2%	25.2	25.1
11.40		25.0	25.1
12.00	24.3	26.8	25.0
13.00	23.7	25.7	25.1
14.00		25.4	25.2
15.00	24.7	25.8	25.5
16.00		26.2	25.7
17.00		26.9	26.0
19.00		26.4	26.3

a) Data set from Ref.19, with scale adjustment of 1.069 instead of 1.100
b) From Ref .18, adjusted in scale by 1.130

In the case of angular distributions measured with counter telescopes back angles should not be affected by the choice of cooling, as knock-out protons from the water-spray are only emitted into the forward hemisphere. Moreover, when the energy of the angular distributed protons from the water-spray is distinctly different from that of the neutrons to be measured (as is the case when measuring ^{3}H(d.n)^{4}He, see Fig.1) the background becomes negligible already at smaller angles by electronic suppression as can be seen in Fig.2

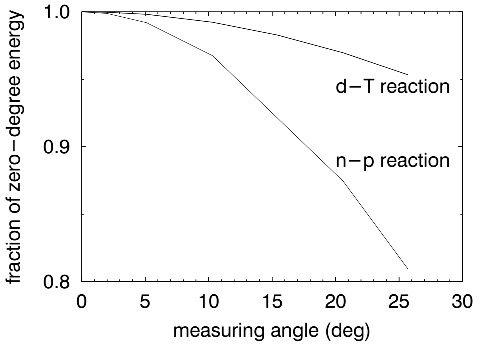

FIG. 1. Proton energy fraction in a counter telescope measurement of the d-T reaction depending on angle.

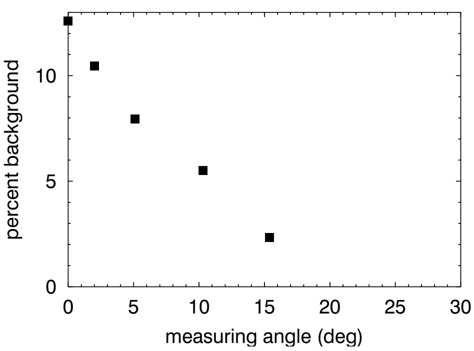

FIG. 2. Correction for external protons due to water-spray cooling (using all four of Simmons'[18)] data sets)

The above was verified using all four data sets of Simmons at al.[18)] who are known to experiment reliably. The data reduction was originally based on Gammel's prediction[20)] for the ^{1}H(n,p)n cross sections at 0 degrees to be used on the proton yield in the proton-recoil counter telescope rather than on YALE[1)] phase shifts as preferred by the author. In general, 0-degrees excitation functions of the reaction d-T appear to be low by 5 to about 10% (Table 1) when measured with proton recoil counter telescopes due to external neutrons increasing the counts in the background run. From any of Simmons' angular distributions at 7.0, 11.4, 15.0, and 19.0 MeV it became clear that only measurements below 20 degs. (Fig. 2) are affected by these background protons. They become (partially) suppressed by the electronics due to the reduced proton energy at angles somewhat >0 degs. (Fig. 1).

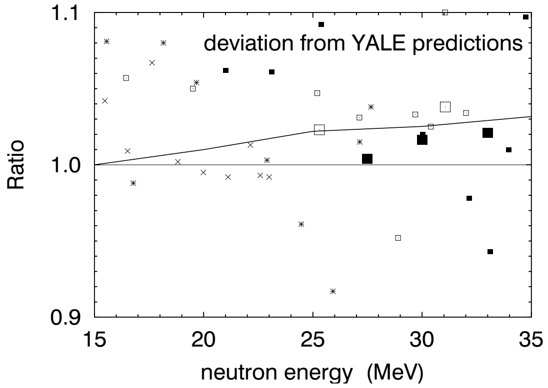

FIG. 3. To give best agreement with the DROSG2000-d-T-data predictions even higher n-p cross sections as predicted by the YALE phase shifts are suggested as can be seen from the fact that more data are above than below the 1.0-line.

Fig. 3 shows the two measured points by Drosg et al.[5)] and three points of Fink et al.[21)] together with the answer of the cross section analysis by Binstock[22)] (full curve in the graph). In addition, the results from the four angular distributions by Simmons et al.[18)] are shown as small symbols. Obviously, there are more symbols above 1.0 than below. This indicates that even the YALE phase shift predictions are low in this energy range even if this result is not conclusive.

Résumé

External protons, e.g. stemming from water-spray cooling, when recorded as background make the 0-dgree cross section too low by virtually reducing the hydrogen content of the radiator. In such cases, 0-degree excitation functions are relative data, as long as the water film stays the same, i.e., the water-spray cooling is constant. For angles > 20 degs. no proton background was observed in the present investigation.

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