Proton SEU Cross Section definition

The proton SEU cross-section function can take the form of Weibull, lognormal or Bendel-2 functions, with parameters defined as in the equations below. In the following equations, proton energy, *E*, has units of MeV.

Weibull function

The cross-section of the Weibull function is defined by parameters σ_{norm}>0, E_0>0, λ>0 and k>1:

$$\sigma(E) = \sigma_{norm} \int_0^E F_{Weibull}(E')dE''$$

where:

$$F_{Weibull}(E) = \begin{cases} \frac{k}{\lambda}\left(\frac{E-E_0}{\lambda}\right)^{k-1} \exp\left[-\left(\frac{E-E_0}{\lambda}\right)^k\right] & : E > E_0 \\ 0 & : E \le E_0 \end{cases}$$

and:

σ_{norm}	= Saturation cross-section [cm^2/bit]
E_0	= Energy shift [MeV]
λ	= Function scale parameter [MeV]
k	= Power index or Weibull shape parameter

Since the function can be integrated analytically, this then becomes:

$$\sigma(E) = \begin{cases} \sigma_{norm}\left\{1 - \exp\left[-\left(\frac{E-E_0}{\lambda}\right)^k\right]\right\} & : E > E_0 \\ 0 & : E \le E_0 \end{cases}$$

Log-normal function

The cross-section of the log-normal function is defined by parameters σ_{norm}>0, μ>0 and σ>0:

$$\sigma(E) = \sigma_{norm} \int_0^E F_{lognorm}(E')dE'$$

where:

$$F_{lognorm}(E) = \begin{cases} \frac{1}{E\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln(E)-\mu)^2}{2s^2}\right] & : E > 0 \\ 0 & : E \le 0 \end{cases}$$

and:

σ_{norm}	= Saturation cross-section [cm^2/bit]
μ	= Mean of the natural logarithm of the lognormal distribution [ln(MeV)]

s = Standard deviation of the natural logarithm of the lognormal distribution [ln(MeV)]

Bendel-2 function

The cross-section of the Bendel-2 function is defined by parameters σ_{norm}>0, A>0:

$$\sigma(E) = \sigma_{norm}\left\{1 - \exp\left[-0.18\sqrt{\sqrt{\frac{18}{A}}(E-A)}\right]\right\}^4$$

where:

σ_{norm} = Saturation cross-section [cm^2/bit]
A = Energy offset and width for distribution [MeV]

SEU Cross Section Definition for Direct Ionisation Effects

The SEU cross-section function for direct ionisation effects (traditionally considered for Z≥2) than can take the form of either a Weibull or lognormal function, with parameters defined as in the equations below. In the following equations, ion LET, *L*, has units of $MeVcm^2/mg$.

Weibull function

The cross-section (as a function of LET, *L*) of the Weibull function is defined by parameters $\sigma_{norm}>0$, $L_0>0$, $\lambda>0$ and $k>1$:

$$\sigma(L) = \sigma_{norm} \int_0^L F_{Weibull}(L')dL''$$

where:

$$F_{Weibull}(L) = \begin{cases} \frac{k}{\lambda}\left(\frac{L-L_0}{\lambda}\right)^{k-1} \exp\left[-\left(\frac{L-L_0}{\lambda}\right)^k\right] & : L > L_0 \\ 0 & : L \leq L_0 \end{cases}$$

and:

σ_{norm}	= Saturation cross-section [cm^2/bit]
L_0	= LET shift [$MeVcm^2/mg$]
λ	= Function scale parameter [$MeVcm^2/mg$]
k	= Power index (or Weibull shape) parameter

Since the function can be integrated analytically, this then becomes:

$$\sigma(L) = \begin{cases} \sigma_{norm}\left\{1 - \exp\left[-\left(\frac{L-L_0}{\lambda}\right)^k\right]\right\} & : L > L_0 \\ 0 & : L \leq L_0 \end{cases}$$

Log-normal function

The cross-section of the log-normal function is defined by parameters $\sigma_{norm}>0$, $\mu>0$ and $\sigma>0$:

$$\sigma(L) = \sigma_{norm} \int_0^L F_{lognorm}(L')dL''$$

where:

$$F_{lognorm}(L) = \begin{cases} \frac{1}{L\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln(L)-\mu)^2}{2s^2}\right] & : L > 0 \\ 0 & : L \leq 0 \end{cases}$$

and:

σ_{norm}	= Saturation cross-section [cm^2/bit]
μ	= Mean of the natural logarithm of the lognormal distribution [ln($MeVcm^2/mg$)]

s = Standard deviation of the natural logarithm of the lognormal distribution [ln(MeVcm^2/mg)]