The Fission Spectrum

When a heavy nucleus
(for example ^{236}U, produced by $^{235}U + n$)
fissions, a great deal of energy is released (something like 200 MeV).

This energy is mainly divided between the kinetic energy of the fission products and the fission neutrons (refer to a previous slide). As a result, the fission neutrons are *energetic* – they are *fast neutrons*.

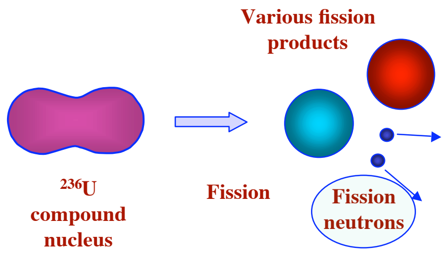
(Remember that neutrons with energies in the MeV range are known as "fast" neutrons.)

These neutrons can be thought of as "evaporating" from the surface of the highly excited compound nucleus during the fission process.

The energy distribution of these *fission spectrum* neutrons is often represented by the so-called *Watt Distribution*.

The Fission Spectrum

Neutrons evaporating during fission.



These fast neutrons have different energies but with a definite *spectrum*, an *energy distribution*.

The energy distribution of these *fission spectrum* neutrons is often represented by the so-called *Watt Distribution*.

The Watt Distribution (Spectrum)

The distribution of the number of neutrons with energy in the fission spectrum is well represented by a mathematical function, the *Watt* function.

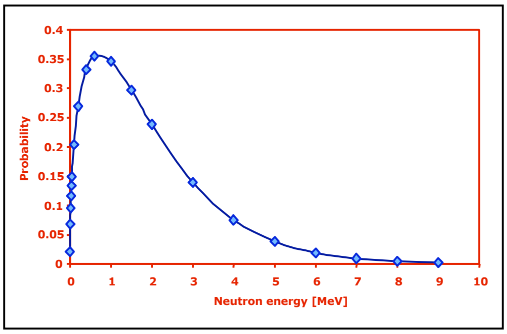
The probability of a neutron from fission having an energy between *E* and *E+dE* is the function *P*(*E*)*dE*.

$$P(E) = 0.4865 \sinh\left(\sqrt{2E}\right) e^{-E} \text{ MeV}^{-1}$$

This is an *empirical* formula – it is just a convenient way of expressing the experimental distribution.

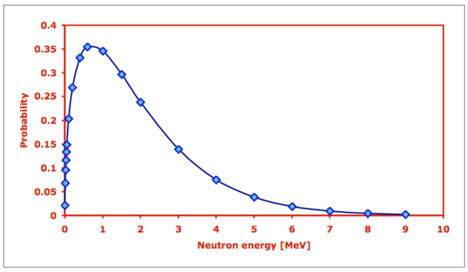
This distribution is for neutrons from the fission of ^{235}U with a slow neutron and is shown in the figure.

Note: **It only changes slightly for other types of fission.**

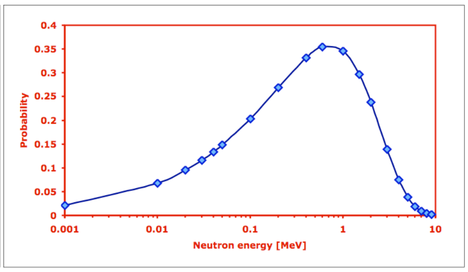


The Watt Distribution (Spectrum)

A better insight can be gained into what happens in a thermal reactor by plotting this using a log scale on the *x* axis.



Linear plot



Same data but a log plot on the *x* axis – showing low energy detail.

$$P(E) = 0.4865 \sinh\left(\sqrt{2E}\right) e^{-E}$$

Note that very few neutrons are in the eV range.

Next we turn this into a *flux* distribution …

The Watt neutron *flux* spectrum

The neutron flux is, of course, just the neutron density multiplied by the speed.

Why do we need to look at the *flux* distribution (flux spectrum)?

Well, remember that the *reaction rate* is calculated as the *flux* multiplied by the *cross section*.

$$\Psi = \Phi\sigma$$

Or the *convolution* of the *flux distribution* and the *excitation function*.

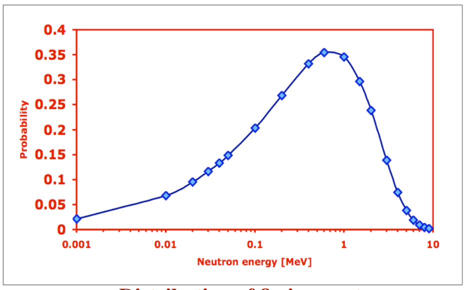
$$\Psi = \int \Phi(E)\sigma(E)dE$$

The Watt neutron flux spectrum

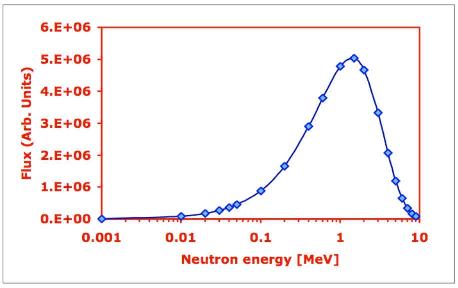
The neutron flux is just the neutron density multiplied by the speed.

$$\Phi(E) = N(E)v \propto P(E)v \quad \text{and} \quad E = \frac{1}{2}m_n v^2 \quad \text{so} \quad v = \sqrt{\frac{2E}{m_n}}$$

therefore $$\Phi(E) = 0.4865\sqrt{\frac{2\times(3\times10^8)^2}{939.6}}\sqrt{E}\sinh\left(\sqrt{2E}\right)e^{-E}$$ **for a *Watt* distribution.**



Distribution of fission neutrons



… resulting flux

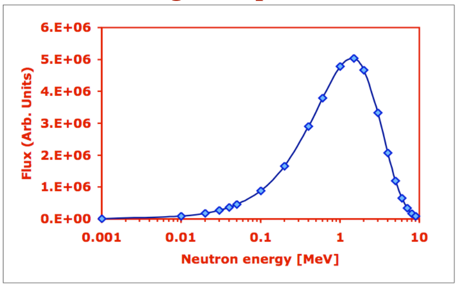
As you can see, when the fission neutrons are formed, there are hardly any "slow" neutrons.

The Watt neutron flux spectrum

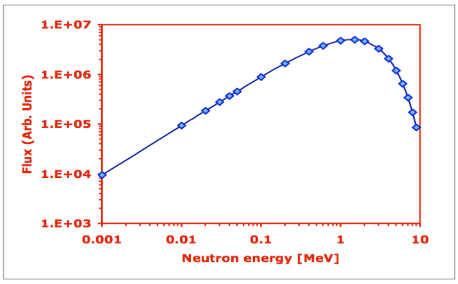
To repeat …neutron flux from a Watt distribution.

$$\Phi(E) = 0.4865\sqrt{\frac{2\times\left(3\times10^{8}\right)^{2}}{939.6}}\sqrt{E}\,\sinh\left(\sqrt{2E}\right)e^{-E}$$

A good representation of the raw flux resulting from fission.



As a linear-log plot (as on the previous slide)

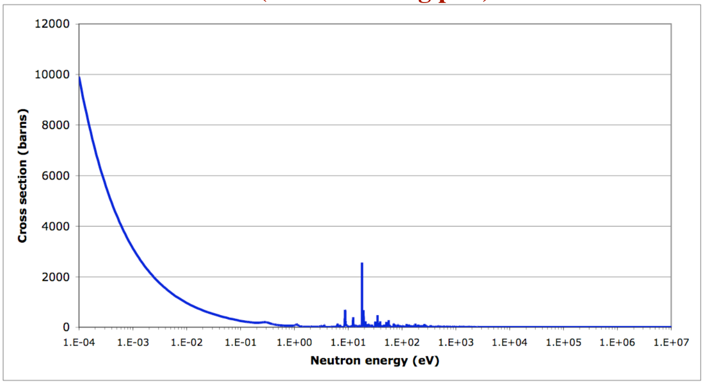


The same thing but on a log-log plot

Now let's compare this with the cross-section (the excitation function for the reaction ^{235}U(n,f).

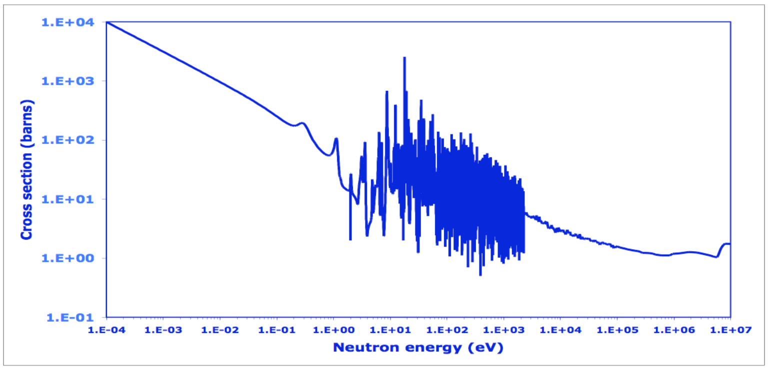
Comparison between the fission spectrum and the cross-section

Let's remind ourselves what the excitation function (the cross-section as a function of energy) for ^{235}U(n,f) looks like (on a linear-log plot).



Comparison between the fission spectrum and the cross-section

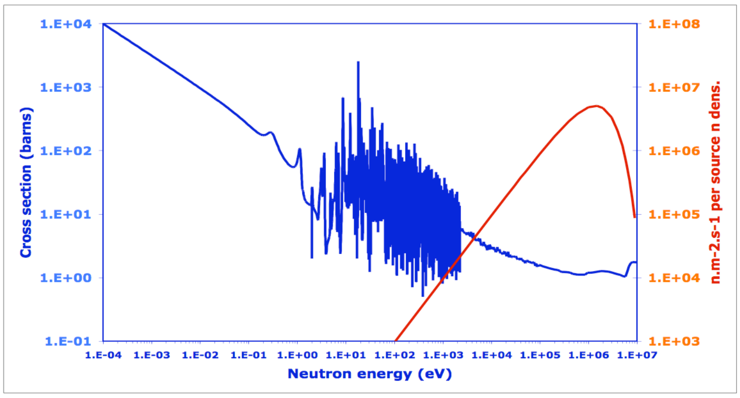
Here is the same thing, the excitation function (the cross-section as a function of energy) for $^{235}U(n,f)$ but on a log-log plot.



Fission Spectrum

Now, let's compare this distribution with the cross section for the fission of uranium-235, $^{235}U(n,f)$ on a log-log plot.

Note that this is a log-log plot to show all the detail.

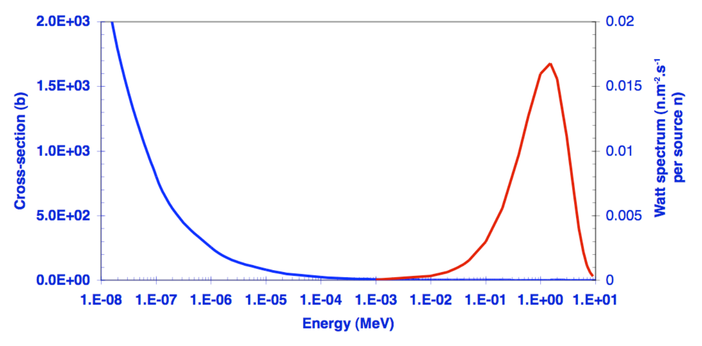


The next slide shows the same data on a linear log plot

Fission Spectrum

Let's compare this distribution with the cross section for the fission of uranium-235, $^{235}U(n,f)$.

Same data as on the previous slide, but a linear-log plot. (This is schematic the resonances have been omitted)



Here you can see that there is very little overlap between the Watt spectrum and the large values of the $^{235}U(n,f)$ cross-section at low energies.