LEXFOR "Thick- and Thin-Target Yields"

(N. Otsuka, S. Takács, 2014-07-24, Memo CP-D/850)
See also our article Radiochim. Acta **103** (2015) 1 (Free Access!)

There have been various confusions in compilation of the thick target yields due to the large variety of nomenclature in the literature and also insufficient description on the definition of the yields reported by the authors, and we have tried to improve the coding rule and dictionary for many years (e.g., Memo CP-D/631). In order to maintain better consistency in EXFOR, not only compilers but also experimentalists must be encouraged to understand the concepts of various yields, and we decided to summarize definitions of various yields defined in EXFOR for publication in Radiochimica Acta. Our manuscript was revised several times following communications with the reviewers and chief editor (S.M. Qaim), and it has been recently accepted for publication.

During revisions of our manuscript, we decided to propose the following changes in EXFOR to make the names and quantity codes more understandable for EXFOR users:

1. "Production thick target yield" → "end-of-bombardment thick target yield"
2. `,TTY,,DT` → `,TTY,,EOB` for the end-of-bombardment thick target yield
3. `,TTY` → `,TTY,,SAT` for the saturation thick target yield

Once our manuscript is accepted, we need to check all existing EXFOR data sets providing thick target yields of radioactive products (especially data sets coded with `MBQ/MUAHR`) against the definition described in our article, and need to update the quantity codes step by step.

A revised LEXFOR entry is appended to this memo as our proposal.

Thick- and Thin-Target Yields

~~Definition~~
Thick-target Yield is the yield of a product ~~an outgoing particle (or radiation)~~ measured on a target whose thickness is such that the incident beam is degraded in energy to or below the threshold for producing the measured product. ~~either:~~

- ~~completely stopped within the target,~~
- ~~significantly degraded in energy,~~
- ~~degraded in energy to below the threshold for producing the measured product.~~

Thin-target yield is the yield of a product ~~an outgoing particle (or radiation)~~ measured on a target whose thickness is such that the incident beam is less significantly degraded in energy, and which is given as a function of incident beam current. The incident energy range must be given in the data table under the field

headings `EN-MIN` and `EN-MAX`, or, if the final energy is not specified, the incident energy and target thickness must be given under `EN` and `THICKNESS`.

The distinction between the thick- and thin-target yields explained above is a typical one, but there is no common established boundary between them.

The data are sensitive to target thickness ~~and beam profile~~. The energy loss is a function of the stopping power ~~(S)~~ of the target material.

The **thick target product yield** y is the number of the products per unit induced electric charge (e.g., μC, μA-h) is

$$y=\int_0^{E_0}dE[-(1/\rho)(dE/dx)]^{-1}\sigma(E)(1/Ze),$$

where
  E_0: initial beam energy,
  $\sigma(E)$: energy dependent cross section
  ρ: target isotope number density,
  x: sample thickness,
  Z: beam particle electric charge,
  e: elemental charge.

The quantity $[-(1/\rho)(dE/dx)]$ is known as the stopping power. The thick target product yield may be also expressed as the number of the product per beam particle.

The **end-of-bombardment thick target yield** a(t), the activity of the sample material per unit current at irradiation time t, is

$$a(t)=y(1-e^{-\lambda t}),$$

and its unit is the decay rate per unit current (e.g., MBq/μA). Especially this quantity for infinite irradiation $a_{sat}=a(t\rightarrow\infty)=y$ is defined as the **saturation thick target yield**.

The **physical thick target yield** α_{phys} is the time differential of the end-of-bombardment thick target yield at t=0:

$$\alpha_{phys}=da(t)/dt|_{t=0}=\lambda y.$$

The unit of the physical thick target yield is the decay rate per unit electric charge (e.g., MBq/C or MBq/μA-h).

See also Ref. [1] for the definitions and typical units of the above mentioned thick target yields.

By replacing the lower-boundary of the integral with the beam energy at the exit of the sample, we may also define these yields for thin targets.

Saturat~~ioned~~ Thick/Thin-Target Yield
Target yield measured after a long irradiation time (*i.e.*, longer than 3 half-lives of the product activity) and usually given as decay rate per unit of incident beam current.

REACTION Coding: `,TTY,,SAT`

Units: a code from Dictionary 25 with dimension `TTY` (decay rate per unit of beam current), *e.g.*, `MBQ/MUA` or `MCI/MUA`.

~~Production[1]~~ **End-of-Bombardment** Thick/Thin-Target Yield

(~~Unsaturated~~ Irradiation time dependent) target yield measured after any irradiation time ~~that is short compared to the product half-life~~ and given as decay rate per unit of incident beam current ~~* time~~ at the end-of-bombardment (EOB).

REACTION Coding: `,TTY,,`~~`DTEOB`~~

Units: a code from Dictionary 25 with dimension ~~`TTT`~~`TTY` (decay rate per unit of beam current ~~* time~~), *e.g.*, `MBQ/MUA` or `MCI/MUA`~~`HR` or `DPS/MUAHR`~~.

Some authors use MBq/µA-h instead of MBq/µA for the 1-hour end-of-bombardment yield interpreting that "h" means "1-hour irradiation". The yield must be coded not with `MBQ/MUAHR` but with `MBQ/MUA`. The `(PHY)` modifier is used if the compiler is uncertain whether the yield given in MBq/µA-h, MBq/C etc. is physical yield.

The irradiation time is an essential variable for this quantity and is given under the heading `TIME-IRRD`.

Physical Thick/Thin-Target Yield

Target yield ~~measured after an irradiation time that is short compared to the product half life, is~~ given as decay rate per unit of incident charge (or beam current * time), ~~and has been corrected for decays during irradiation~~ which is equal to the time differential of the end-of-bombardment yield at the beginning of irradiation..

REACTION Coding: `,TTY,,PHY`

Units: a code from Dictionary 25 with dimension `TTT` (decay rate per unit of incident charge or beam current * time), *e.g.*, `MBQ/COUL`, `MBQ/MUAHR`, `MCI/MUAHR` or `DPS/MUAHR`.

Thick Target Product Yields

Thick target yield of a reaction product coded in SF4 under keyword `REACTION`, where the value is given as the number of formed product ~~nuclei~~ per incident particle or charge.

REACTION Coding: `,PY,,TT` (for number per incident particle) or `,PY,,TT/CH` (for number per incident charge).

Units: a code from Dictionary 25 with dimension `YLD`, *e.g.*, `PRD/INC` (for number per incident particle) or dimension `PYT`, *e.g.*, `PRD/MUAHR` (for number per incident charge)

Thick Target Multiplicities

Thick target yield of a product ~~n outgoing particle (or radiation)~~ coded in SF3 or SF7 under keyword `REACTION`, where the value is given as the number of formed product ~~particle~~ per incident particle or charge.

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[1] ~~Do not confuse with product yields.~~

REACTION Coding: `,MLT,,TT` (for number per incident particle) or `,MLT,,TT/CH` (for number per incident charge).

Units: a code from Dictionary 25 with dimension `YLD`, *e.g.*, `PRT/INC` (for number per incident particle) or dimension `PYT`, *e.g.*, `PRT/MUAHR` (for number per incident charge)

Thick Target Discrete Gamma-Ray Yields
Discrete gamma spectrum, where the value is given as the number of particles per incident projectile as a function of gamma energy.

REACTION Coding: `,TT,,SPC`

Units: a code from Dictionary 25 with dimension `YLD`, *e.g.*, `PRT/INC`

Production Thick Target Yield per 1 MeV of Target Thickness

REACTION Coding: `TTY,,TM` in SF 6.

Units: a code from Dictionary 25 with dimension `TTTE`, *e.g.*, `CI/AHR/MEV`

Data not Corrected for Target Thickness

    a)   Thick Target Cross Sections: cross section measured on a thick target.

REACTION Coding: `SIG` in SF6; `TT` in SF8.

Units: a code from Dictionary 25 with dimension `B`, *e.g.*, `MB`

~~b) Thick Target Product Yields: thick target yield of a reaction product coded in SF4 under keyword~~ ~~REACTION~~~~, where the value is given in units of number of nuclei per incident projectile.~~

~~**REACTION Coding**: PY in SF 6; TT in SF8.~~

~~**Units**: a code from Dictionary 25 with dimension YLD, *e.g.*, PRD/INC~~

~~c) Thick Target Multiplicities: yield of an outgoing particle (or radiation) coded in SF3 or SF7 under keyword~~ ~~REACTION~~~~, where the value is given as the number of particles per incident projectile.~~

~~**REACTION Coding**: MLT in SF 6; TT in SF8.~~

~~**Units**: a code from Dictionary 25 with dimension YLD, *e.g.*, PRT/INC~~

~~d) Thick Target Gamma-Ray Yields: gamma spectrum, where the value is given as the number of particles per incident projectile as a function of gamma energy.~~

~~**REACTION Coding**: SPC in SF 6; TT in SF8.~~

~~**Units**: a code from Dictionary 25 with dimension YLD, *e.g.*, PRT/INC~~

Similarly, all quantities may be given as angular distributions, excitation functions, *etc*. See Table following and Dictionary 236 for a complete list of quantities.

Unit Definitions

Saturated thick target yields are most often measured as observed decay rate per unit of beam current. Unsaturated thick target yields are most often measured as observed decay rate per unit of beam current per unit time.

Measures of beam current

Ampere: SI fundamental unit of current.

Coulomb: SI fundamental unit of charge; 1 C = 1 Ampere of current for 1 second.

Measures of decay rate

Becquerels   SI fundamental unit of radioactivity; 1 Bq = 1 decay/second.

Curies[2]:   unit of radioactivity; 1 Ci = 3.7×10^{10} decays/second.

   1 Bq = 2.7×10^{-11} Ci

Table of data types versus unit types

Type of data compiled		Unit type for			
		type	d/dΩ	d/dE	d2/dΩ/dE
Saturation thick/thin-target yield End-of-bombardment thick/thin-target yield		TTY	TDA	TDE	TD2
~~Production thick/thin-target yield and~~ Physical thick/thin-target yield		TTT	TTDA	TTTE	TTD2
Thick target cross section	Cross section	B	DA	DE	DAE
Thick target product yield and multiplicity	per incident charge	PYT	PYTA	PYTE	PYT2
~~Thick target product and gamma yield, multiplicity~~	per incident particle	YLD	1/A	1/E	1/AE
Production thick target yield per 1 MeV of target thickness.		TTTE			

Reference
[1] N. Otsuka, S. Takács, Radiochim. Acta, in press.

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[2]   The Curie has been replaced in usage by the Becquerel.