Week 11, Lecture 2 – Fission Process

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Nuclear Power, Nuclear Reactors

-- Overview
--- Reactor types
--- Reactors in Michigan
--- Reactors in France
-- Nuclear Fission process
--- fission energetics, fissile nuclei
--- limits to heavy nuclei
--- dynamical process
-- Nuclear Fission Operations
--- control and reactivity

7th Homework due Monday

^{235}U vs. ^{238}U for Fission

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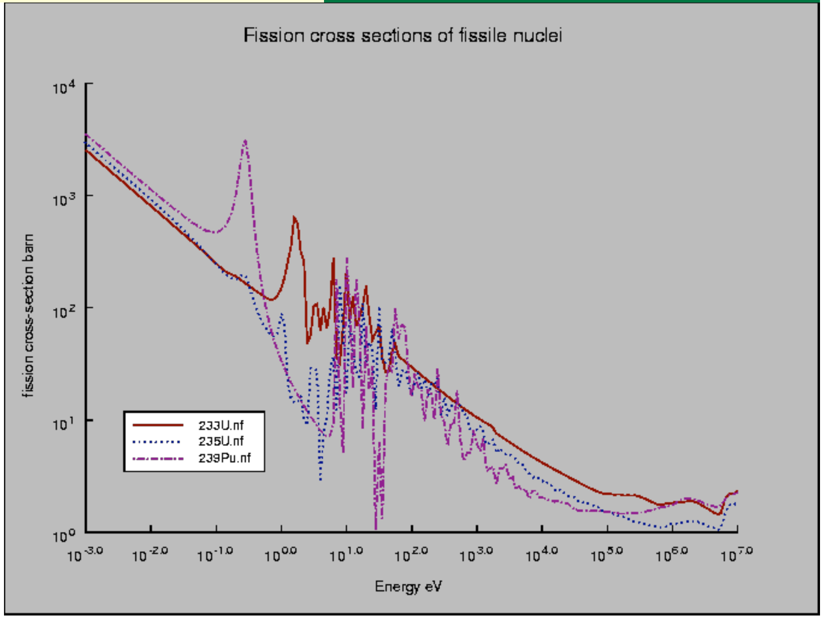

It is obvious to take nuclei with the highest atomic number for fission since they are the most unstable due to the coulomb force. But there are two isotopes of uranium available in nature but only one is 'fissile'.

Recall that the cross section for neutron capture increases dramatically at low energies (1/v). So it is best to use as low a neutron energy as possible from the stand point of capturing the neutron ...

The excitation energy is the Q value plus a very small kinetic energy from the neutron:

$$^{1}n + {}^{235}U \rightarrow ({}^{236}U_{144})^{*} + Q \quad \text{where} \quad Q = 6.545\ \text{MeV}$$

$$^{1}n + {}^{238}U \rightarrow ({}^{239}U_{147})^{*} + Q' \quad \text{where} \quad Q' = 4.406\ \text{MeV}$$

The formation of the Even-Even nucleus gives about 2 MeV more energy than the formation of the Even-Odd nucleus – this makes all the difference in driving the fission process.

Fissile Nuclei

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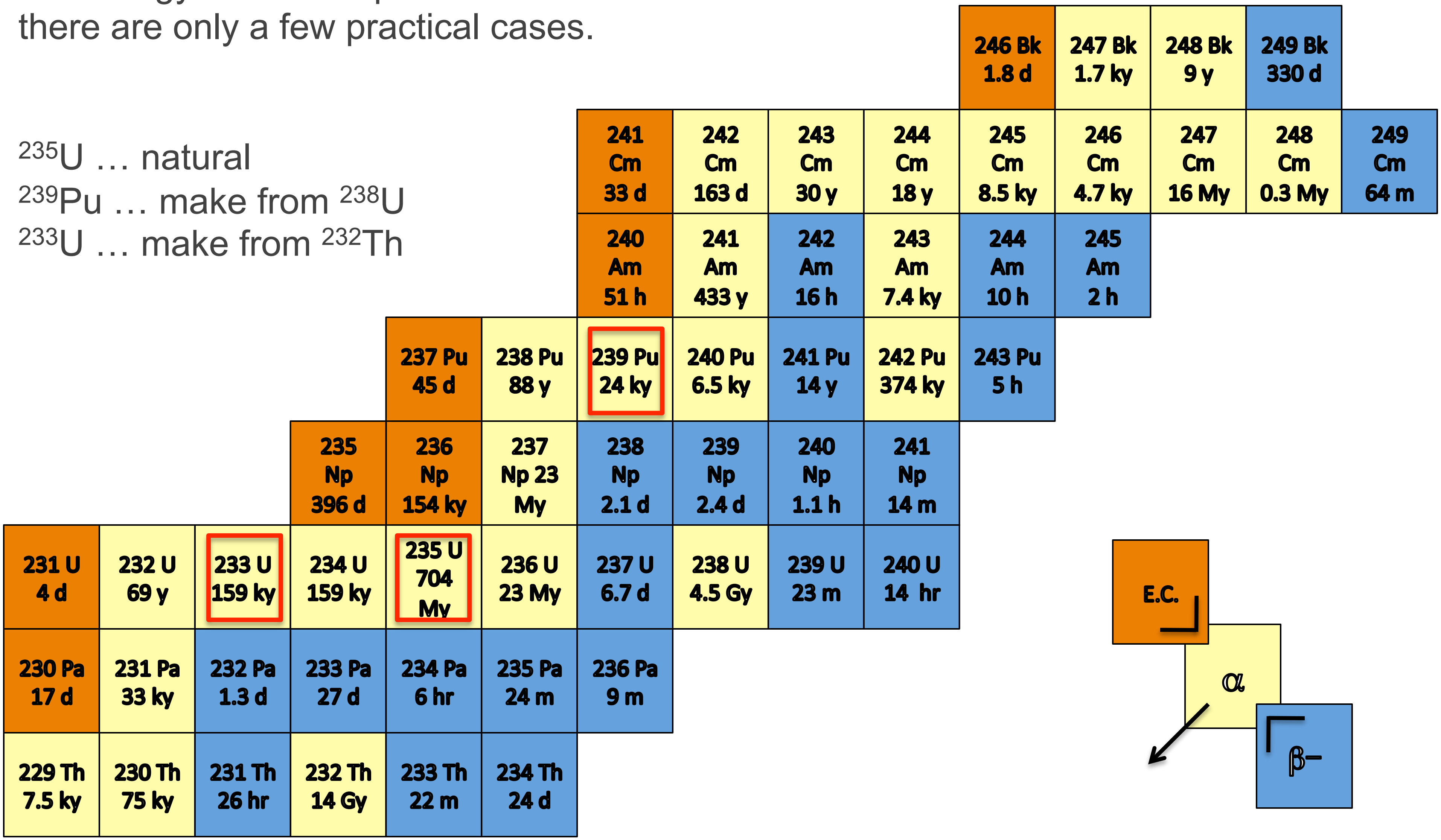
Those nuclei that are Even-Odd and undergo fission after low energy neutron capture are called ‘fissile’ nuclei – there are only a few practical cases.

^{235}U … natural
^{239}Pu … make from ^{238}U
^{233}U … make from ^{232}Th



Critical (large) Size for Nuclei

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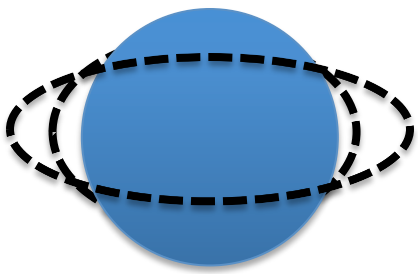
Recall that the equilibrium shape of (most) nuclei is a sphere. Since fission converts a single nucleus into two separate nuclei – one needs to consider how the energy of a nucleus changes with deformation.



$$Sphere: BE(Z,A) = a_V A - a_S A^{2/3} - a_C \frac{Z^2}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} \pm \delta$$

Small deformations of the sphere:

- constant volume
- no change in numbers of nucleons
- Surface area grows
- Coulomb energy drops

$$E_C \approx E_C^o\left(1 - \frac{\alpha^2}{5}\right) \overset{?}{=} E_S \approx E_S^o\left(1 + \frac{2\alpha^2}{5}\right) \quad \text{Eq. 11.2}$$

$$E_C - E_C^o = -\frac{E_C^o \alpha^2}{5} \overset{?}{=} E_S - E_S^o = \frac{2E_S^o \alpha^2}{5}$$

$$-\frac{E_C^o \alpha^2}{5} = \frac{2E_S^o \alpha^2}{5} \rightarrow \frac{E_C^o}{2E_S^o} = 1 \quad \text{Eq. 11.3}$$

Fission Barrier

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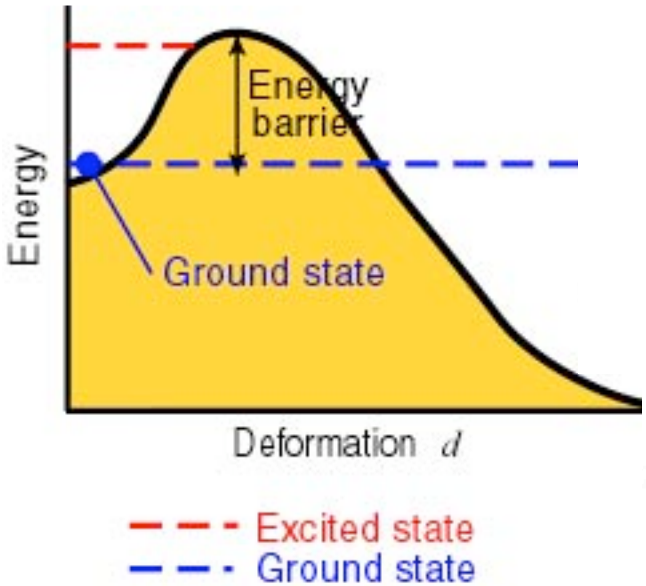
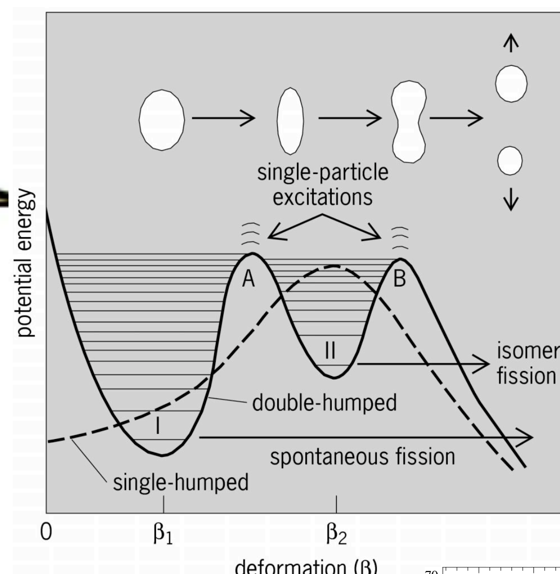
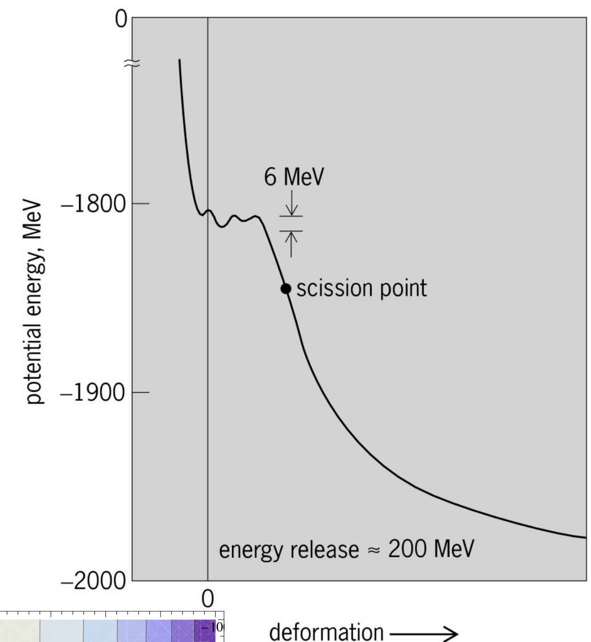


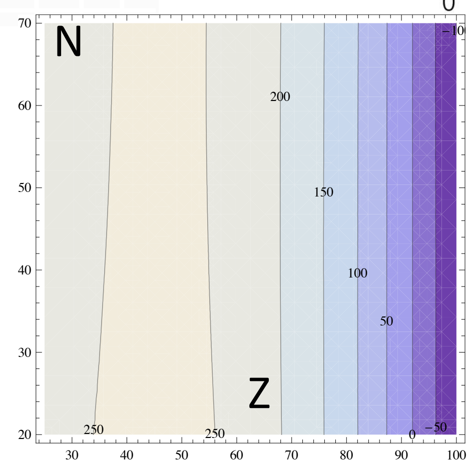
The deformation process reaches a point of no return that is called the fission barrier.





The fission process is an energy amplifier in that a small amount of excitation energy can lead to the output of a large energy release.

$$V_{Coulomb} = \frac{Z_1 Z_2 e^2}{R_1 + R_2} = \frac{Z_1(92 - Z_1)1.439\,MeV}{1.2[A_1^{1/3} + (238 - A_1)^{1/3}]}$$



Energy Contours

Mass and Charge of FF's

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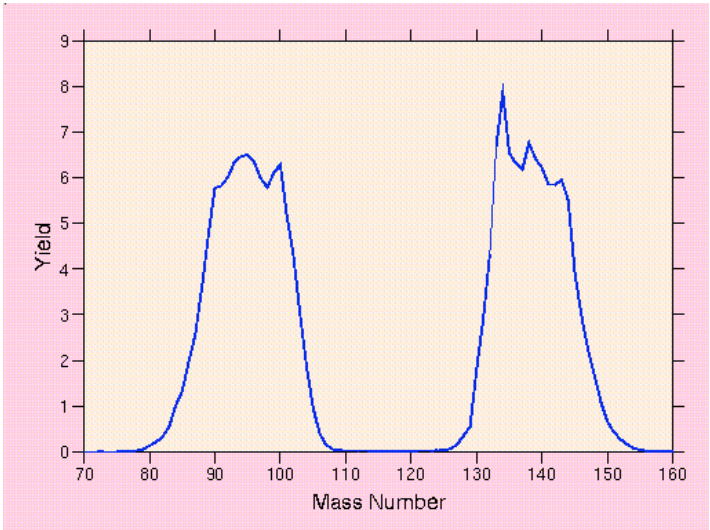
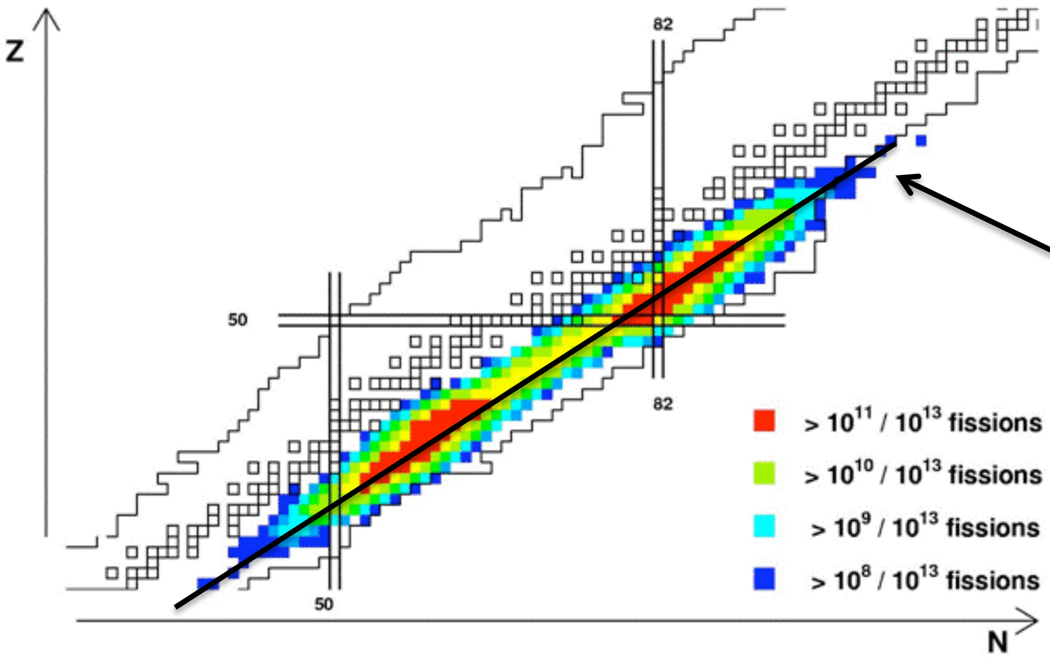
$^{1}n + ^{235}U \rightarrow (^{236}U_{144})^{*} + 6.545\ \text{MeV} \rightarrow {}^{A1}Z_1 + {}^{A2}Z_2 + Q_f$

A1 = A2 = 236/2 – rare event

A1 ~ 140 , A2~(236-140) – common





Unchanged Charge Ratio

$Z/A = 92/238 = Z_1/A_1 = Z_2/A_2$

Modern Calculation of Fission

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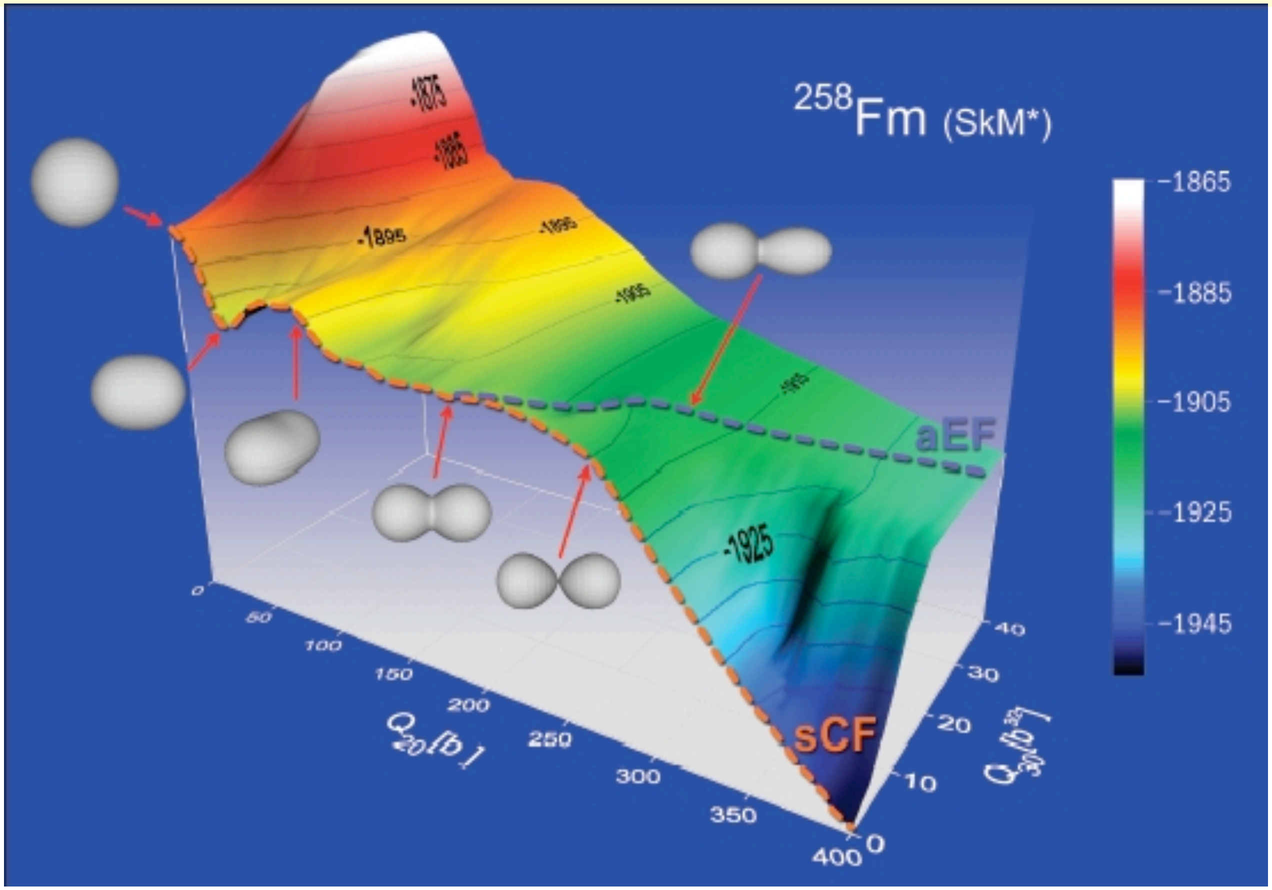
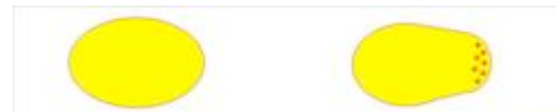


$^{258}Fm_{158}$ -> ${}_{50}Sn$ + ${}_{50}Sn$



quadrupole shape (L=2)

octupole shape (L=3)

The figure shows the energy surface of the transuranic element ^{258}Fm calculated with the self-consistent nuclear density functional theory as a function of two collective variables:
(a) the total quadrupole moment Q_{20} representing the elongation of nuclear shape,
(b) the total octupole moment Q_{30} representing the left-right shape asymmetry

www.scidacreview.org/0704/html/unedf.html