# Proton-induced Secondary Emission Yield (SEY) from Beam Interceptive Devices in the ESS Linac

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**WEPP10**

EUROPEAN SPALLATION SOURCE

IBIC '20 International Beam Instrumentation Conference


## Abstract

During the ESS linac commissioning, a wealth of **beam-interceptive devices** will be exposed to protons with nominal and non-nominal energies spanning from 75 keV to 2 GeV.
Therefore, a **database of proton-induced Secondary Emission Yield (SEY) values** was prepared for the structural materials of devices insertable into the ESS linac.
The database relies on calculations of collision stopping powers in MCNPX and the Sternglass theory applied to protons in the [0.001, 2000]~MeV energy range. Results are reported for relevant materials to wire scanners, bunch shape monitors and target imaging systems: **Cu, Ti, Ni, W, SiC, TZM and graphite.**
In the future, the novel method can be used also for determining the impact of secondaries on emittance or beam-current measurements with Emittance Monitor Units or Faraday cups of the ESS linac, respectively.
Moreover, the database can be extended to **critical structural materials of the ESS linac itself**, in order to estimate the impact of secondary electrons on the overall beam quality.


## Introduction

The **European Spallation Source (ESS)** is currently one of the largest science and technology infrastructure projects being built today [1]. The ESS accelerator high-level requirements are to provide a 2.86 ms long proton pulse at 2 GeV at repetition rate of 14 Hz. This represents 5 MW of average beam power with a 4% duty cycle on the spallation target [2].
A comprehensive suite of beam instrumentation and diagnostics [3] has started to support the **commissioning and operation** of the normal-conducting linac (NCL) section of the ESS linac. Additional devices are going to be deployed in the superconducting linac (SCL) section, and finally in the transport lines to the tuning dump and to the spallation target.

A wealth of **beam-interceptive devices** will be exposed to **protons** with nominal and non-nominal energies, spanning **from 75 keV to 2 GeV**.
The Wire Scanners (WS), Bunch Shape Monitors (BSM) and target imaging systems rely on secondary emission from thin wires or grids, from which a current proportional to the beam intensity is measured.
There is another set of beam-interceptive devices whose performance can be severely limited by secondary electrons, e.g. Faraday Cups (FC) and Emittance Monitor Units (EMU).

| Device | Proton energy (MeV) | Material |
|---|---|---|
| EMU | [0.075, 3.6] | TZM, Cu, W |
| FC | [0.075, 74] | TZM, Cu, C |
| BSM | [3.6, 90] | C, W |
| WS | [3.6, 2000] | C, W |
| IBS | [73, 360] | C, W, Ti |
| Target imaging | [800, 2000] | Ni, SiC, W |

Therefore, **a database of SEY values** was developed for all the structural materials relevant to beam-interceptive devices in the ESS linac.
The newly developed method for calculating SEY values induced by protons in the [0.001, 2000] MeV range is presented here.

## Methodology

The novel method for calculating SEY values is based on fast calculations of stopping powers in **MCNPX** [10] and the **Sternglass theory** [11]. As a first step, a cylindrical rod of the material of interest is simulated in MCNPX; the radius is set equal to two Molière radius, while the length is set long enough to fully contain a beam of 2 GeV protons.

The proton beam is defined as a monoenergetic source of 2 GeV protons, with a Gaussian distribution having $\sigma$=0.6 cm. The beam is perpendicularly impinging on the base of the cylindrical rod. In addition to protons, also electrons, neutrons and photons are transported. One single run with 1E5 proton histories takes approximately 10 minutes on a standard laptop and provides the collision, radiation and total stopping powers for protons from 2 GeV down to 1keV.

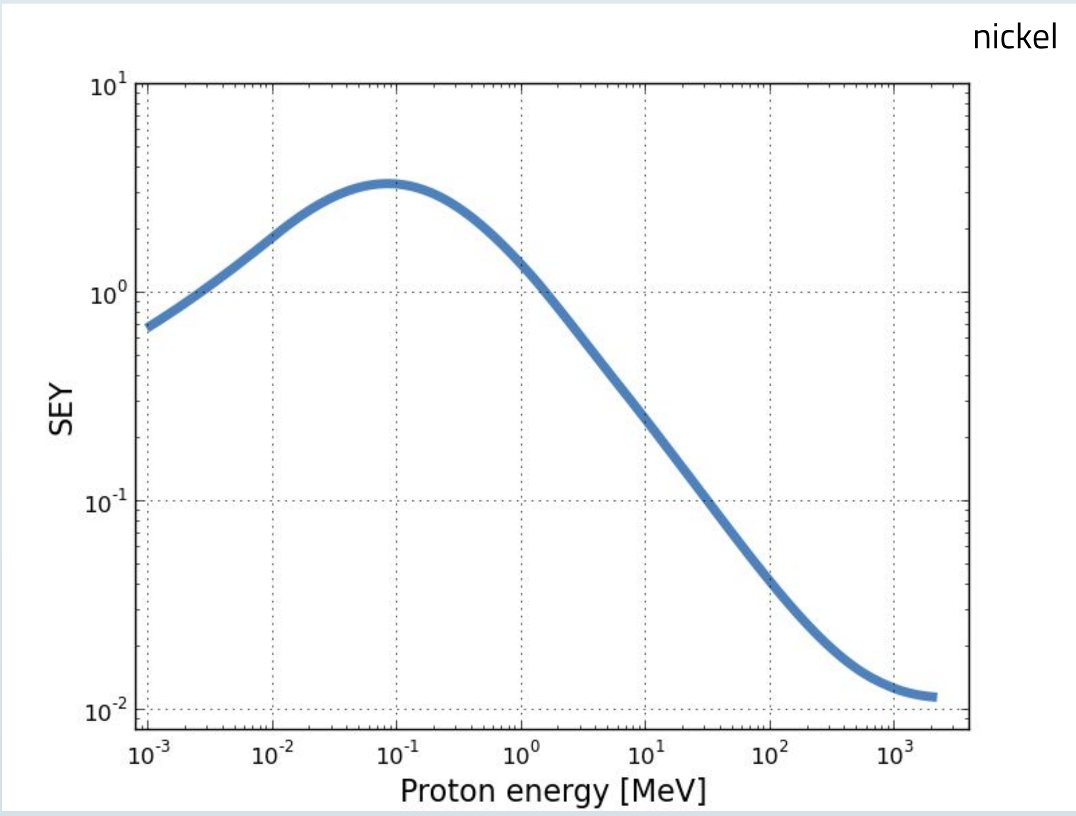
Since in proton-induced SEY calculations it is important to compute the amount of energy lost by protons, the collision stopping power dE/dx is considered (in MeV×cm$^2$/g). The **number of electrons per primary proton** (i.e. the SEY) is computed according to the Sternglass formula:

$$SEY = \frac{P \cdot \rho \cdot t}{25\ eV} \cdot \frac{dE}{dx}$$

where $P$=0.5 and is the probability that an electron escapes from the material surface, $\rho$ is the material density (in g/cm$^3$) and $t$ is the mean free path of secondary electrons which is set equal to 1nm. Since the average energy of the secondary electrons is estimated to be in the 20-30eV range by Sternglass [11], the value of 25 eV appears at the denominator. The SEY values calculated for the materials and compounds of current interest are summarized in the following paragraph.

The method was validated with four elements for which dE/dx values are available from NIST [12], and then applied also to all the materials and compounds of interest.

As representative example, the calculated SEY values are plotted in the figure below in the case of nickel, for which no data were found available from NIST [12] throughout the proton energy range of interest for the present work.




## Results

As expected from the Sternglass theory [11], the SEY curves follows the trend of the dE/dx distribution, spanning over three orders of magnitude for proton energies in the [0.001, 2000] MeV range. The SEY values monotonically decrease with increasing proton energies up to 2 GeV. This is an important aspect to be considered for insertable devices in the NCL linac, where the SEY is maximal.

The **SEY values at relevant energies in the ESS NCL and SCL** are reported in the tables below. Any other SEY value at any non-nominal beam energy can be easily inferred from the newly available dataset.

| | 0.075 MeV | 3.6 MeV | 21 MeV | 74 MeV |
|---|---|---|---|---|
| **C** | 2.238 | 0.315 | 0.080 | 0.029 |
| **Ti** | 2.527 | 0.551 | 0.152 | 0.058 |
| **Ni** | 2.695 | 1.033 | 0.293 | 0.113 |
| **Cu** | 2.560 | 0.982 | 0.280 | 0.108 |
| **W** | 2.971 | 1.339 | 0.432 | 0.175 |
| **TZM** | 3.400 | 0.960 | 0.285 | 0.113 |
| **SiC** | 1.604 | 0.537 | 0.137 | 0.050 |

| | 90 MeV | 360 MeV | 800 MeV | 2000 MeV |
|---|---|---|---|---|
| **C** | 0.025 | 0.010 | 0.008 | 0.006 |
| **Ti** | 0.050 | 0.021 | 0.015 | 0.013 |
| **Ni** | 0.098 | 0.041 | 0.030 | 0.027 |
| **Cu** | 0.094 | 0.039 | 0.029 | 0.026 |
| **W** | 0.154 | 0.067 | 0.050 | 0.045 |
| **TZM** | 0.098 | 0.042 | 0.031 | 0.028 |
| **SiC** | 0.044 | 0.018 | 0.013 | 0.011 |

## Conclusions & Outlook

The results of SEY calculations are based on fast yet reliable MCNPX simulations and on the Sternglass theory. Proton-induced SEY values were calculated over six orders of magnitude i.e. from 1 keV up to 2 GeV.
The lookup tables serve for beam-current estimations, both at nominal and non-nominal beam energies during the ESS linac commissioning.

The **possibilities** offered by the newly developed method are manifold:

1) Since it's possible to define in MCNPX any density, isotope and chemical composition, the method is useful for selecting **novel materials** and **compounds** which may be needed for detectors upgrades.
2) It's possible to explore the impact of **oxides** on metallic surfaces.
3) The presented method can help in investigating the impact of secondaries on key linac components that could be affected by e.g. the **multipacting effect**.
4) In the future, it would be useful to further develop the method to account for **temperature and radiation-induced effects** on SEY.


## Bibliography

[1] ESS Website
https://europeanspallationsource.se/about

[2] R. Garoby et al., Phys. Scr. 93 014001, 2018
https://iopscience.iop.org/article/10.1088/1402-4896/aa9bff/pdf

[3] T.J. Shea et al, Overview and status of diagnostics for the ESS project, Proceedings of IBIC 2017
http:/dx.doi.org/10.18429/JACoW-IBIC2017-MO2AB2

[4] S. Grulja et al., Wire scanner diagnostics system, Proceedings of IBIC 2019
https:/doi:10.18429/JACoW-IBIC2019-TUPP015

[5] C. A. Thomas et al., J-PARC test of the ESS beam on target diagnostics prototype aperture monitor and grid, Proceedings of IBIC 2019
https:/doi.org/10.18429/JACoW-IBIC2019-TUPP032

[6] E.M. Donegani et al., Status of the Faraday cups for the ESS linac, Proceedings of IBIC 2019
https:/doi:10.18429/JACoW-IBIC2019-MOPP044

[7] O. Tuske et al, ESS Emittance Measurements at INFN CATANIA, Proceedings of IPAC2017
http:/dx.doi.org/10.18429/JACoW-IPAC2017-MOPAB023

[8] B. Cheymol et al., High power and high duty cycle slit and grid system for hadron accelerator commissioning, Proceedings of HB2016

[9] E.M. Donegani et al., The insertable beam stop in the ESS SPK section, Proceedings of IBIC 2020
https:/doi:10.18429/JACoW-IBIC2020-WEPP07

[10] D.B. Pelowitz, Ed., "MCNPX Users Manual Version 2.7.0" LA-CP-11-00438 (2011)

[11] E.J. Sternglass, Theory of secondary electron emission by high-speed ions, Phys. Rev. 108, 1 1957

[12] Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions, NIST Standard Reference Database 124
https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html



## Acknowledgements

The author is grateful to Dr. Cyrille Thomas and the colleagues working on the ESS target imaging system for having triggered the work presented in this paper.

In fact, the presented method was initially developed just for the key materials of the aperture monitor and grid system for the beam on the ESS target, recognized to be universally useful and thus applied to the structural materials of all the other beam-interceptive devices in the ESS linac.