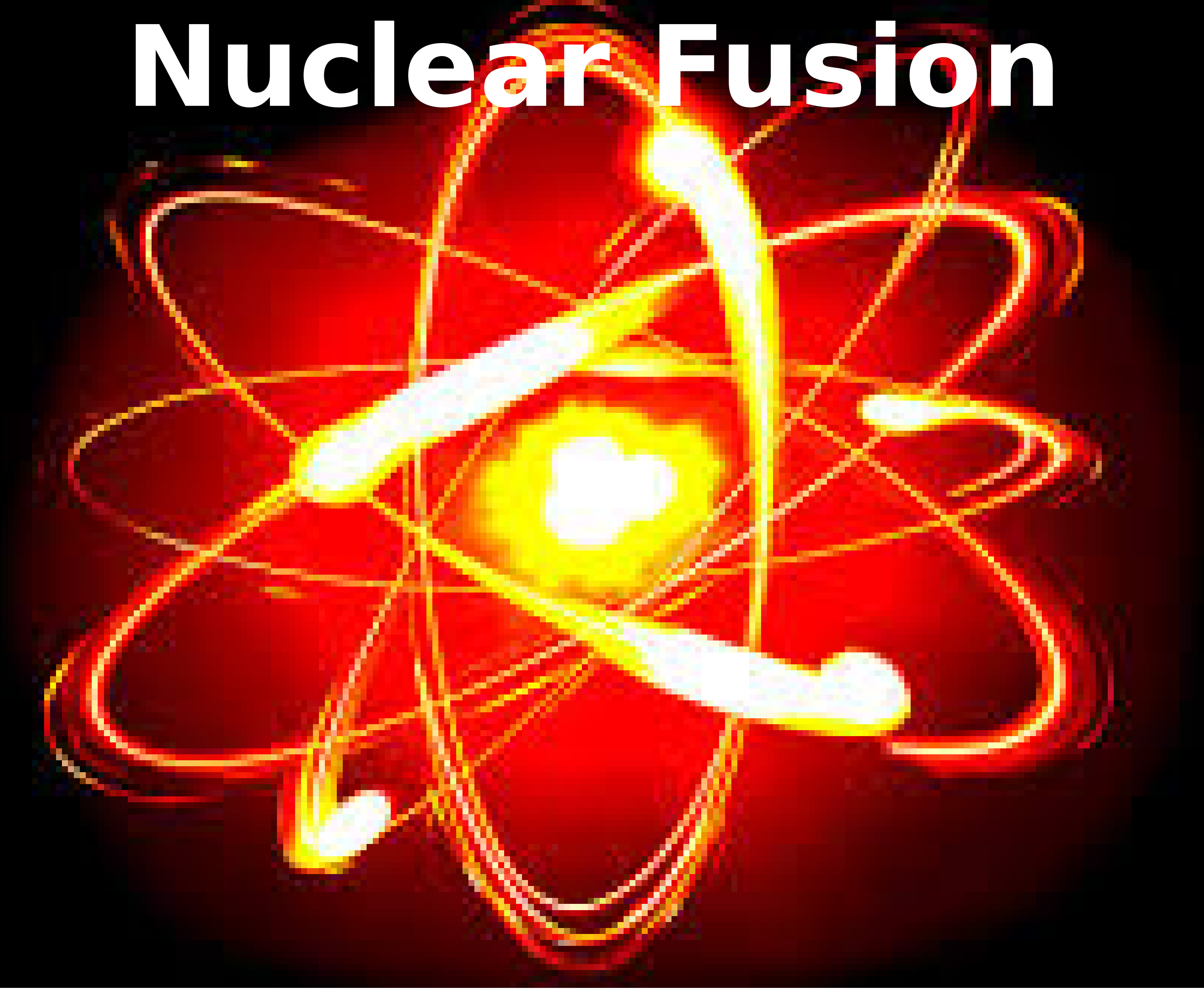
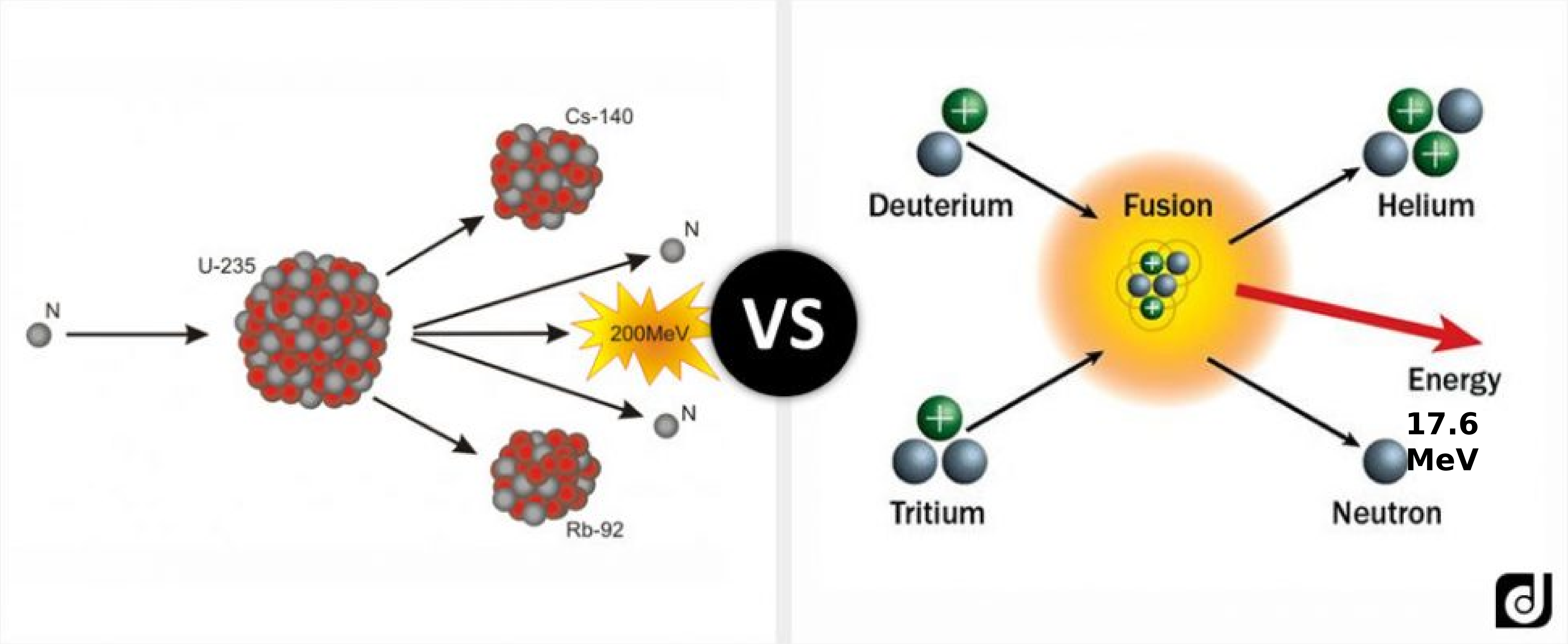
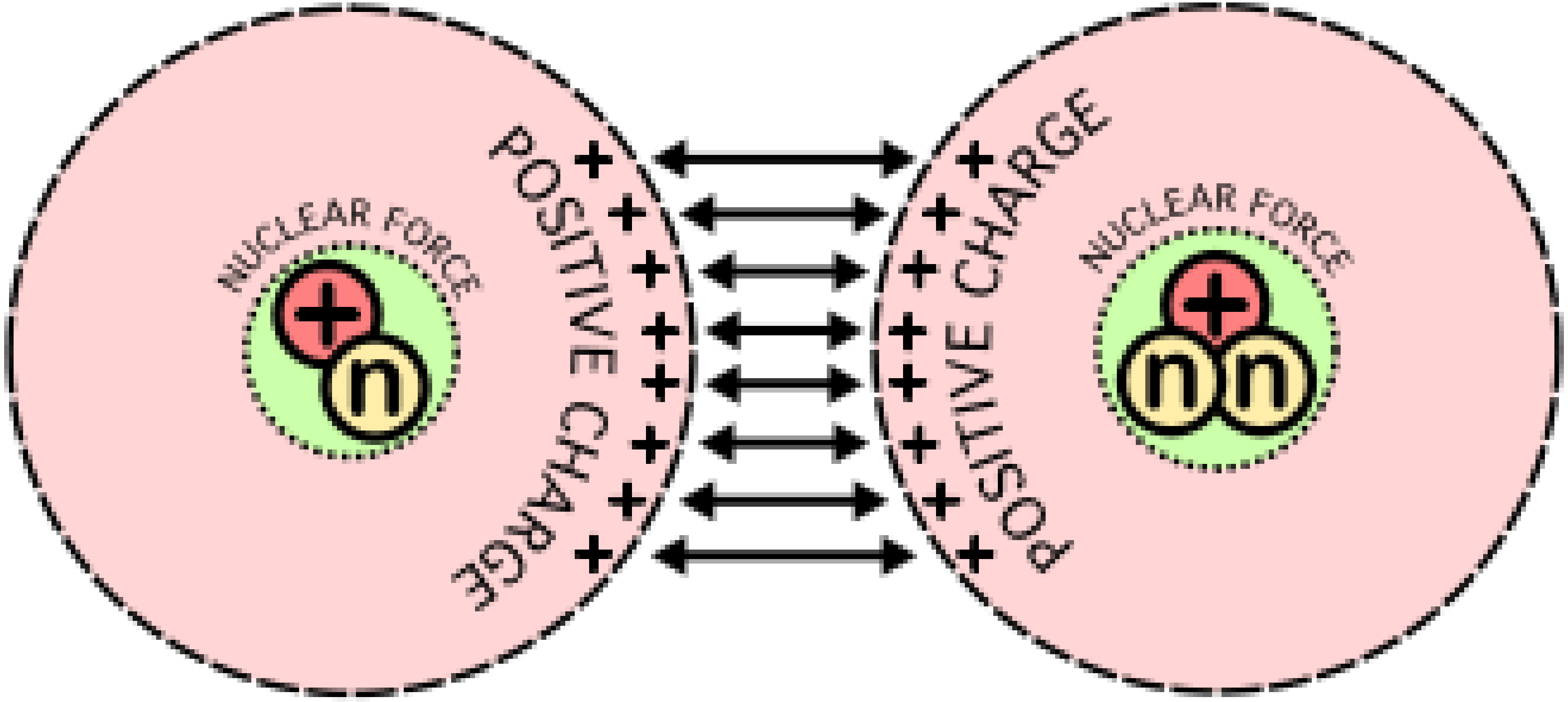
Nuclear Fusion





Nuclear Fission vs. Nuclear Fusion

Coulombic force vs Strong nuclear force



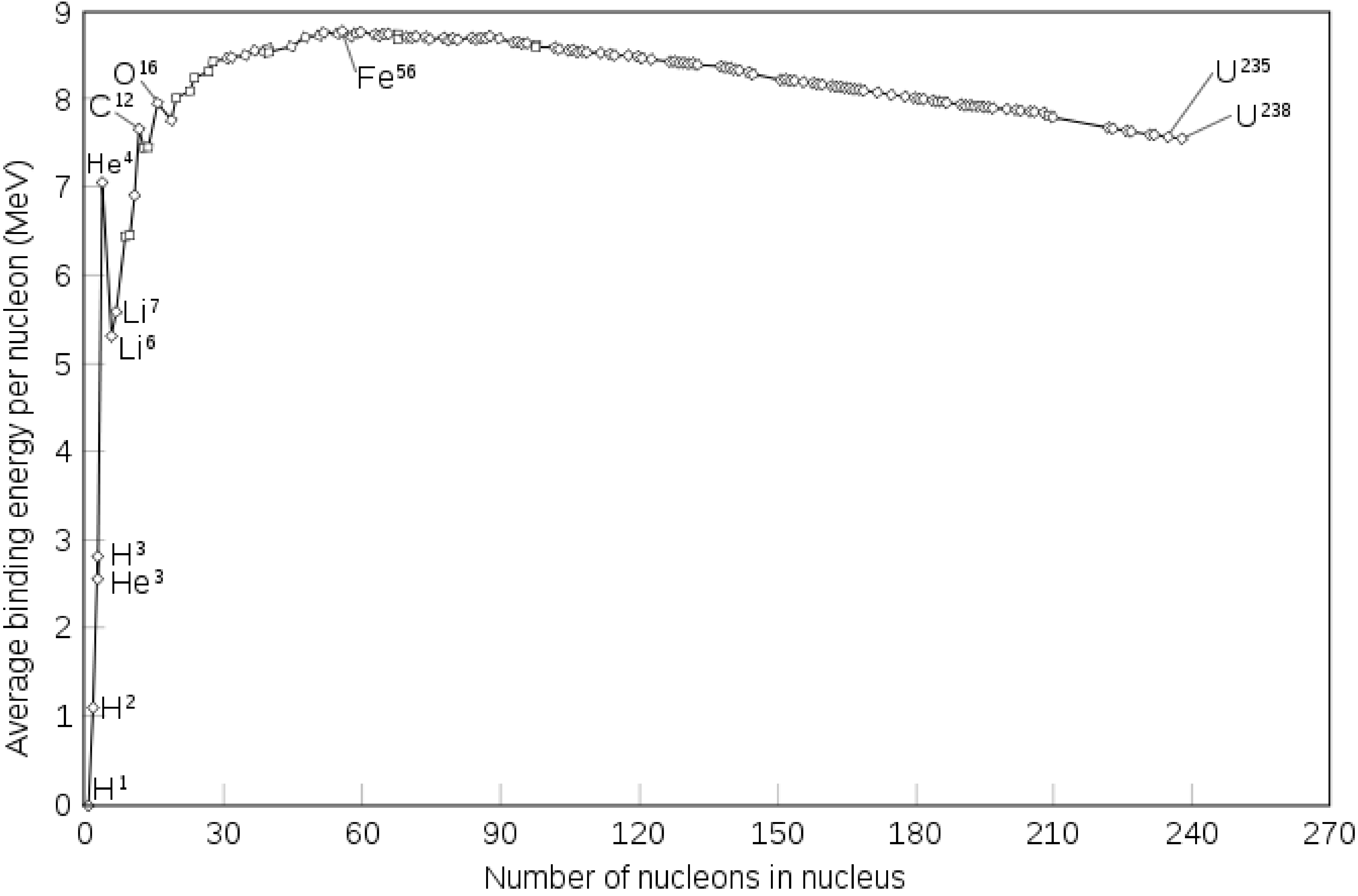

Average binding energy per nucleon (MeV)
Number of nucleons in nucleus
0
1
2
3
4
5
6
7
8
9
0
30
60
90
120
150
180
210
240
270
H1
H2
H3
He3
He4
Li6
Li7
C12
O16
Fe56
U235
U238

TABLE 1.1. LIST OF THE MOST FAVOURABLE FUSION REACTIONS

1.	D + T	→	^{4}He (3.5 MeV) + n (14.1 MeV)
2.	D + D	→	T (1.01 MeV) + p (3.02 MeV) (50%)
		→	^{3}He (0.82 MeV) + n (2.45 MeV) (50%)
3.	D + ^{3}He	→	^{4}He (3.6 MeV) + p (14.7 MeV)
4.	T +T	→	^{4}He + 2 n + 11.3 MeV
5.	^{3}He + ^{3}He	→	^{4}He + 2 p
6.	^{3}He + T	→	^{4}He + p + n + 12.1 MeV (51%)
		→	^{4}He (4.8 MeV) + D (9.5 MeV) (43%)
		→	^{4}He (0.5 MeV) + n (1.9 MeV) + p (11.9 MeV) (6%)
7.	D + ^{6}Li	→	2 ^{4}He + 22.4 MeV
8.	p + ^{6}Li	→	^{4}He (1.7 MeV) + ^{3}He (2.3 MeV)
9.	^{3}He + ^{6}Li	→	2 ^{4}He + p + 16.9 MeV
10.	p + ^{11}B	→	3 ^{4}He + 8.7 MeV

M. Kikuchi, K. Lackner & M. Q. Tran (2012). Fusion Physics

Advantages over Fission

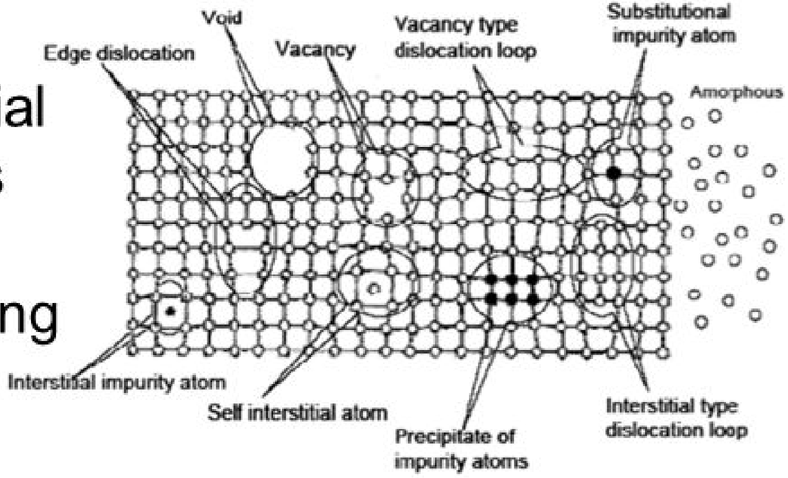
- Readily available fuels which are not radioactive
- Virtually no radioactive waste
- No chance of meltdown
- Fuels and products cannot easily be used to produce weapons

Challenges: Neutrons

The D-T fusion reaction produces a neutron with 14.1 MeV of kinetic energy as compared to 2 MeV neutrons produced in an average fission reaction.

Types of Neutron Radiation Damage

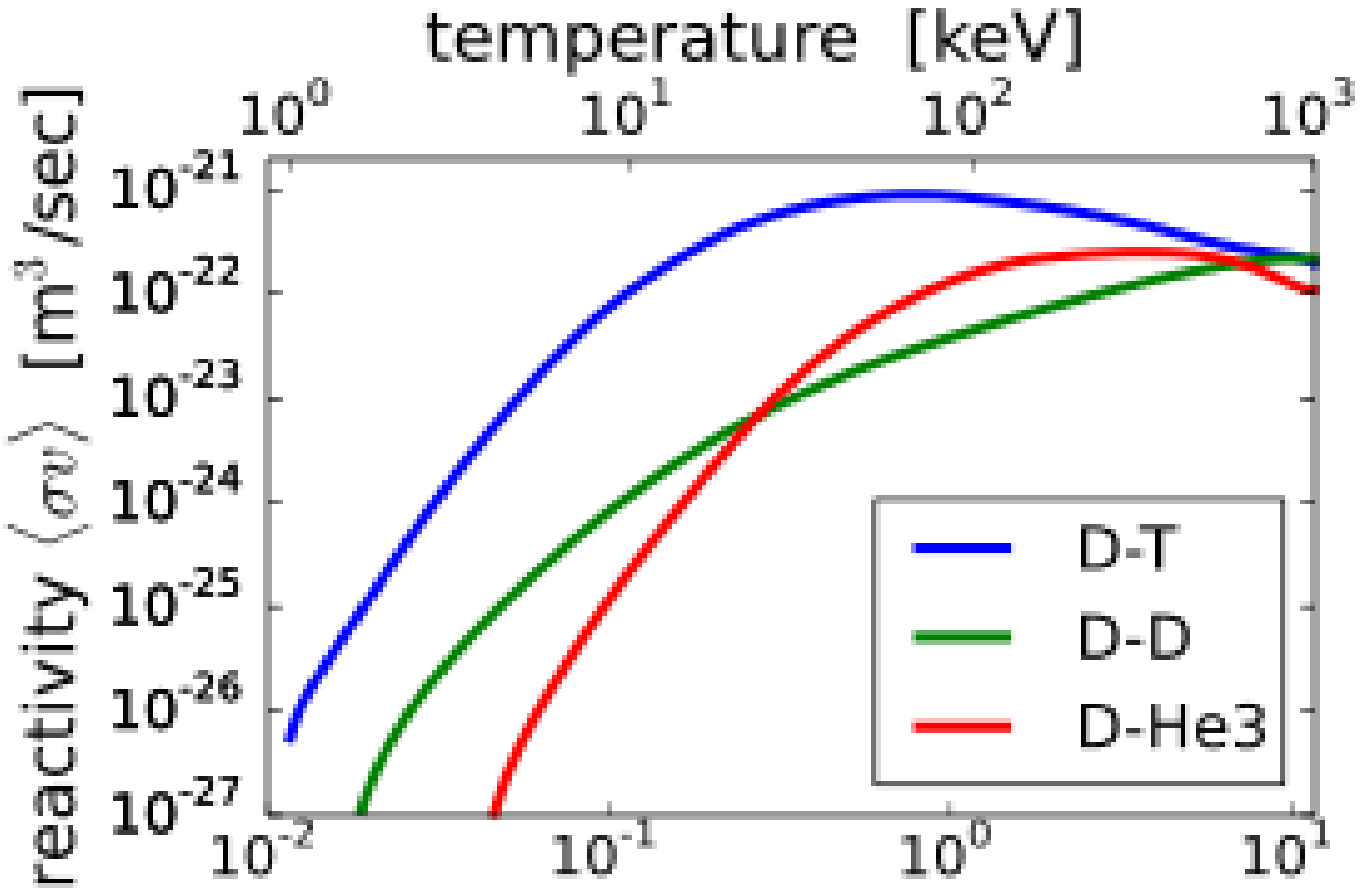
- Microscopic:
  - Changes in the lattice organization of the material (displaces atoms, creates interstitials)
  - Excitation of atoms, heating
  - Activation - can induce radioactivity in materials



Examples of Defects in Lattice Structure

Source: "Neutron Radiation."

Challenges: Extreme temperatures



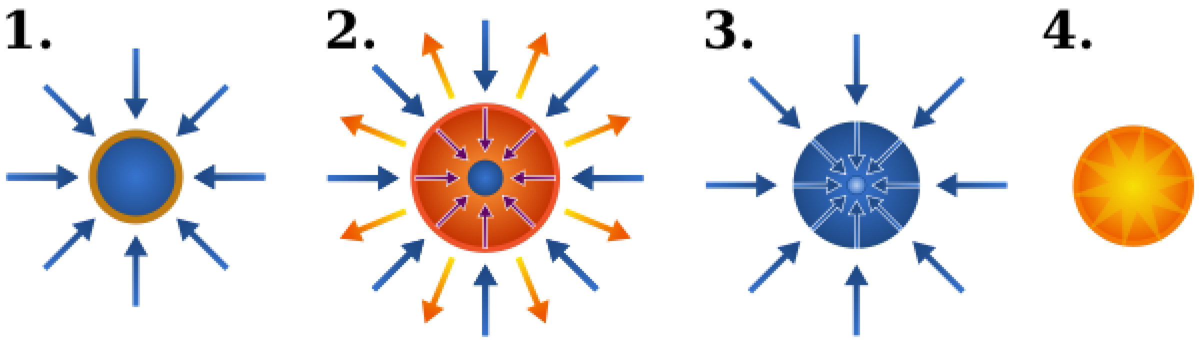
Challenges: Q values

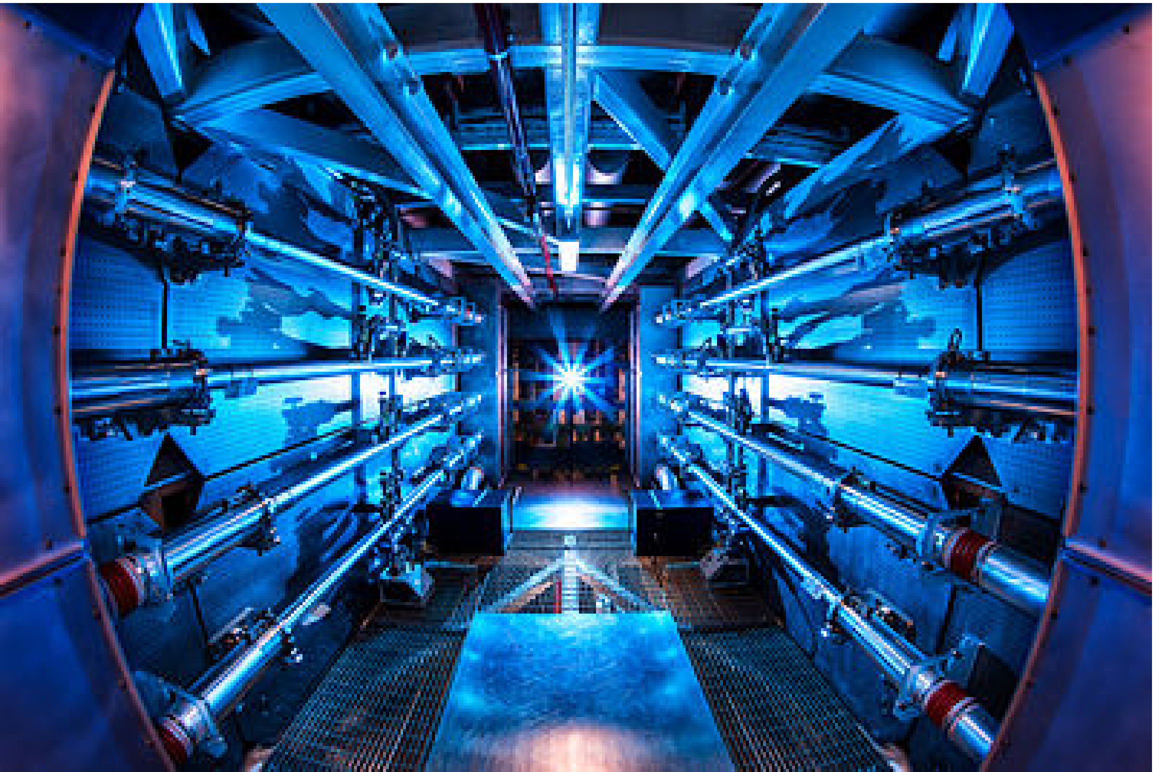
$$Q = \frac{Fusion\ energy}{Energy\ required\ to\ maintain\ fusion}$$

Almost all current reactor designs have a Q value of less than 1, meaning they require more energy to maintain fusion than they produce.

Inertial Confinement

Uses powerful lasers

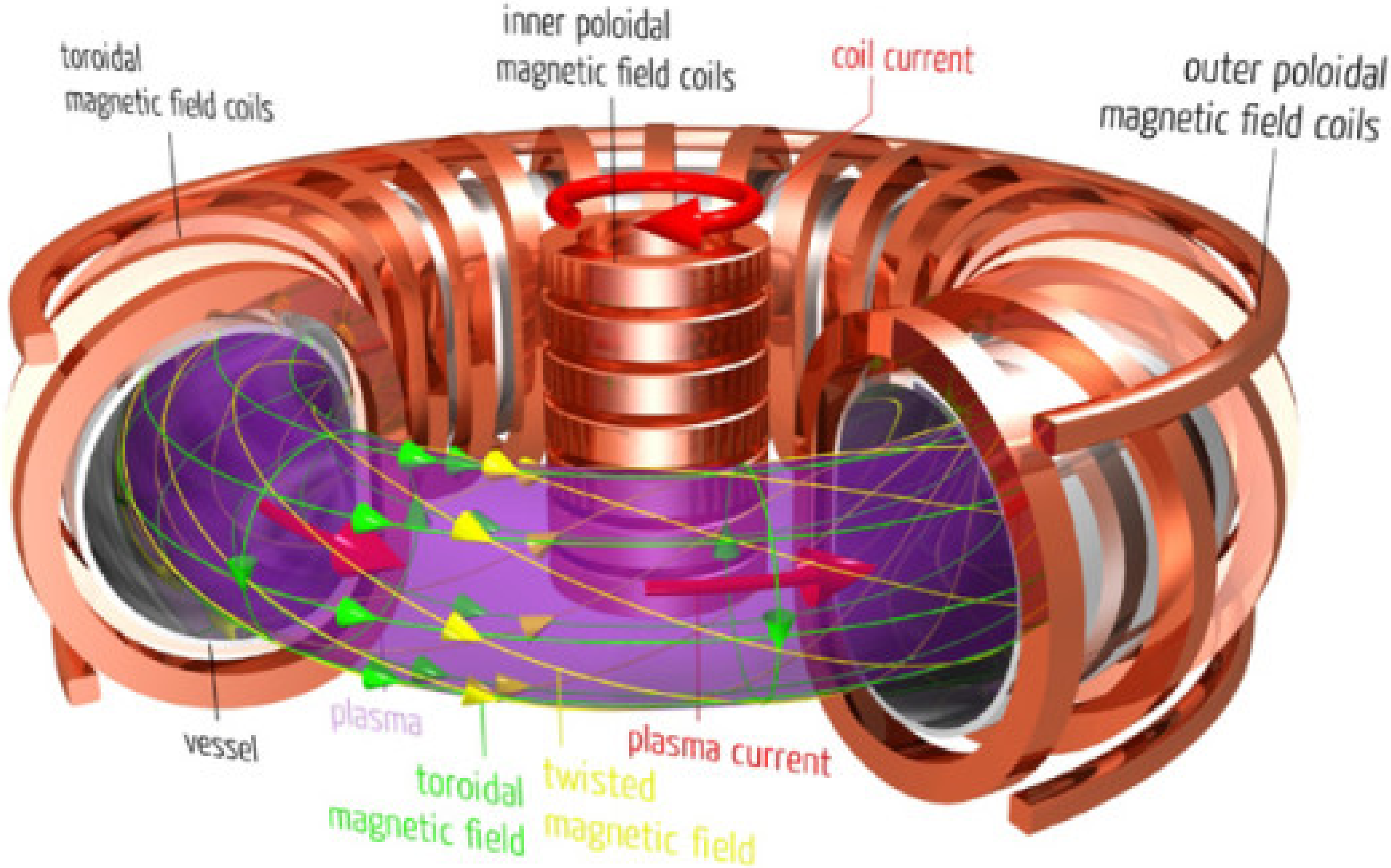




This laser bank at the National Ignition Facility in California can produce a laser shot that delivers **500 TW** of power.

Thermonuclear (controlled)

Uses strong magnetic fields to contain super hot plasma and squeeze it into fusible densities.



(uncontrolled)

- Uses a fission reaction to quickly compress and fuse a fusion fuel
- Relatively easy to construct
- Large output power compared to input (huge Q)
- One drawback…

$$57 \times 10^{6}\, tons\, TNT\ \times 1.17\ \times 10^{3}\ \frac{kWh}{ton\, TNT} = 5.8\ \times 10^{10} kWh$$

Enough energy to run the entire US for ¾ of a day was released in a fraction of a second.