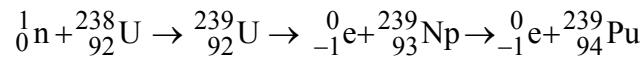


22.05 – Reactor Physics – Part Six

Burners, Converters, and Breeders

1. Fissile vs. Fertile Fuels

We earlier classified fuel types as either fissile or fertile. Fissile (Th-233, U-235, P-239) undergo fission upon being struck by a thermal (low energy) neutron. Fertile (Th-232, U-238) absorb a neutron to become a fissile material. The most well known such reaction is:



Under what conditions can we design a reactor to produce fissile isotopes from fertile ones?

2. Definition: We define three possible fuel cycles:

- Breeder: More than one fissile atom is produced for each one that is consumed.
- Converter: Converts fertile material to fissile but does not breed.
- Burner: Neither converts nor breeds.

3. Number of Neutrons from Fission: The symbol ν denotes the number of neutrons produced per fission. For thermal fission of U-235, its value is 2.5. This quantity by itself is insufficient to determine if conversion or breeding is possible because it only states the number of neutrons emitted once fission occurs. We need to know the number of neutrons emitted once a neutron is absorbed by a fissile nucleus. We denote that parameter as η and define it as

$$\eta = \nu \frac{\sigma_f}{\sigma_a} = \nu \frac{\sigma_f}{\sigma_\gamma + \sigma_f}$$

Where σ_f is the microscopic fission cross-section

σ_a is the microscopic absorption cross-section, and

σ_γ is the microscopic radiative capture cross-section.

For even a burner to operate, η must be greater than 1 because some neutrons are lost to processes other than absorption in U-235. Some are absorbed in the core structure, some diffuse out into the shield, and others are absorbed by the steel, etc., that forms the reactor's structure. For breeding, we need an additional neutron from each fissile absorption in order to convert fertile nuclei to fissile ones. Thus, η must exceed 2.

4. **η as a Function of Energy:** η is a function of the energy of the incident neutron. The following three figures show it for U-233, U-235, and Pu-239. Over what energy ranges is breeding possible?

- a) **Thermal Energies:** For 0.025 eV, the value of η for the three fissile isotopes is:

	η	Breeding Feasible	Fertile Material
U-233	2.29	Yes	Th-232
U-235	2.07	No	None
Pu-239	2.14	No	U-238

$\eta = 2.29$ is sufficiently above 2.0 so that a U-233/Th-232 core would produce more U-233 than it consumes. The values of η for both U-235 and Pu-239 are also above 2.0, but not so much above it that breeding is practical. So, at thermal energies, only the U-233/Th-232 cycle is possible for breeding.

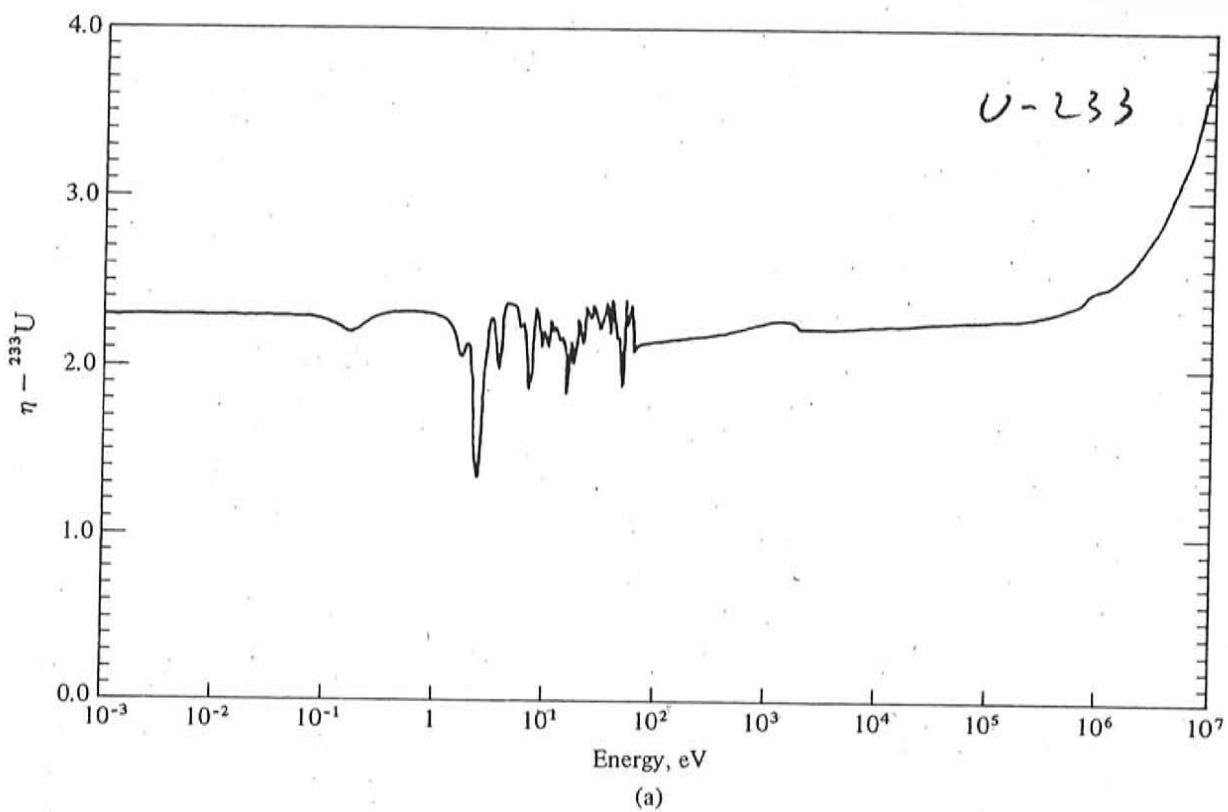
- b) **Epithermal Energies:** Here we define epithermal as

1 eV – 100 keV for U-235 and 10-20 keV for Pu-239. In both cases, the value of η is below 1.0. For U-233, the value of η might be able to sustain breeding, but this has not been established.

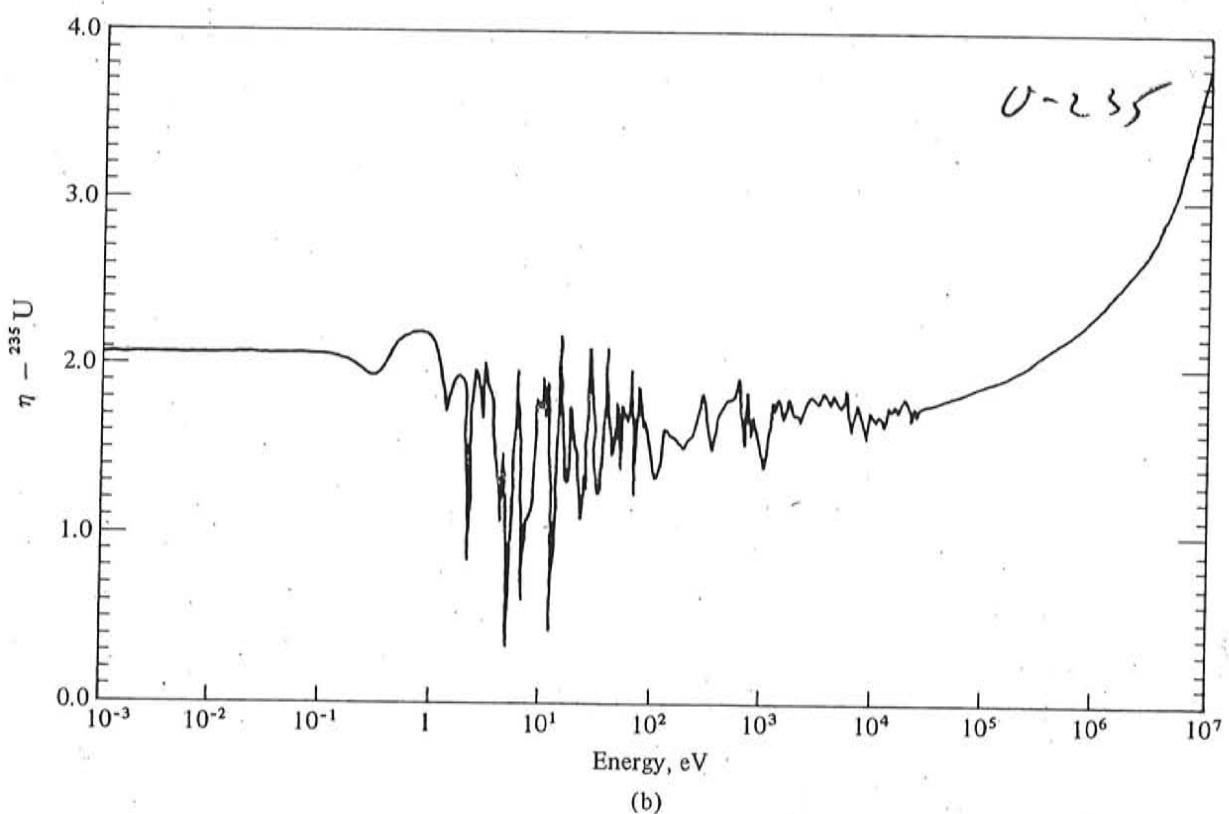
- c) **Fast Energies:** The value of η is sufficiently above 2.0 for all three fuels to function as a breeder.

5. Caveat on U-235:

There is no fertile nuclide that transmutes to U-235 upon neutron absorption. So, once supplies of U-235 have been consumed, it is gone. We can have a U-233/Th-232 cycle or a Pu-239/U-238 cycle. For U-235, the cycle would most likely involve Pu-239 and U-238 with the U-235 present only initially.



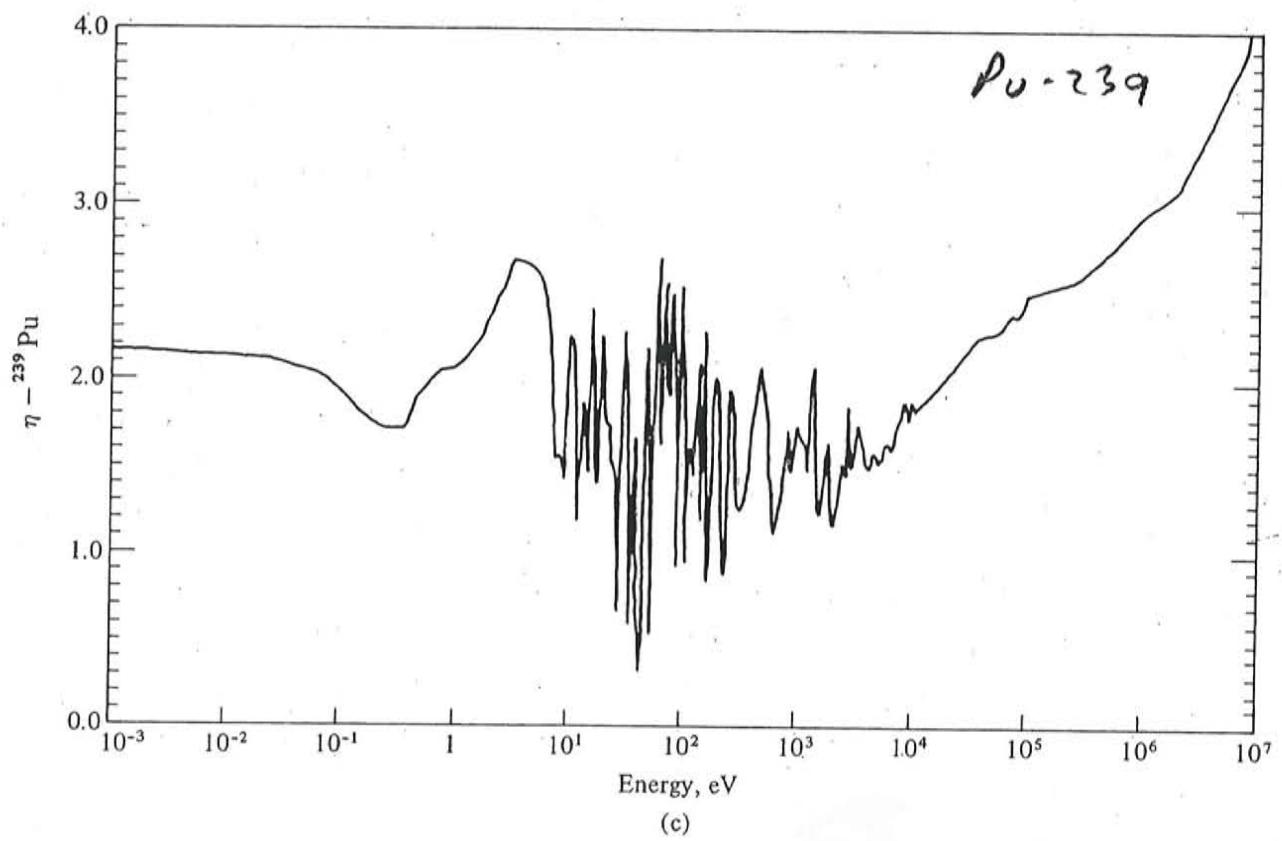
(a)



(b)

Fig. 4.2 Variation of η with energy for (a) ${}^{233}\text{U}$, (b) ${}^{235}\text{U}$, and (c) ${}^{239}\text{Pu}$. (Plotted by machine from data on tape at the National Neutron Cross Section Center, Brookhaven National Laboratory.)

From Lamarsch.



From Lamarsh.