Bab.10.Reaksi Inti

- Dimungkinkan untuk mengubah struktur inti dengan cara membombardir inti tersebut dengan partikel energetik
- Tumbukan seperti itu yang dapat mengubah identitas inti target disebut reaksi inti
- Reaksi inti pertama kali diamati oleh rutherford pada tahun 1919
- Setelah ditemukannya alat pemercepat partikel tahun 1930, telah banyak dilakukan reaksi inti.

Hukum kekekalan untuk reaksi inti

- Inti target X yang dibombardir oleh partikel a sehingga menghasilkan inti baru Y dan partikel baru b, reaksinya ditulis

$$a + X \longrightarrow Y + b$$

atau X(a,b)Y

Pada reaksi inti berlaku hukum kekekalan

- Nomor massa
- Muatan
- Energi,momentum linier dan momentum angular

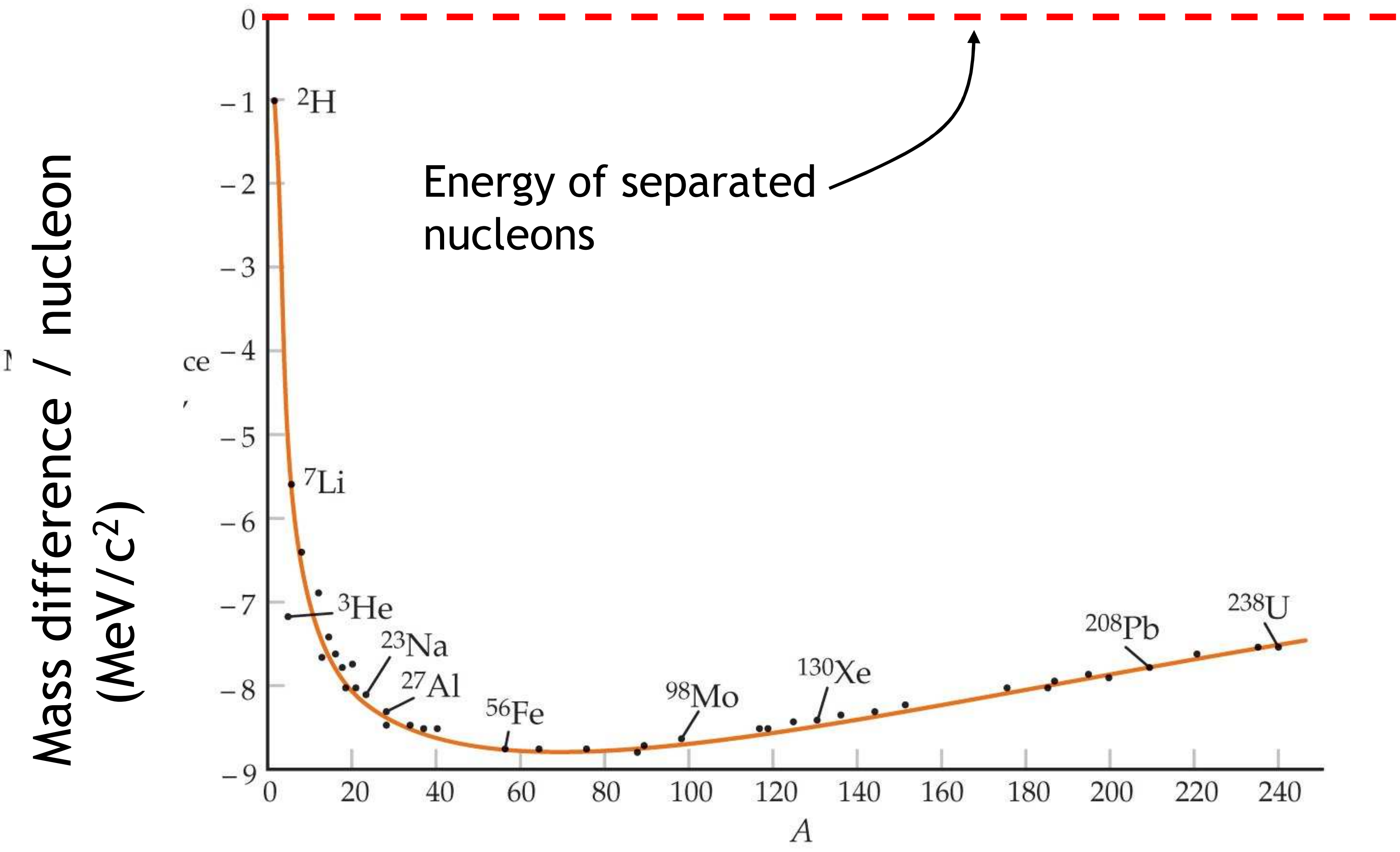
Energi Reaksi

- Pada reaksi inti terdapat energi reaksi Q,yaitu energi kinetik total yang dibebaskan atau diserap

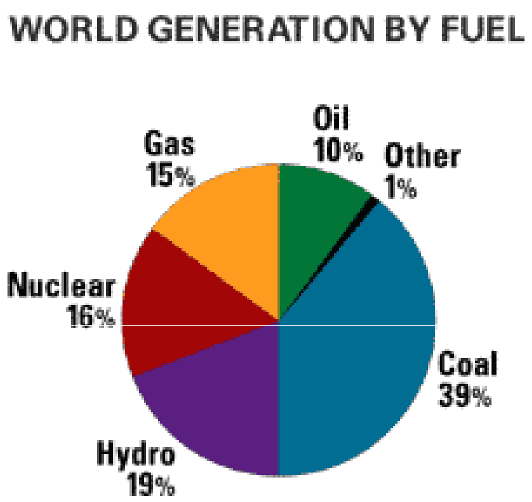
  $Q = (M_x + M_a - M_y - M_b).931,49\ MeV$
- Bila pada reaksi inti Q nya positif maka reaksinya disebut reaksi eksotermik. Pada reaksi ini dibebaskan sejumlah energi dalam wujud energi kinetik inti baru Y dan partikel baru b
- Bila pada reaksi inti, Q nya negatif maka reaksinya disebut reaksi endothermik,artinya untuk berlangsungnya reaksi inti diperlukan energi dari luar
- Pada reaksi endothermik,partikel datang harus memiliki energi kinetik minimum yang disebut energi ambang

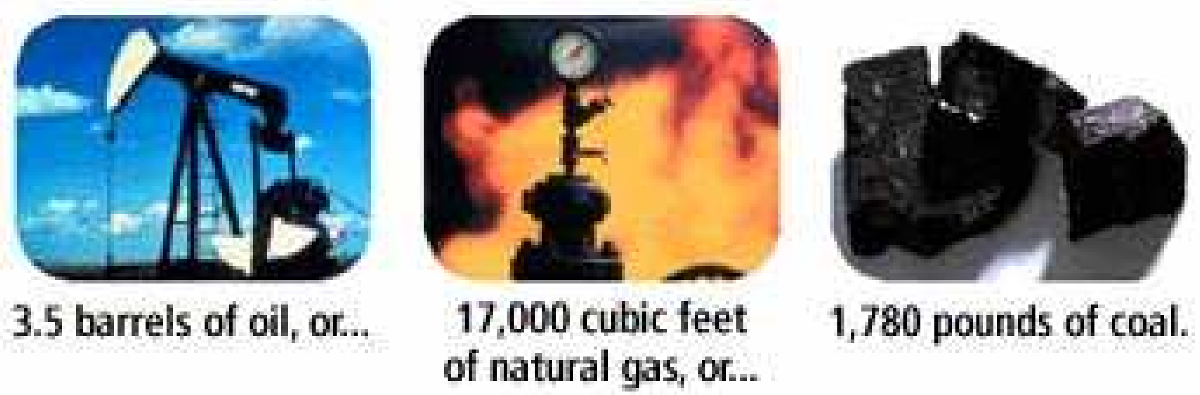
  $K_{th} = -Q(1 + M_a/M_x)$

Energi ikat berbagai inti atom



Penghasil Energi

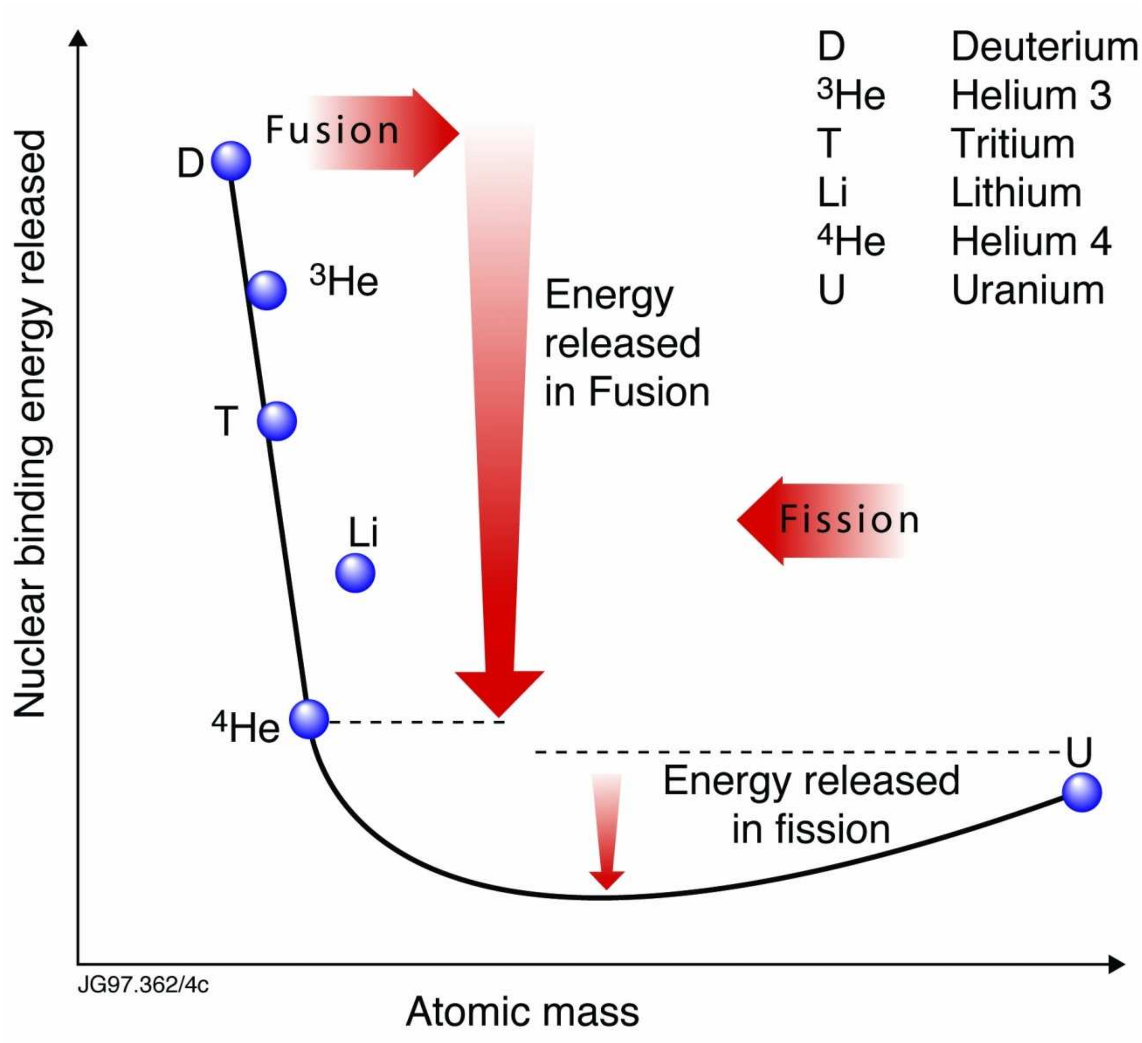




Bagaimana kita dapat menghasilkan energi ini?

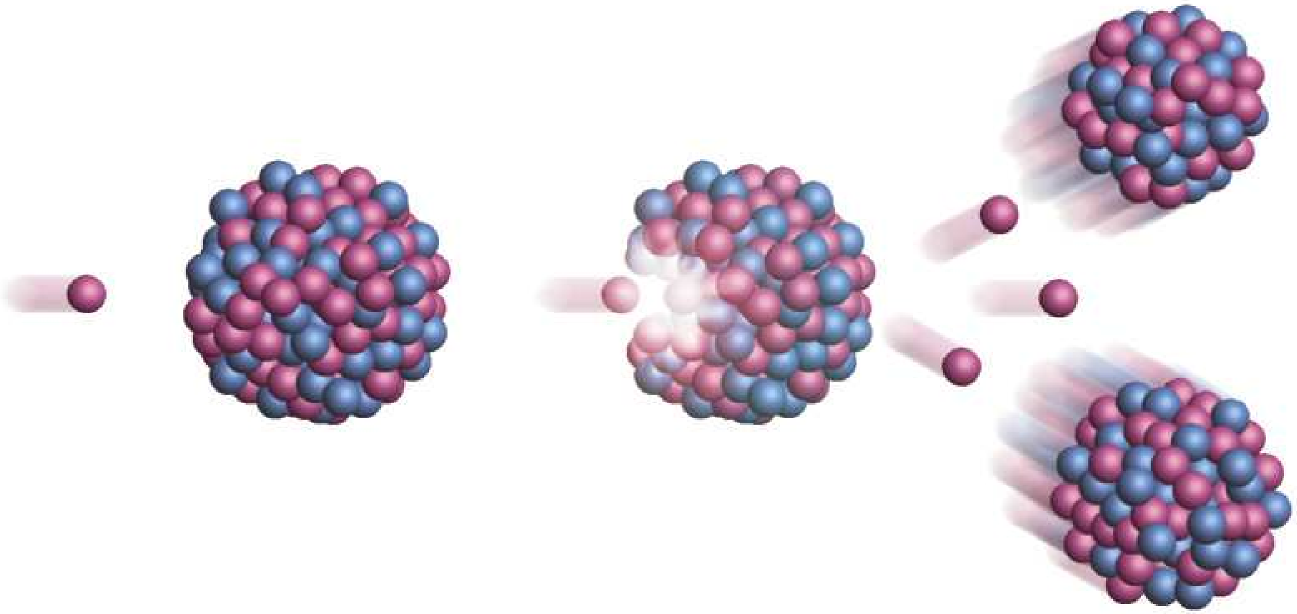
Perbedaan antara inti

- Schematic view dari diagram sebelumnya
- ^{56}Fe lebih stabil
- Maju menuju energi rendah melalui fissi atau fusi.
- Energi yg dihasilkan berhubungan dengan perbedaan dalam binding energy.



Fisi Nuklir(Nuclear fission)

- Inti berat pecah menjadi dua inti baru yang lebih ringan.
- Jumlah massa setelah reaksi lebih kecil dari jumlah massa sebelum reaksi
- Massa yang hilang diubah menjadi Energi yang dibebaskan $E=mc^2$



Fisi

$$X + n \longrightarrow \text{fisi} \longrightarrow Y^* + Z^* + \text{neutrons}$$

$M(Y) + M(Z) + M(\text{neutrons}) < M(X) + M(n)$

massa yang hilang

$\Delta M = M(X) + M(n) - M(Y) - M(Z) - M(\text{neutrons})$

energi yang dibebaskan

$$Q = \Delta M c^2$$

Latihan

Tentukanlah energi yang dibebaskan pada reaksi fisi berikut

$n + U \longrightarrow Ba \; + Kr \; + 3\,n$

Bila U memiliki A=235 ,z=92 dan

massanya 235,043915 u

Ba memiliki A=141,z=56 dan massanya 140,9139 u

Kr memiliki A=92 ,z=36 dan massanya 91,8973 u

Massa neutron = 1,0088665 u

Jawab

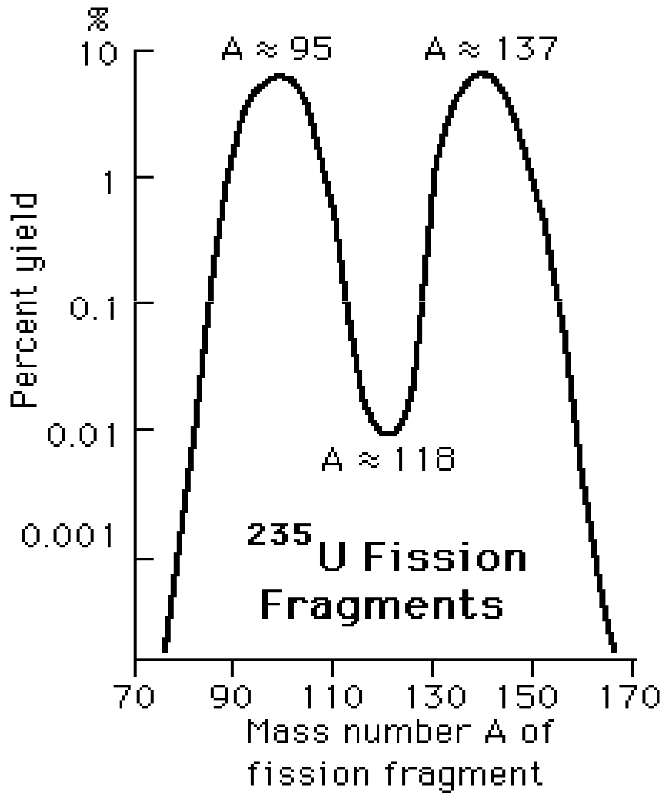
Q={(235,043915 + 1,008665) –(140,9139 + 91,9873 +

3x1,008665)}.931,49 MeV

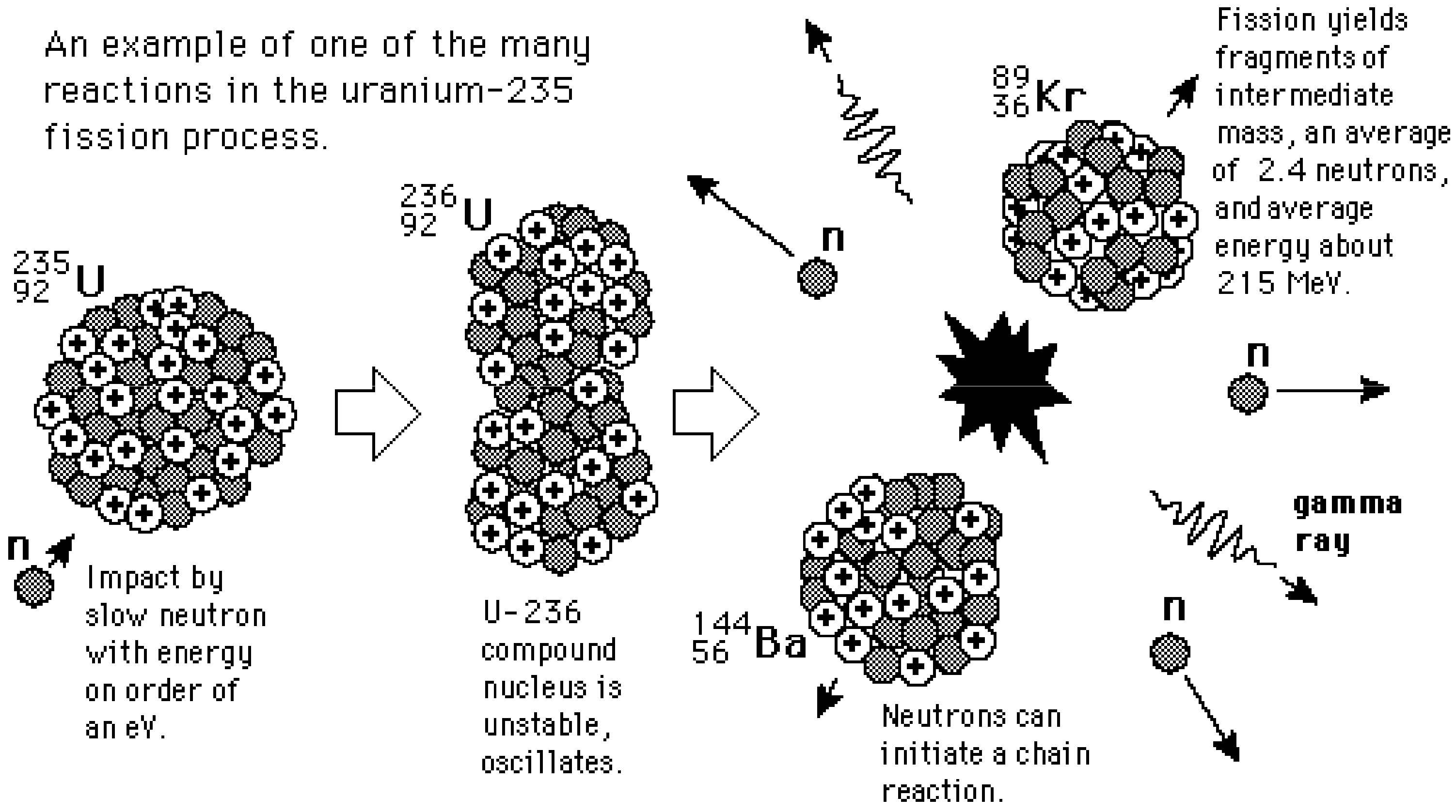
= 200,6 MeV

Fission Fragments

- ketika ^{235}U terjadi fissi, massa fragmen(inti anak) rata rata ialah sekitar 118, tetapi sedikit sekali ditemukan massa fragmen yang mendekati rata rata. Kemungkinan terbesar ialah pecah menjadi fragmen yang massanya tidak sama, dan sebagian besar massa fragmen adalah sekitar 95 dan 137.

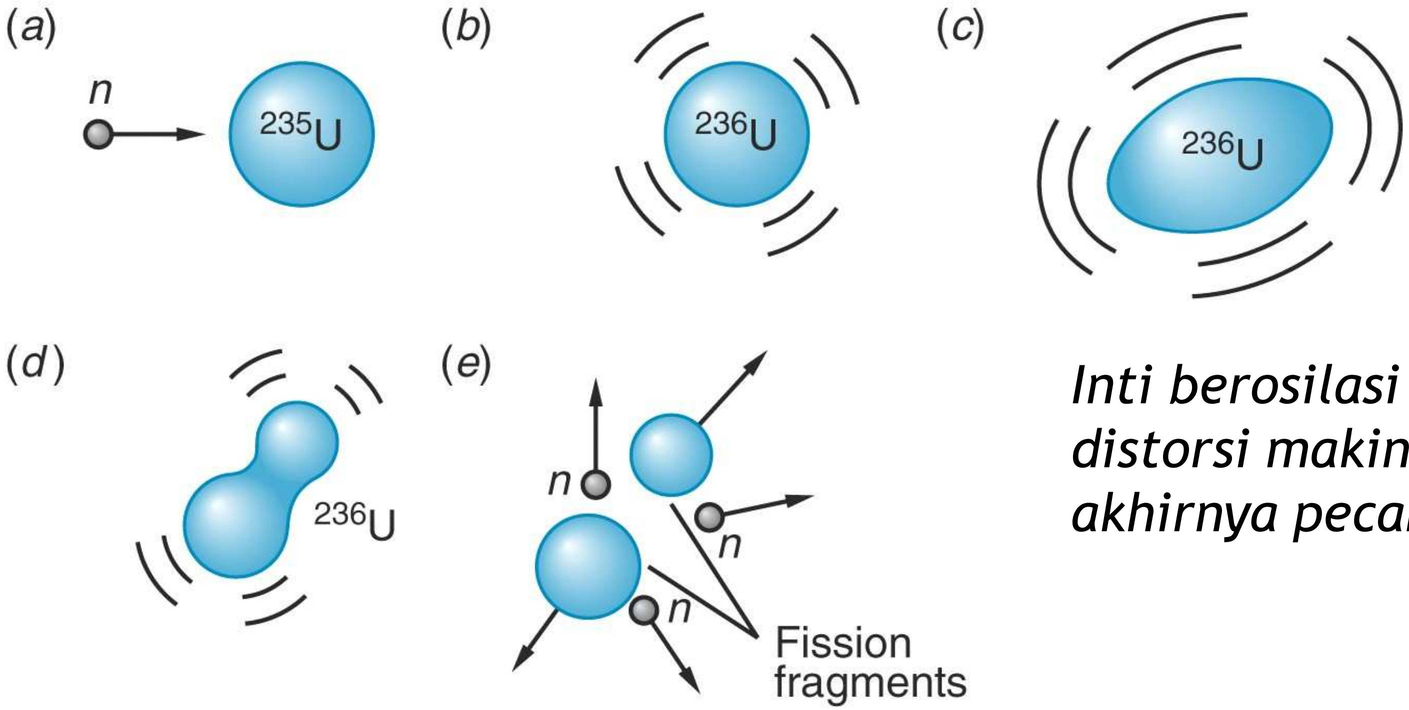


Fisi pada Uranium



Fisi Nuklir: Penangkapan Neutron

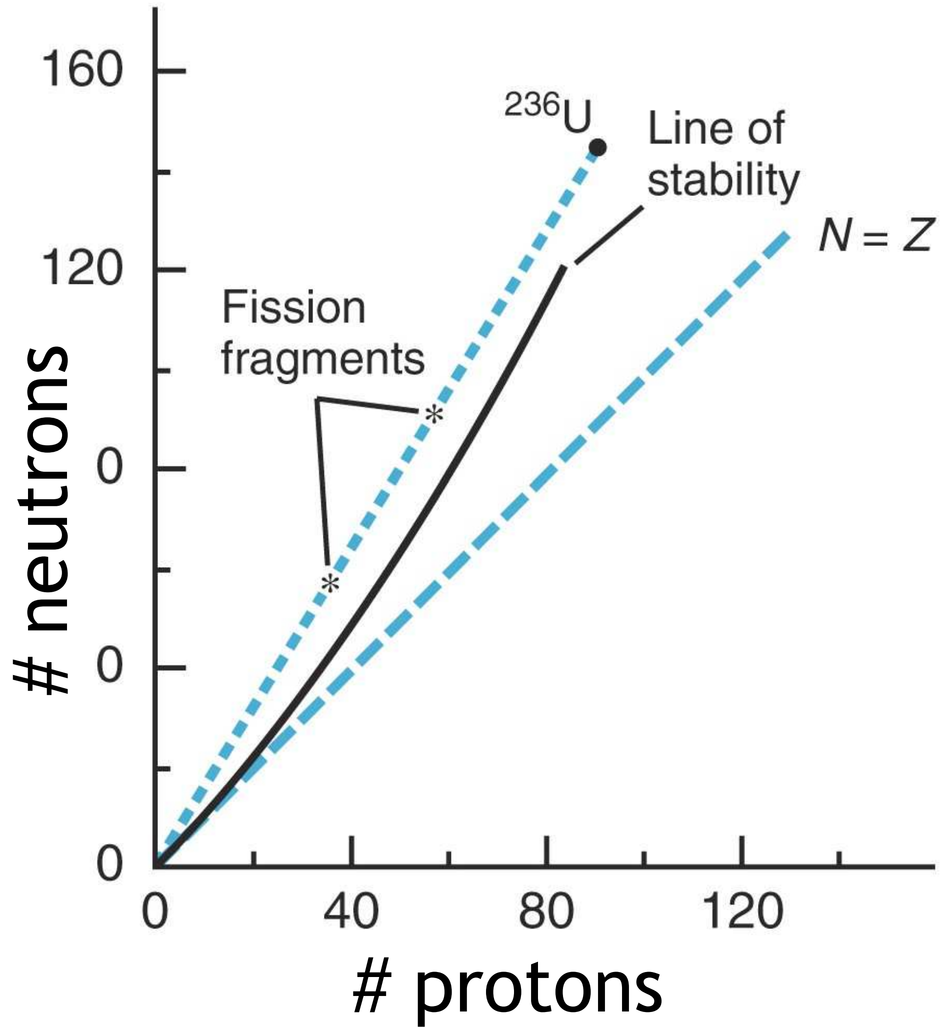
- Fissi: inti berat pecah menjadi inti inti ringan.
- tidak spontan, diinduksi oleh penangkapan neutron
- ketika neutron ditangkap, ^{235}U menjadi ^{236}U
  - jumlah neutron berubah, jumlah proton sama.



Inti berosilasi dan distorsi, distorsi makin kuat dan akhirnya pecah (fissi)

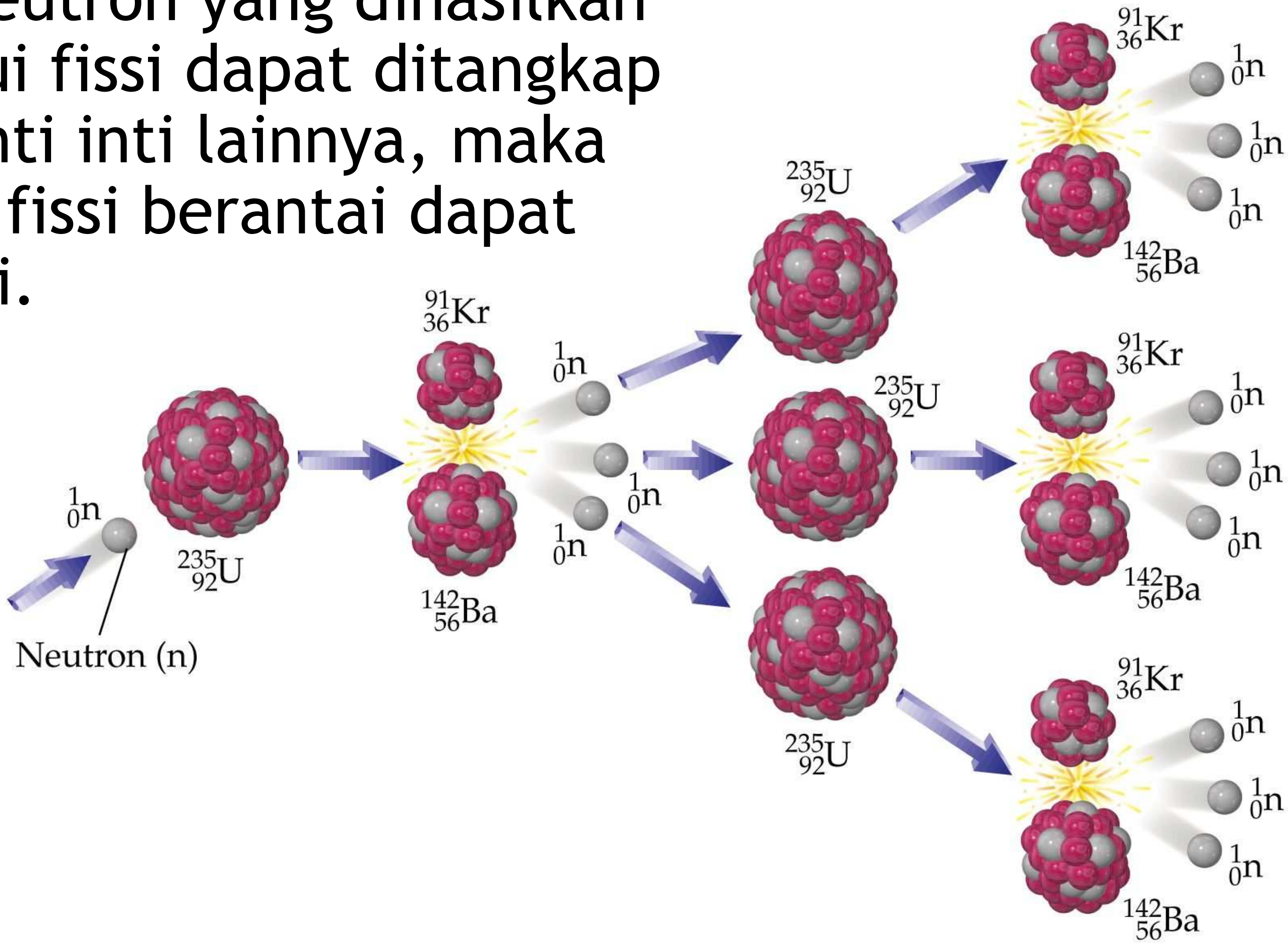
Neutron production

- Fission fragments memiliki neutron terlalu banyak untuk menjadi stabil.
- Jadi neutron bebas dihasilkan sebagai tambahan pada fission fragment besar.
- Neutron ini dapat menginisiasi terjadinya fissi lebih banyak



Reaksi berantai(Chain reaction)

- Jika neutron yang dihasilkan melalui fissi dapat ditangkap oleh inti inti lainnya, maka reaksi fissi berantai dapat terjadi.



Neutron

- Pada setiap reaksi fisi dihasilkan 2 atau 3 neutron baru atau rata ratanya 2,5 dan disebut konstanta reproduksi, diberi notasi k
- Neutron dapat ditangkap oleh inti inti yang belum melakukan fissi
  - Sebagian besar, neutron ditangkap oleh ^{238}U
  - Neutron lambat peluangnya ditangkap oleh ^{238}U adalah rendah.
- Moderator berfungsi untuk meminimalkan penangkapan neutrons oleh ^{238}U dengan cara memperlambatnya,

The critical mass

- Bergantung pada probabilitas dari neutron ditangkap oleh ^{235}U.
- Jika neutron lepas sebelum ditangkap, reaksi tidak akan berlangsung self-sustaining chain reaction.
- Level operasi reaktor dinyatakan oleh parameter konstanta reproduksi k
- Self sustained chain reaction dicapai pada k=1 , dikatakan reaktor pada keadaan kritis. Bila k<1 maka reaktor dalam keadaan subkritis dan reaktor akan mati
- Massa dari fissionable material harus cukup besar, dan fraksi ^{235}U cukup tinggi, untuk menangkap neutron neutron sebelum mereka lepas.

Chain reaction pertama

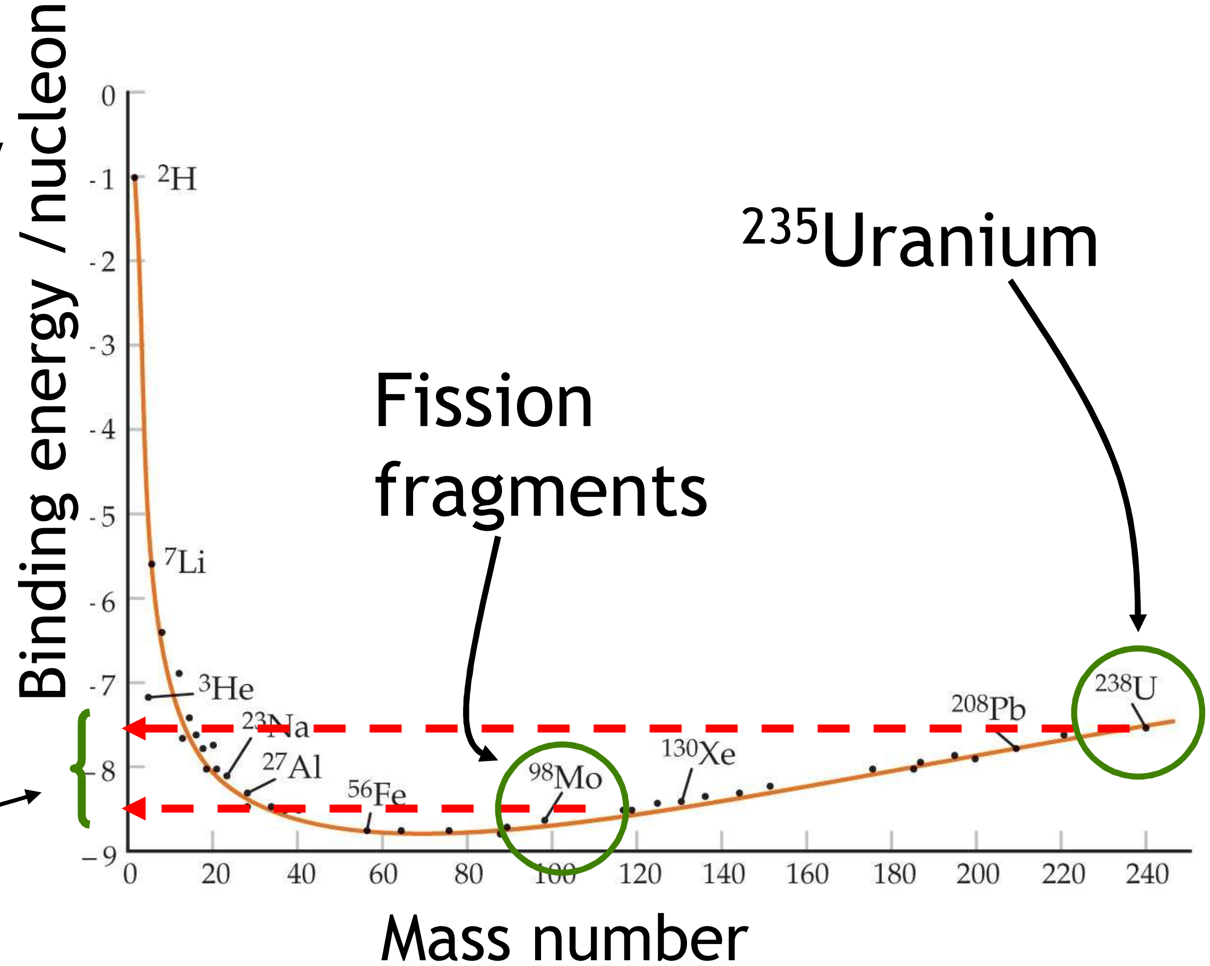
- Construction of CP-1, (Chicago Pile Number One) under the football stadium in an abandoned squash court.
- A 'pile' of graphite, uranium, and uranium oxides.
- Graphite = moderator, uranium for fission.
- On December 2, 1942: chain reaction produced 1/2 watt of power.

- 771,000 lbs graphite,
  80,590 pounds of uranium oxide and
  12,400 pounds of uranium metal,
- Cost ~ $1 million.
- Shape was flattened ellipsoid
  25 feet wide and 20 feet high.

Berapa jumlah energi?

Binding energi/nukleon ~1 MeV lebih kecil untuk fission fragments dari pada untuk original nucleus

Perbedaan ini muncul sebagai energi.

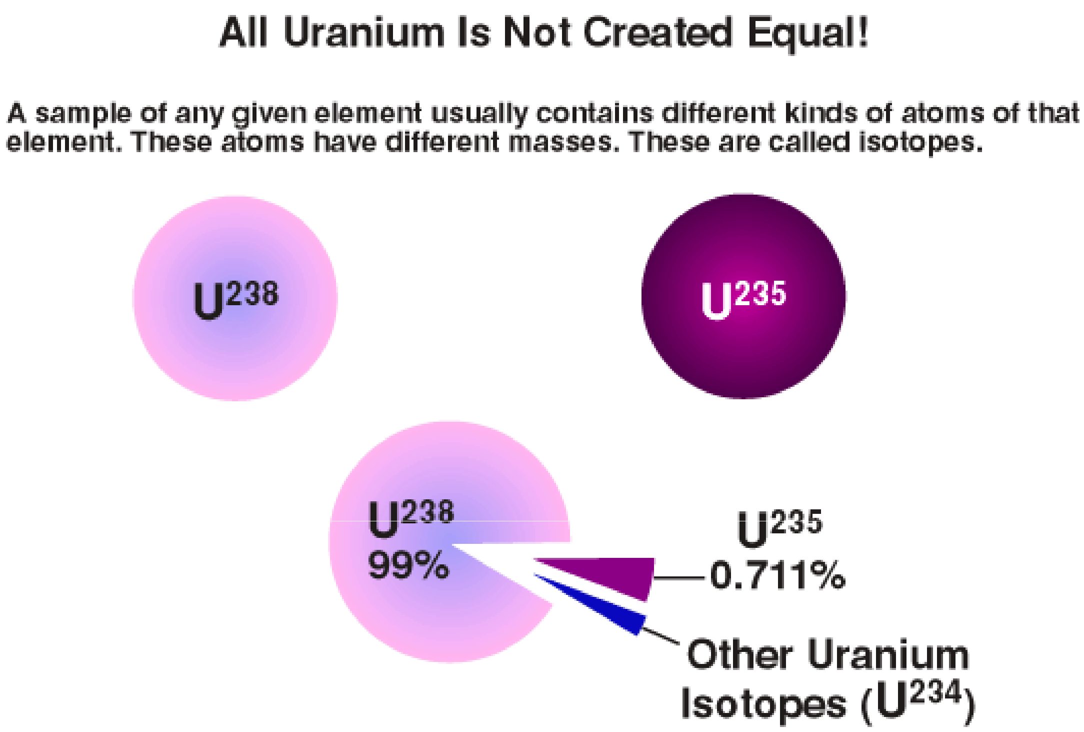


Energi/nukleon dibebaskan oleh fissi

Energi dihasilkan

- ^{235}U memiliki 235 total nukleon,
  ~240 MeV dibebaskan dalam satu kejadian fissi.
- ^{235}U memiliki molar massa ~235 gr/mole
  - 1 kg ~ 4 mole = $4x(6x10^{24})=2.5x10^{25}$ partikel
- Fissi satu kg dari ^{235}U
  - Menghasilkan ~$6x10^{33}$ eV = 10^{15} Joules
  - 1 kilo-ton = 1,000 tons of TNT = $4.2x10^{12}$ Joules
  - Ini akan menghasilkan ~250 kilo-ton energi!!!
- Pada Chain reaction energi tersebut dibebaskan /dihasilkan dalam waktu yang singkat

Isotop Uranium



- Only the less abundant ^{235}U will fission.
- Natural abundance is less than 1%, most is ^{238}U

- Note: 3-5% enrichment ok for reactor.
- Bomb needs much higher fraction of ^{235}U
- Oppenheimer suggested needed as much as 90% ^{235}U vs ^{238}U

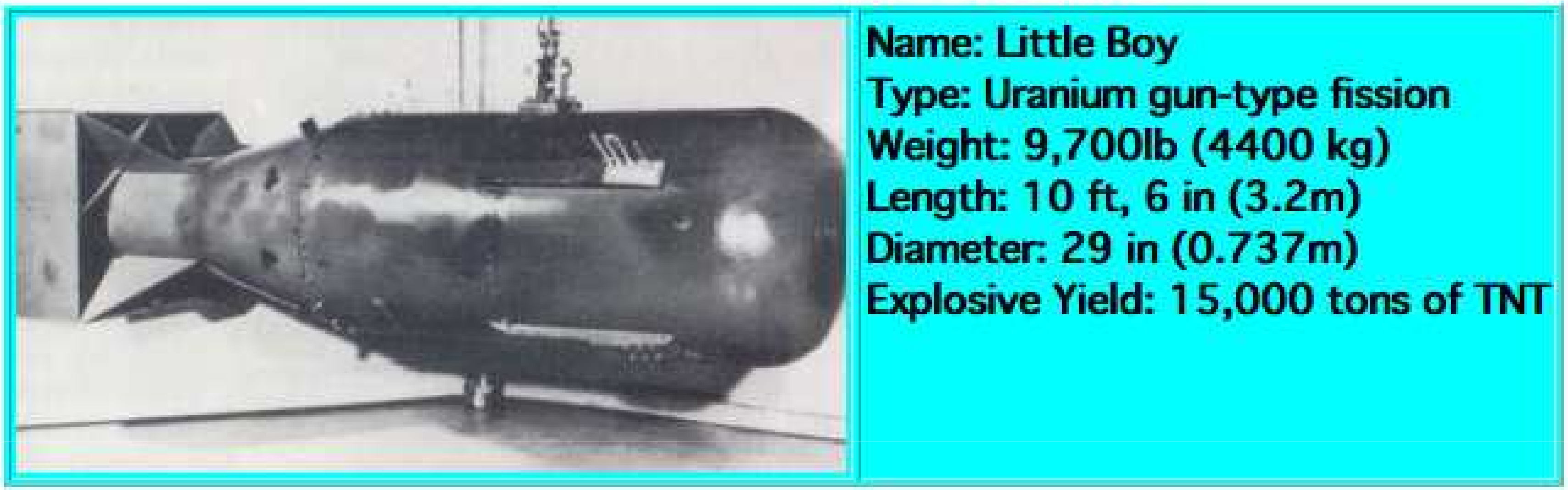
Dari manakah uranium berasal?

- Uranium tersedia melimpah namun dengan konsentrasi yang rendah
- Contoh. uranium tercampur dengan granite, meliputi 60% dari batuan bumi (Earth's crust).
- Namun konsentrasi uranium dalam batuan granite tersebut sangat kecil sekali.

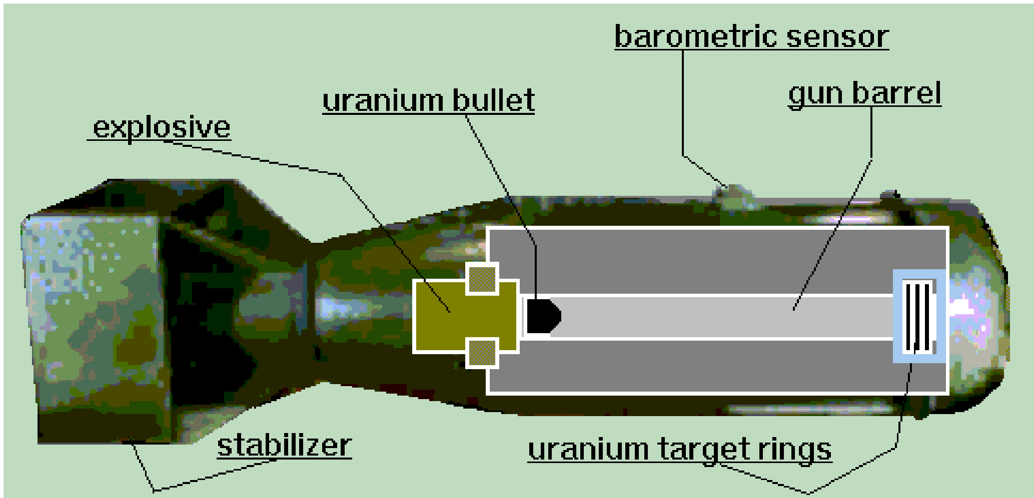
Gas centrifuge enrichment

- Gaseous UF_6 is placed in a centrifuge.
- Rapid spinning flings heavier U-238 atoms to the outside of the centrifuge, leaving enriched UF_6 in the center
- Single centrifuge insufficient to obtain required U-235 enrichment.
- Many centrifuges connected in a 'cascade'.
- U-235 concentration gradually increased to 3 – 5% through many stages.
- Simplest method of enrichment which is why you hear about it on the news

Uranium fission bomb

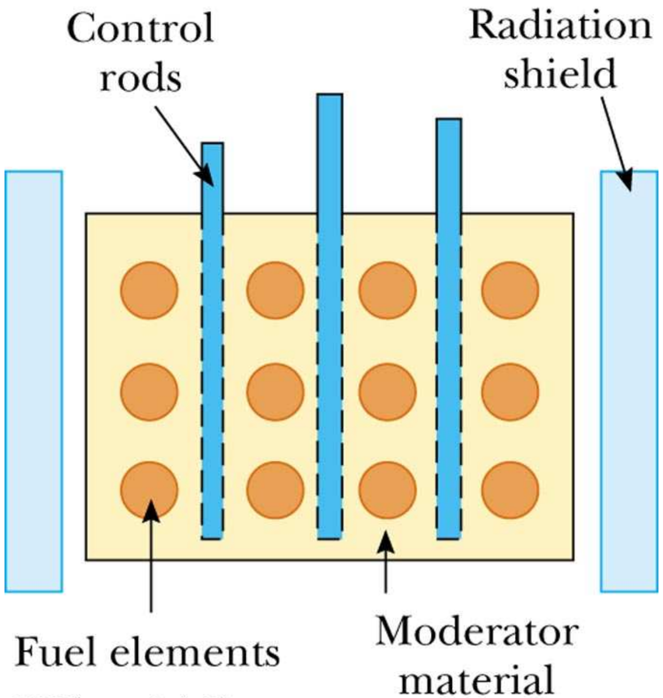


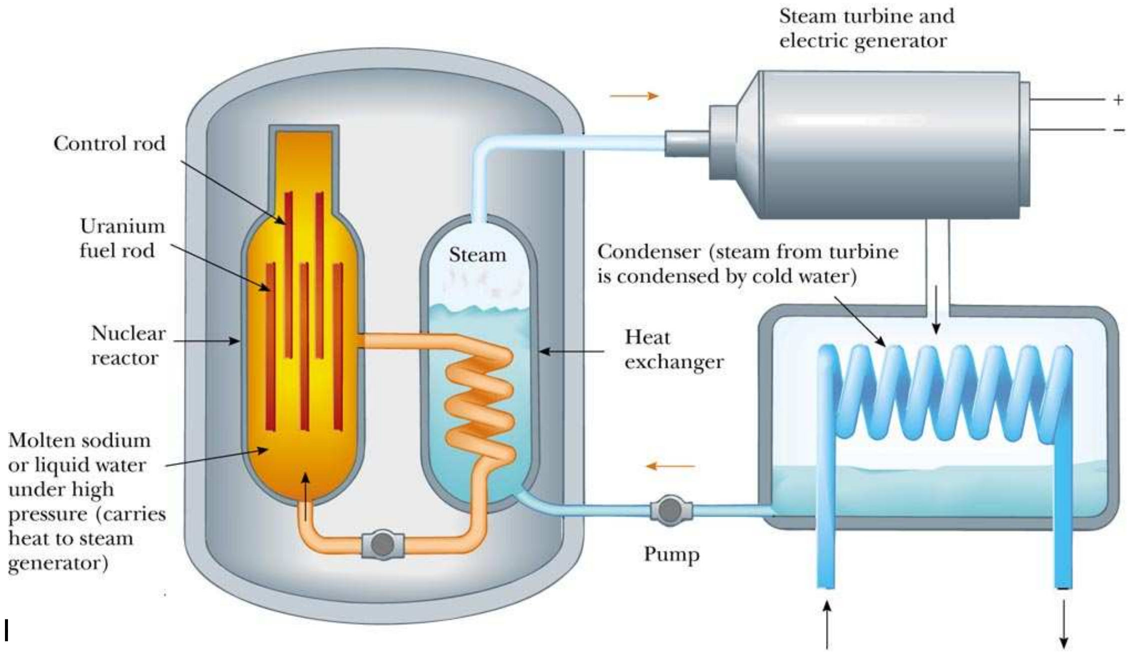
- Uranium ‘bullet’ ditembakan ke Uranium target
- Terjadi Critical mass , dihasilkan reaksi berantai fisi tak terkendali



Reaktor Nuklir Terkendali

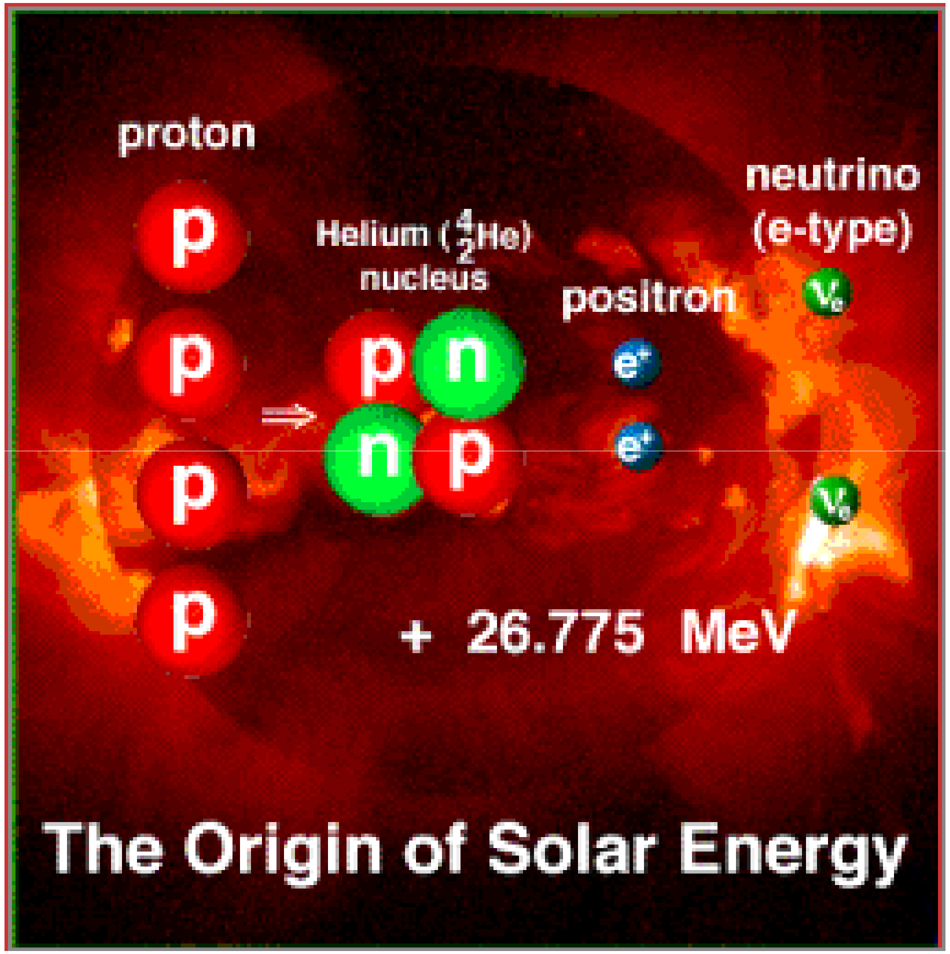
- Reaktor dalam nuclear power plant serupa dengan boiler pada fossil fuel plant – Sebagai penghasil panas.
- Bagian bagian dasar reaktor:
  - Core (*contains fissionable material*)
  - Moderator (*slows neutrons down to enhance capture*)
  - Control rods (*controllably absorb neutrons*)
  - Coolant (*carries heat away from core to produce power*)
  - Shielding (*shields environment from radiation*)





Nuclear Fusion(Fusi Nuklir)

- Bergabungnya dua inti ringan menjadi inti yang lebih berat. Dihasilkan energi
- Energi pernukleon 6.7MeV .
- Ingat fisi U^{235} dibebaskan 1MeV per nukleon
- Sulit untuk menghasilkan kondisi seperti di matahari. Digunakan proses yang berbeda dalam eksperimen fusi



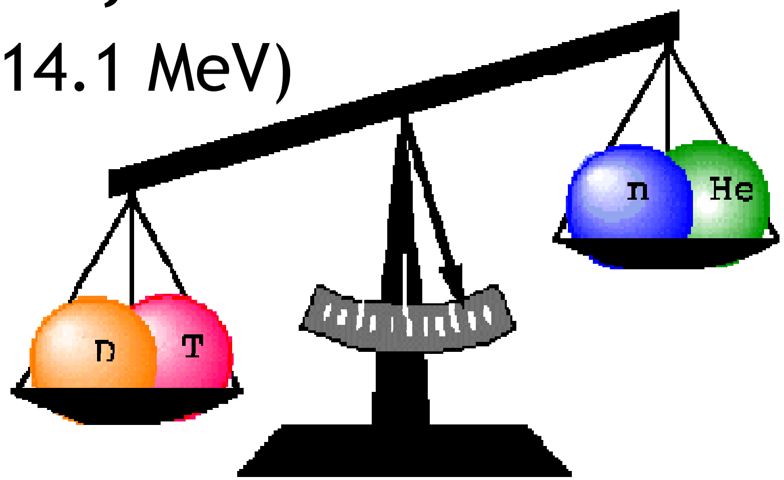
Reaksi Fusi buatan

- Deuterium = nucleus (1 proton & 1 neutron)
- Tritium = nucleus (1 proton & 2 neutrons)
- Dua reaksi fusi dasar:
  - deuterium + deuterium -> ^{3}He + n
  - deuterium + tritium -> ^{4}He + n

Energi dibebaskan sebagai hasil fusi:

D + T -> ^{4}He (3.5 MeV) + n (14.1 MeV)

Energi ditentukan oleh perbedaan massa



Fusion

$$X + Y \longrightarrow \text{fusion} \longrightarrow Z + \text{nucleon}$$

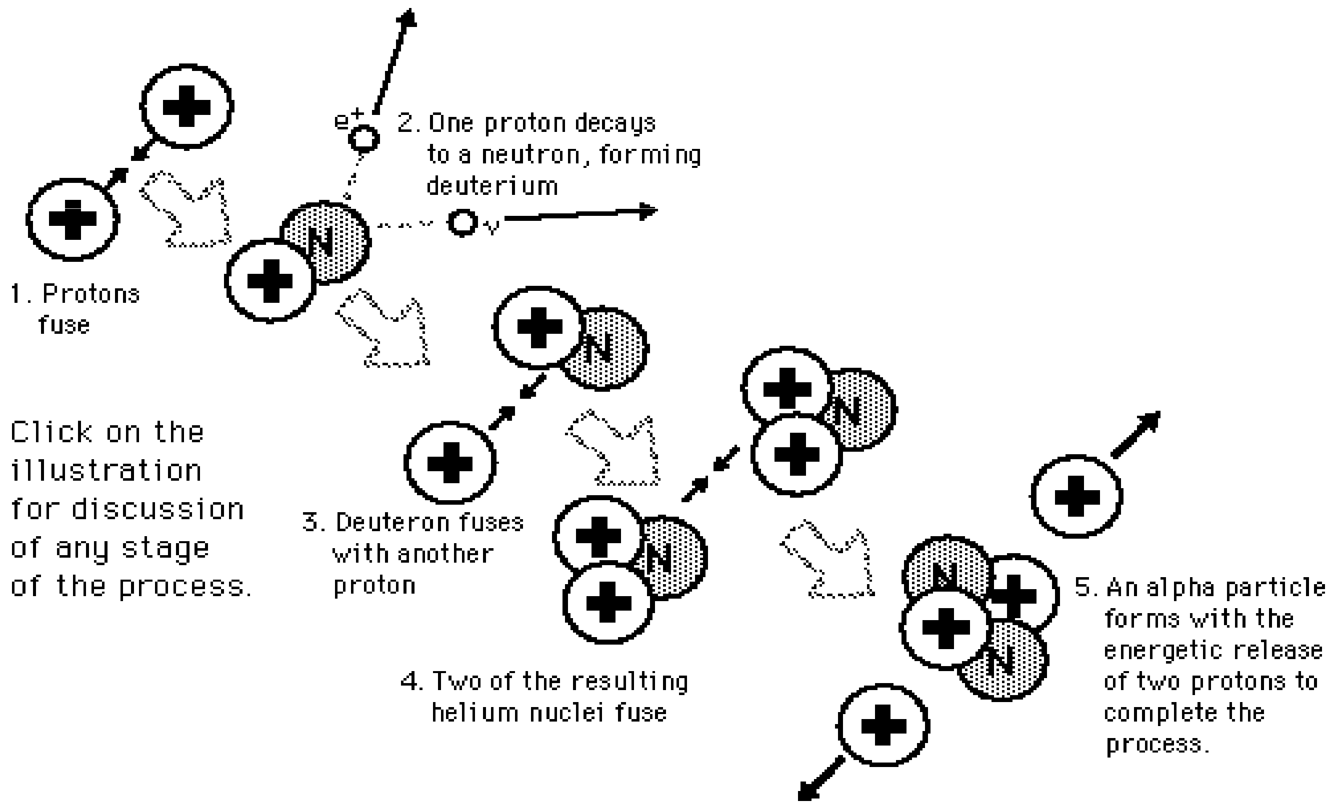
$$M(Z) + M(\text{nucleon}) < M(X) + M(Y)$$

$$\Delta M = M(X) + M(Y) - M(Z) - M(\text{nucleon})$$

$$E = \Delta M c^2$$

Fusi Proton-Proton

- This is the nuclear fusion process which fuels the Sun and other stars which have core temperatures less than 15 million Kelvin. A reaction cycle yields about 25 MeV of energy



Fusi Deuterium-Tritium

deuterium-tritium fusion reaction contained by some kind of magnetic confinement seems the most likely path.

- Reaksi ini menghasilkan energi 17.6 MeV tetapi diperlukan temperature mendekati 40 juta Kelvins untuk mengatasi coulomb barrier . The deuterium fuel is abundant, but tritium must be either bred from lithium or gotten in the operation of the deuterium cycle.

$$^{2}H + {}^{3}H \longrightarrow {}^{4}He + n + 17.6\ MeV$$

Latihan

Tentukanlah energi yang dihasilkan pada reaksi fusi nuklir berikut

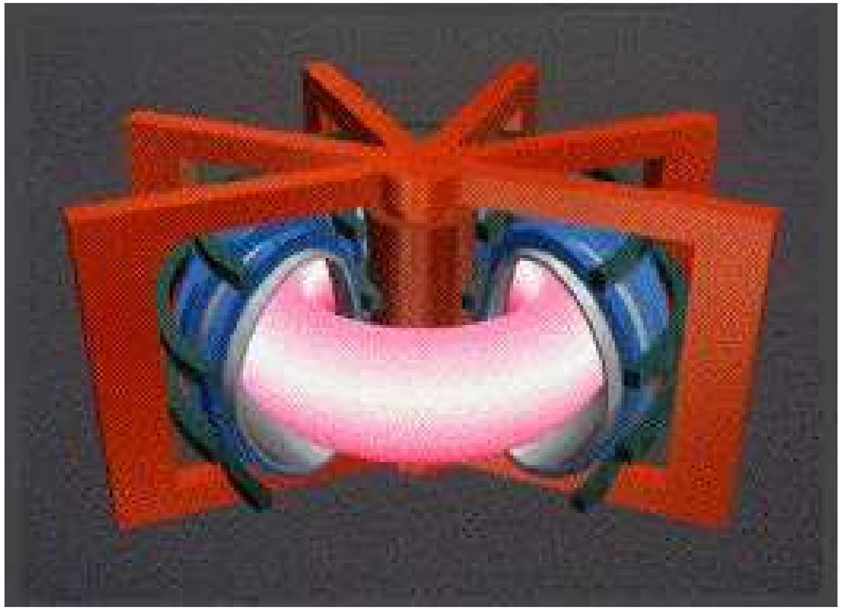
Dua buah deuterium bergabung membentuk Tritium dan sebuah proton

Jawab

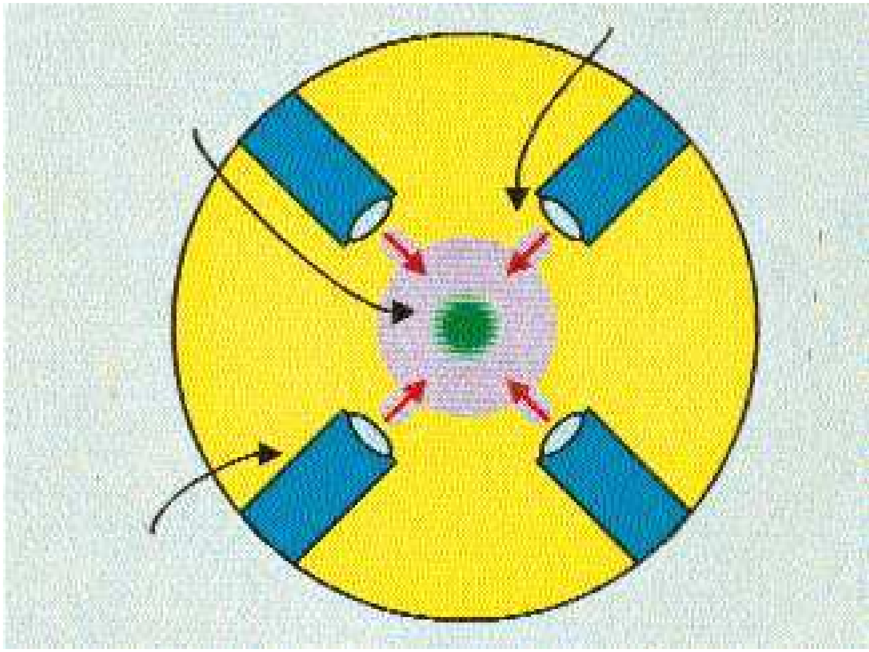
$Q=\{(2{,}014102+2{,}014102)-(3{,}016029+1{,}007825)\}.931{,}49$ MeV

$= 4{,}03$ MeV

Routes to fusion



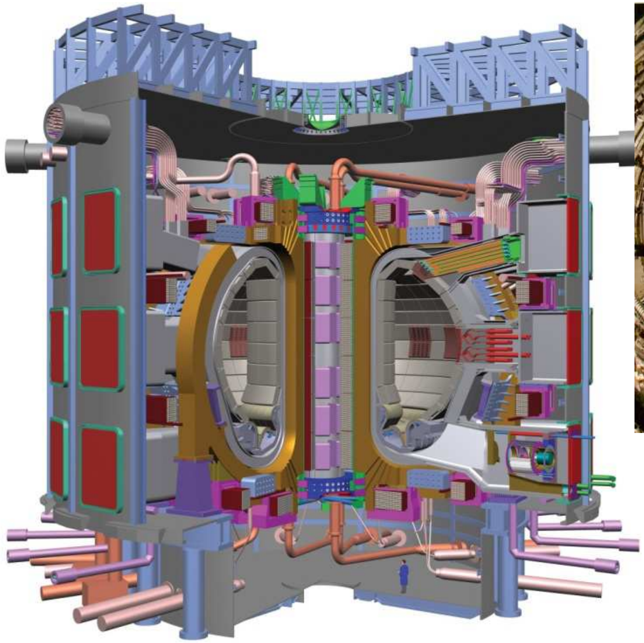
Laser beams compress and heat the target; after implosion, the explosion carries the energy towards the wall

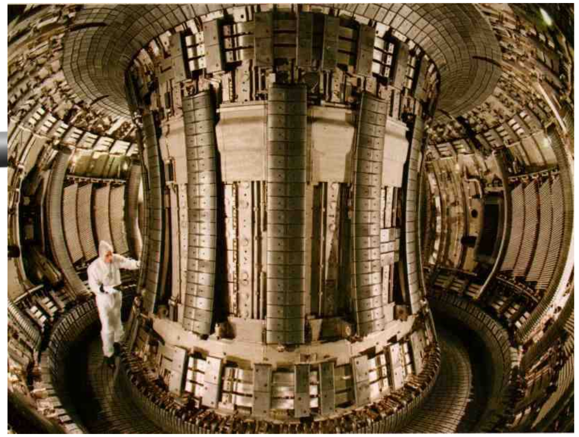


- Magnetic confinement in a torus (in this case a tokamak).
- The plasma is ring-shaped and is kept well away from the vessel wall.

Reaktor Reaktor Fusi

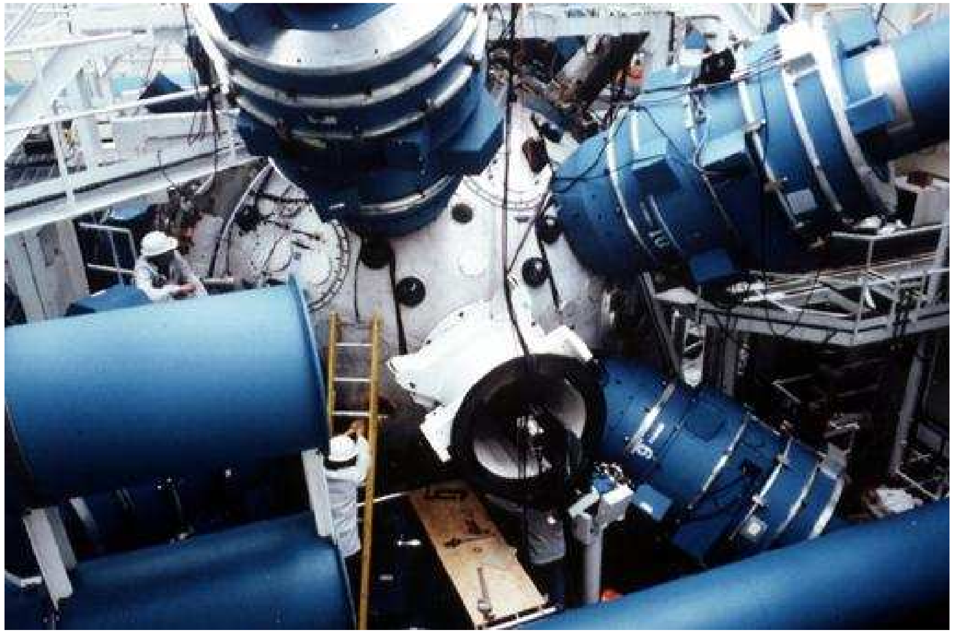
Proposed ITER fusion test reactor





Superconducting magnet form a Plasma confinement torus

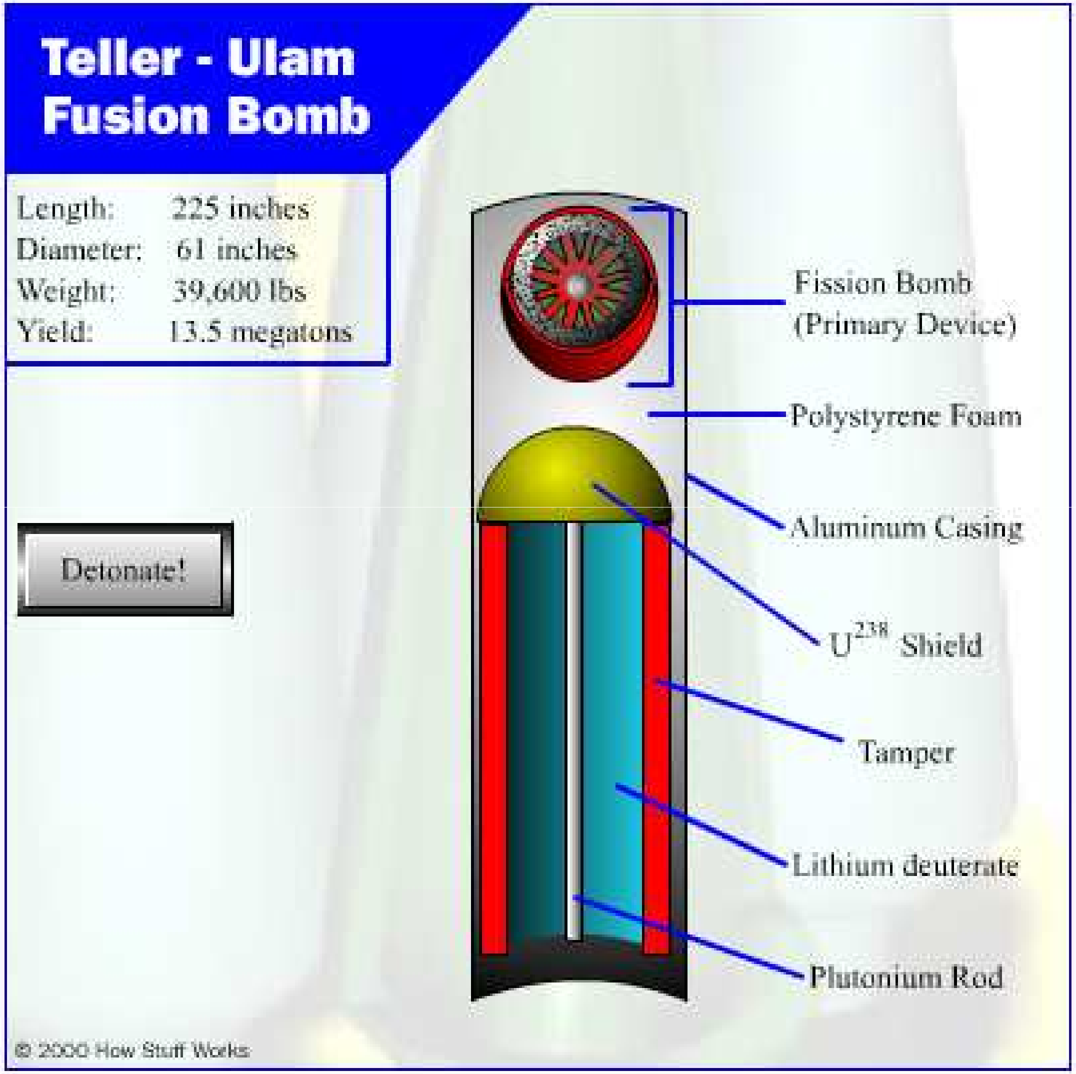
Nova



Fusion bombs

Fission bombs worked, but they weren't very efficient.

- Fusion bombs, have higher kiloton yields and efficiencies, But design complications
- Deuterium and tritium both gases, which are hard to store.
- Instead store lithium-deuterium compound which will fuse



Fission and Fusion

- Fission:
  - Heavy nucleus is broken apart
  - Total mass of pieces less than original nucleus
  - Missing mass appears as energy $E=mc^2$
  - Radioactive decay products left over

- Fusion
  - Light nuclei are fused together into heavier nuclei
  - Total mass of original nuclei greater than resulting nucleus
  - Missing mass appears as energy.

Reaktor Chernobyl Meledak

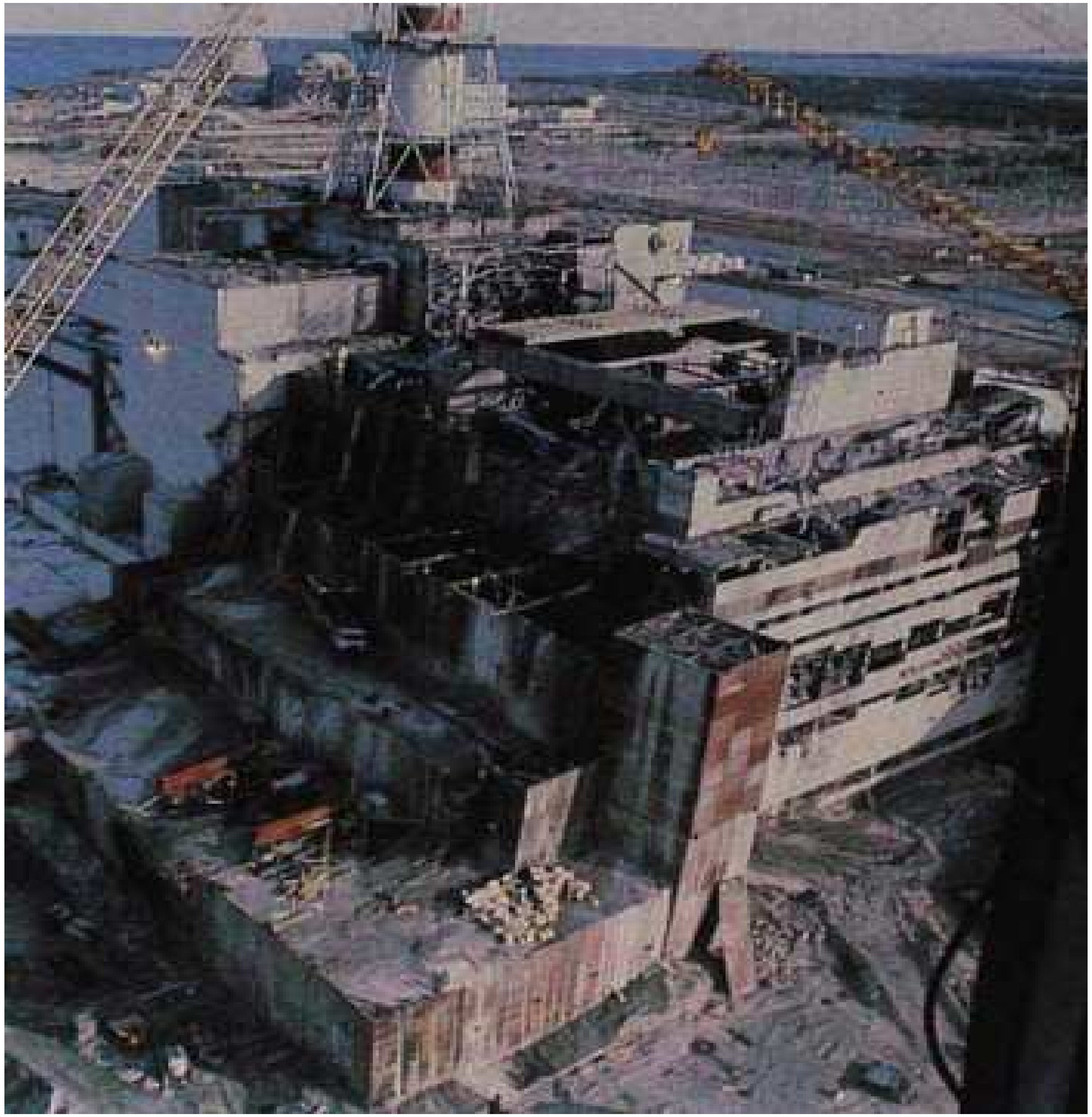
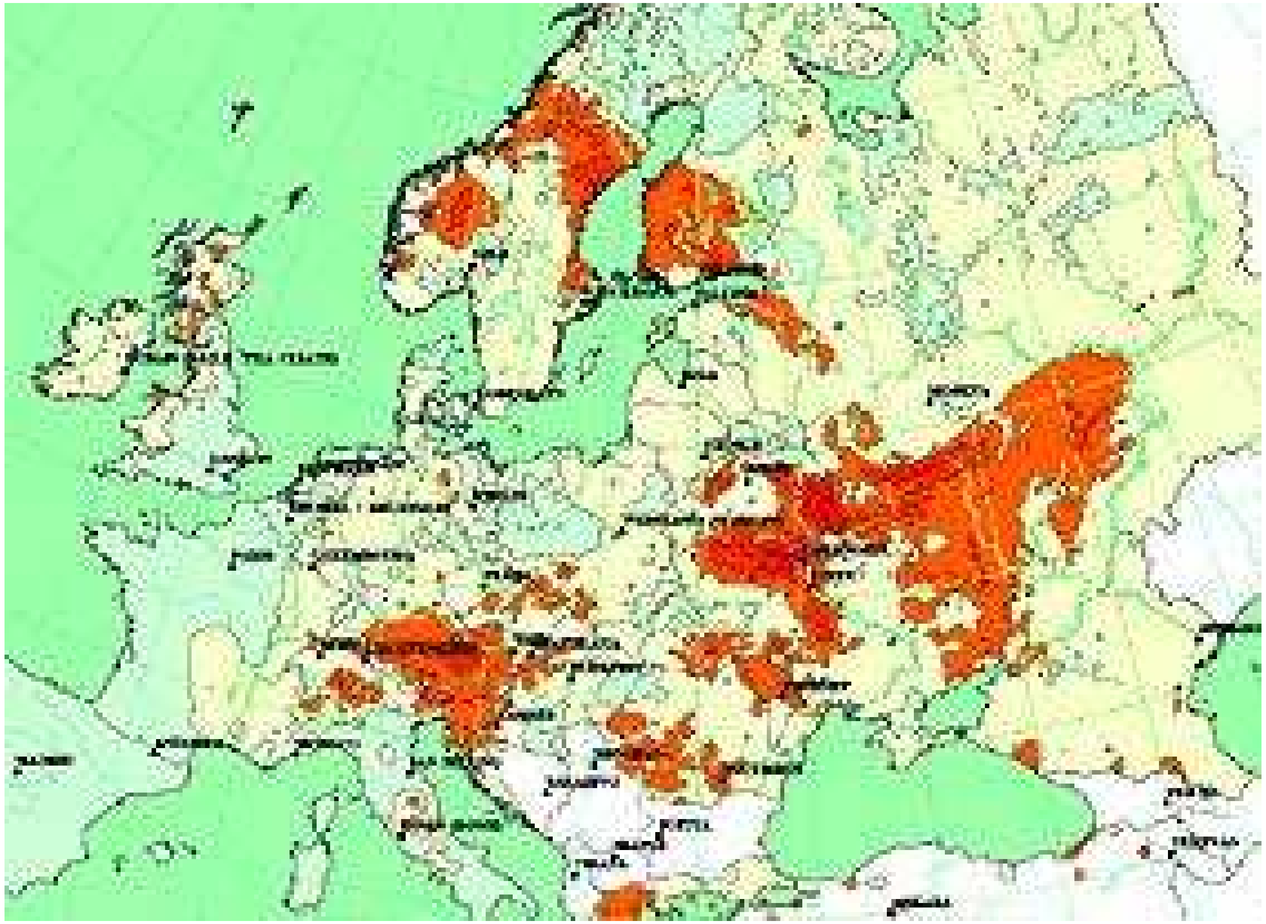


Figure 32
Radiation Hotspots Resulting From the Chornobyl' Nuclear Power Plant Accident, April 1986

400 juta orang terkena dampak radiasi di 20 negara



Penyebaran debu radioaktif dari Chernobiyl

8000 orang meninggal dalam14 tahun

Ekspresi masyarakat yang kena dampak radiasi

Three-Mile Island, PA 1979

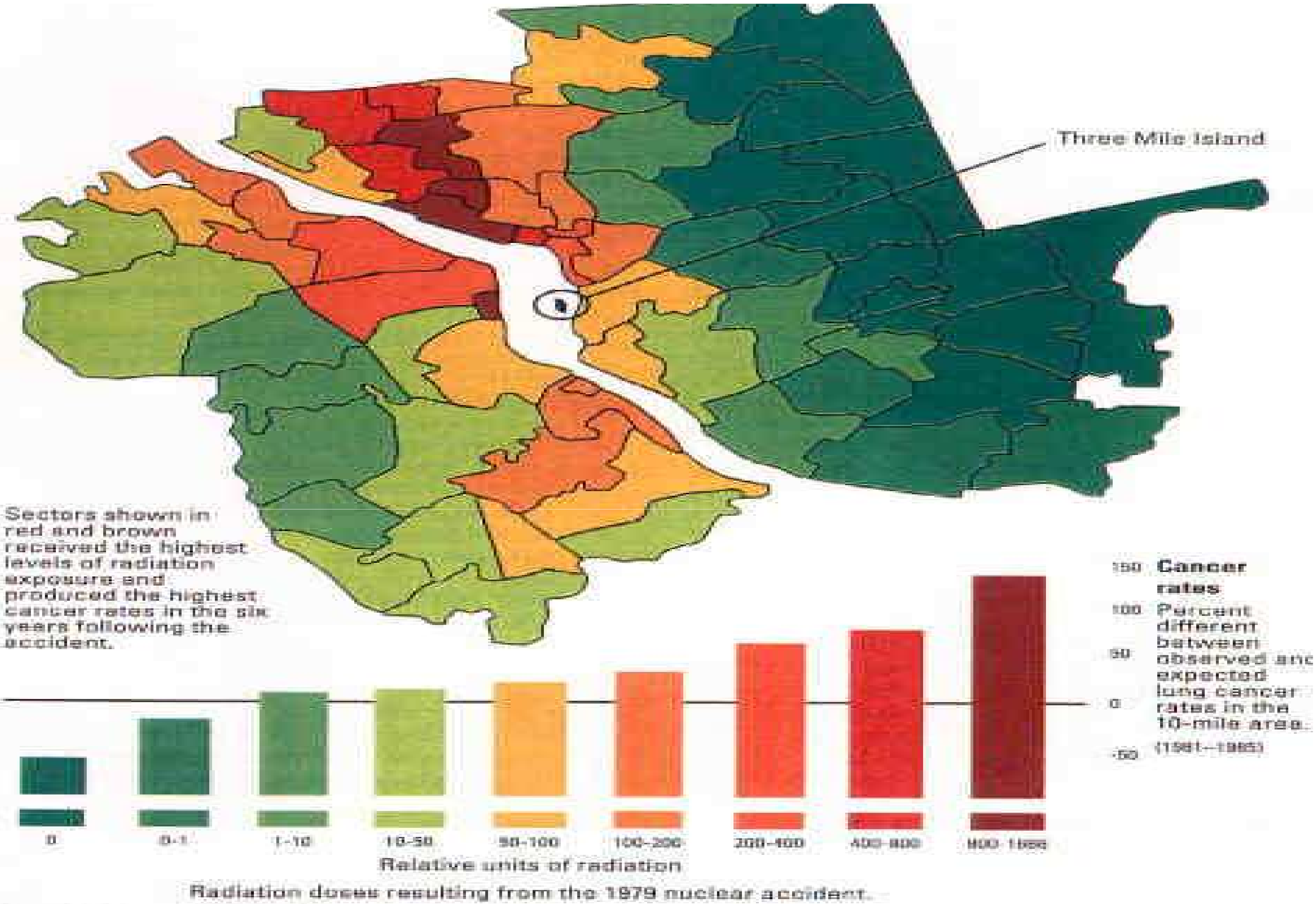
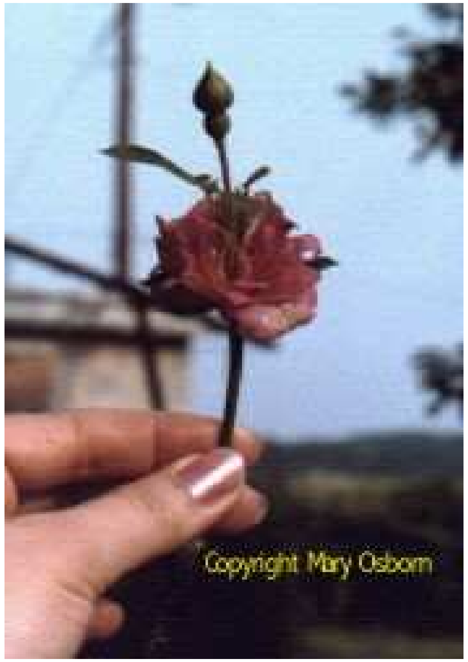


Figure 1. Three Mile Island postaccident lung cancer rates for 1981–1985 (adjusted for age, sex, and preaccident incidence) in relation to the estimated distribution of radioactive emissions from the accident. Reprinted with permission from *Endeavors* (5).

Credit: Julie Bryan

Plants near TMI



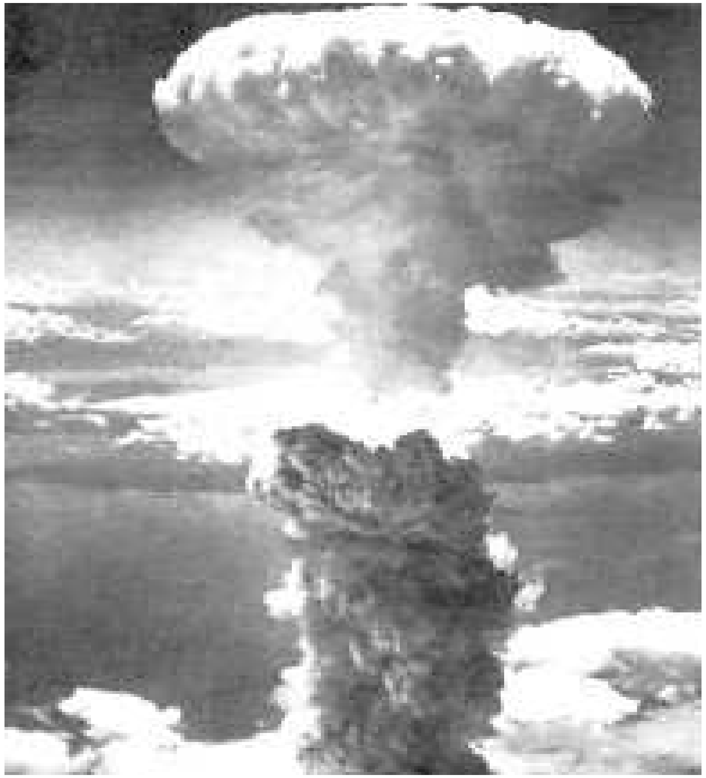
lack of chlorophyll
- deformed leaf patterns
- thick, flat, hollow stems
- missing reproductive parts
- abnormally large

TMI dandelion leaf at right

Animals Nearby TMI

Many insects disappeared for years.

- Bumble bees, carpenter bees, certain type caterpillars, or daddy-long-leg spiders
- Pheasants and hop toads have disappeared.



1938– Scientists study Uranium nucleus

1941 – Manhattan Project begins

1942 – Controlled nuclear chain reaction

1945 – U.S. uses two atomic bombs on Japan

1949 – Soviets develop atomic bomb

1952 – U.S. tests hydrogen bomb

1955 – First U.S. nuclear submarine

Peace” “Atoms for

Program to justify nuclear technology

Proposals for power, canal-building, exports

First commercial power plant, Illinois 1960

States with nuclear power plant(s)

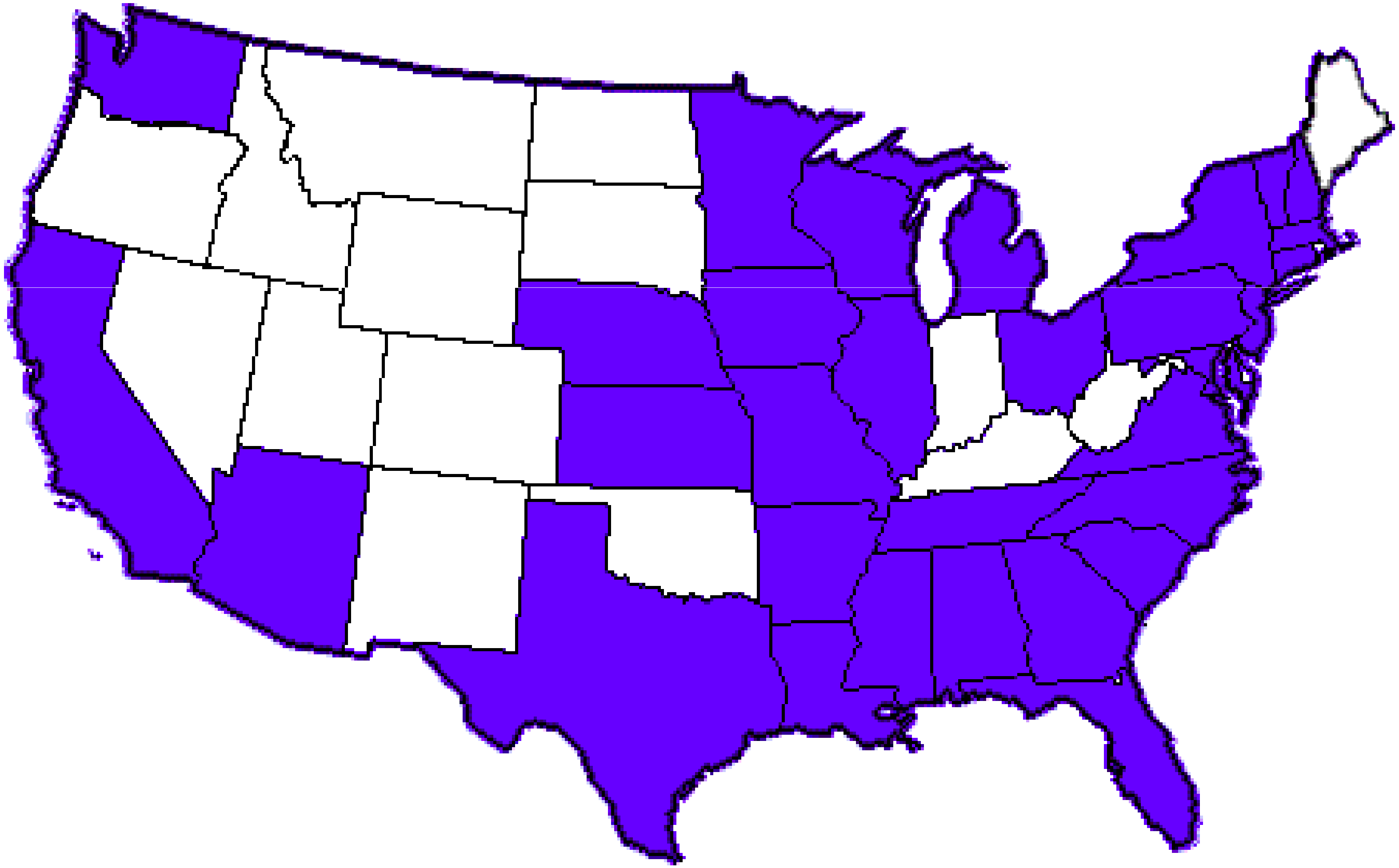
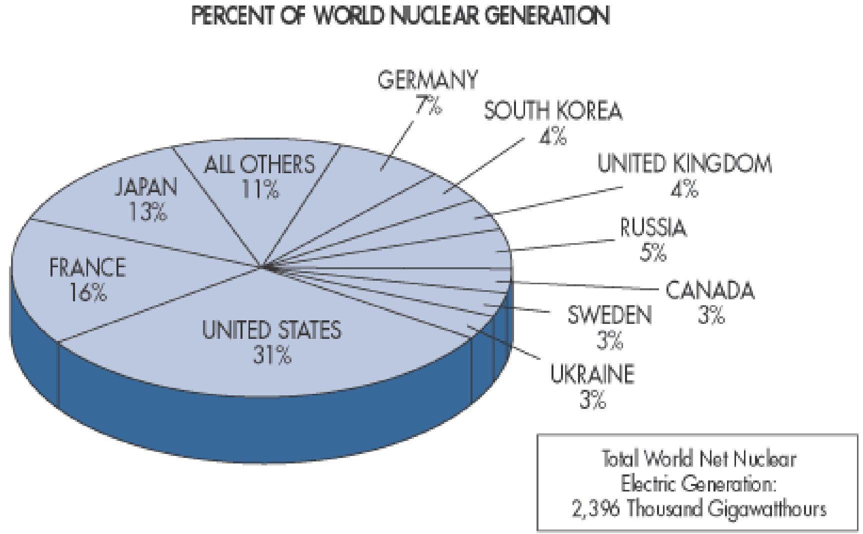
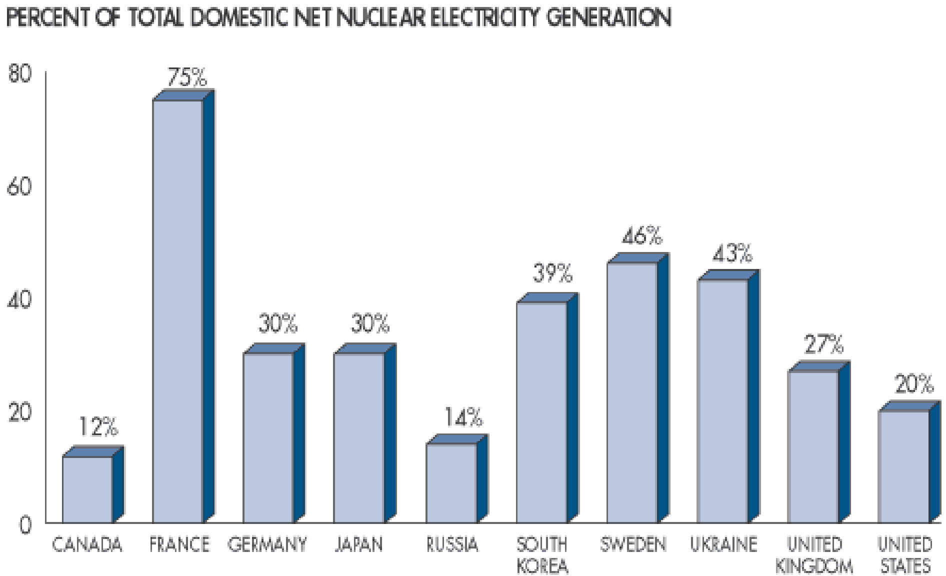


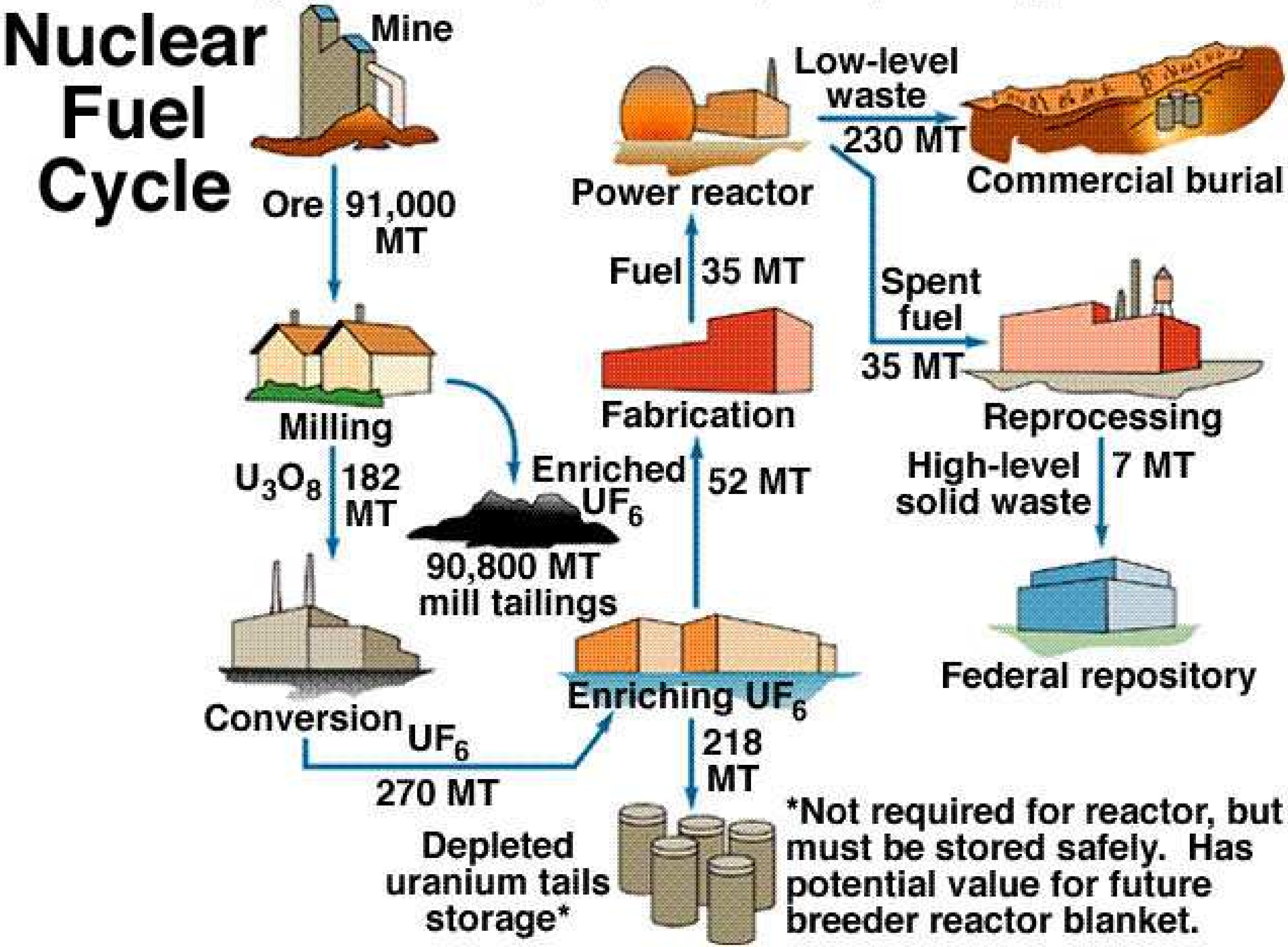
Figure 13. **Net Nuclear Electric Power as Percent of World Nuclear and Total Domestic Electricity Generation, 1999**



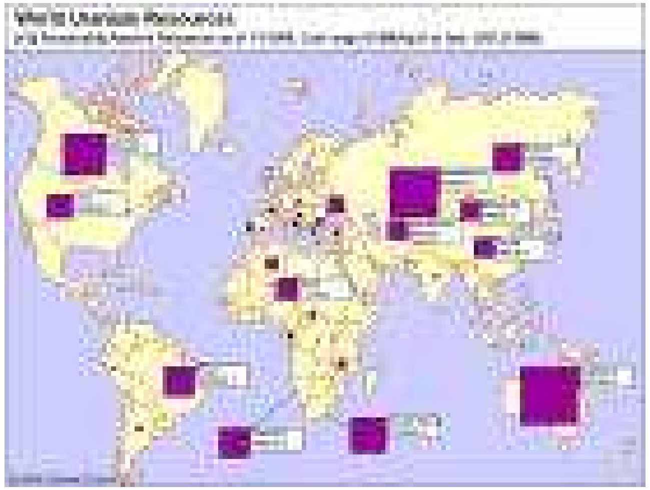


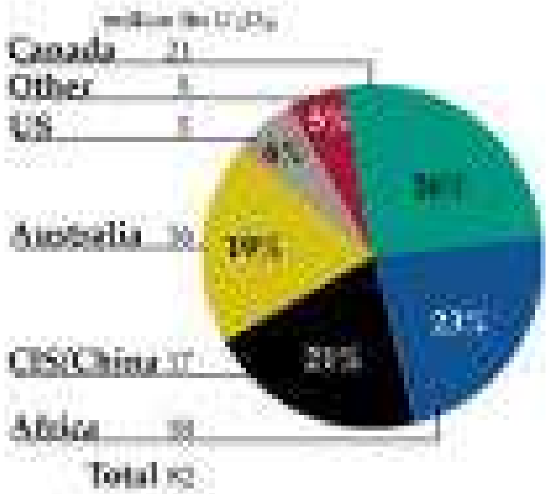
Note: Percentages are rounded to the nearest whole number.

Source: DOE/EIA International Energy Information, Tables 2.6, 2.7, 2.8, 6.1 <http://www.eia.doe.gov>.


Nuclear Fuel Cycle
Mine
Ore 91,000 MT
Milling
U_3O_8 182 MT
90,800 MT mill tailings
Conversion
UF_6
270 MT
Enriching UF_6
218 MT
Depleted uranium tails storage*
Enriched UF_6
52 MT
Fabrication
Fuel 35 MT
Power reactor
Low-level waste
230 MT
Commercial burial
Spent fuel
35 MT
Reprocessing
High-level solid waste
7 MT
Federal repository
*Not required for reactor, but must be stored safely. Has potential value for future breeder reactor blanket.

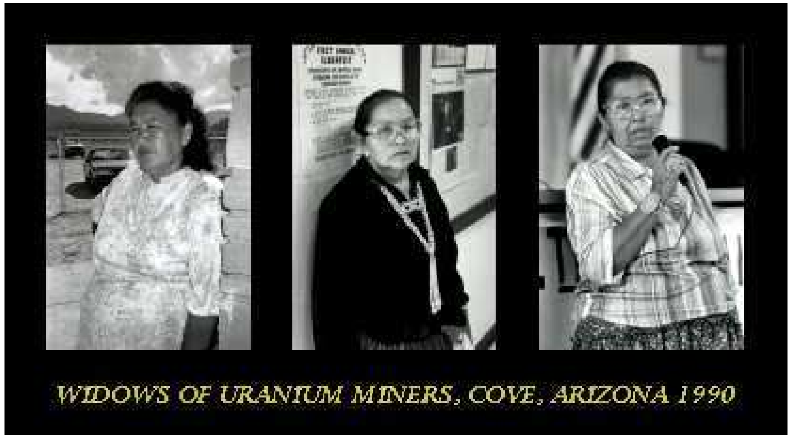
Front end:
Uranium mining and milling





Uranium tailings and radon gas

Deaths of Navajo miners since 1950s

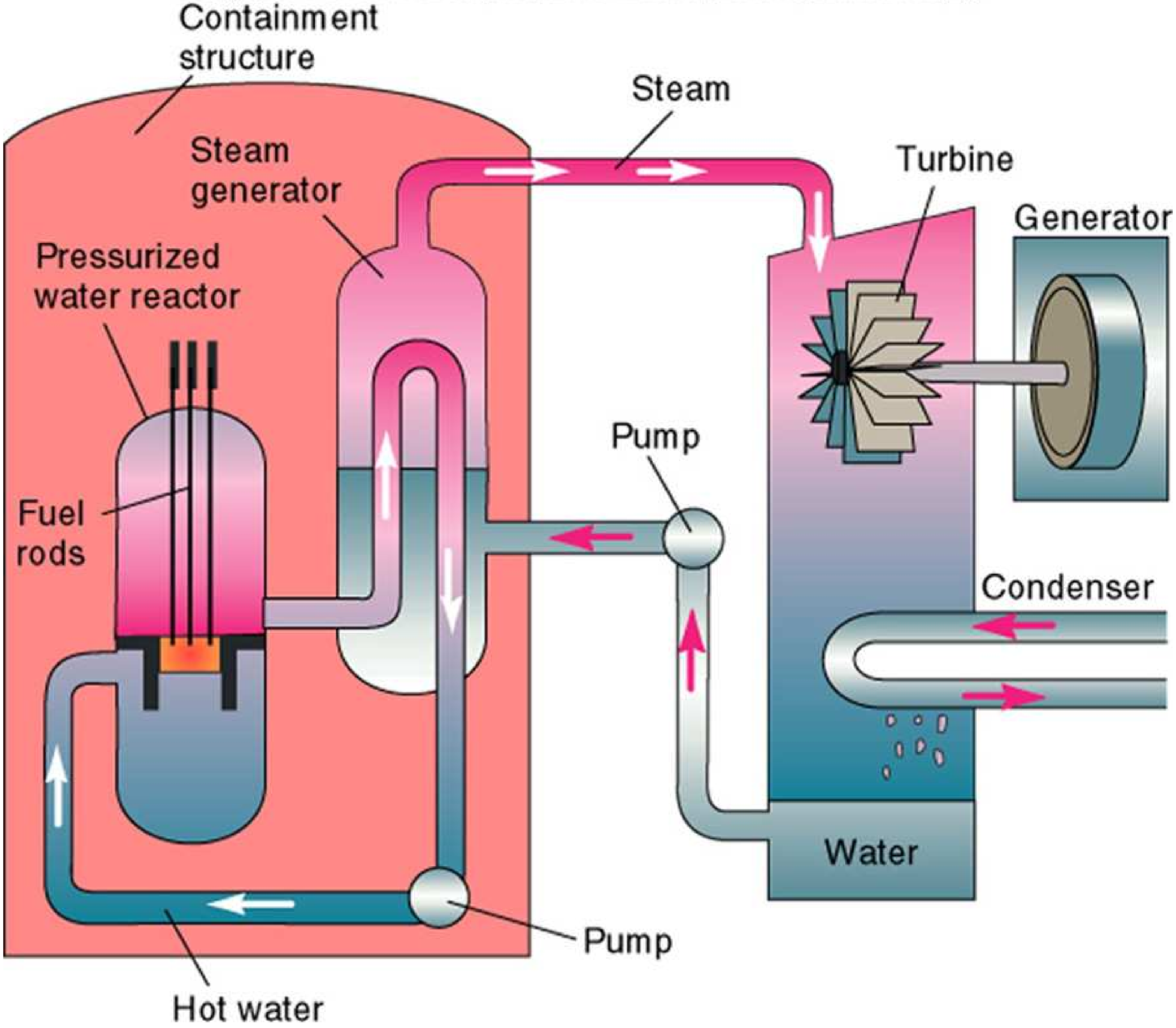


Radioactivity of plutonium

Life span of least
240,000 years

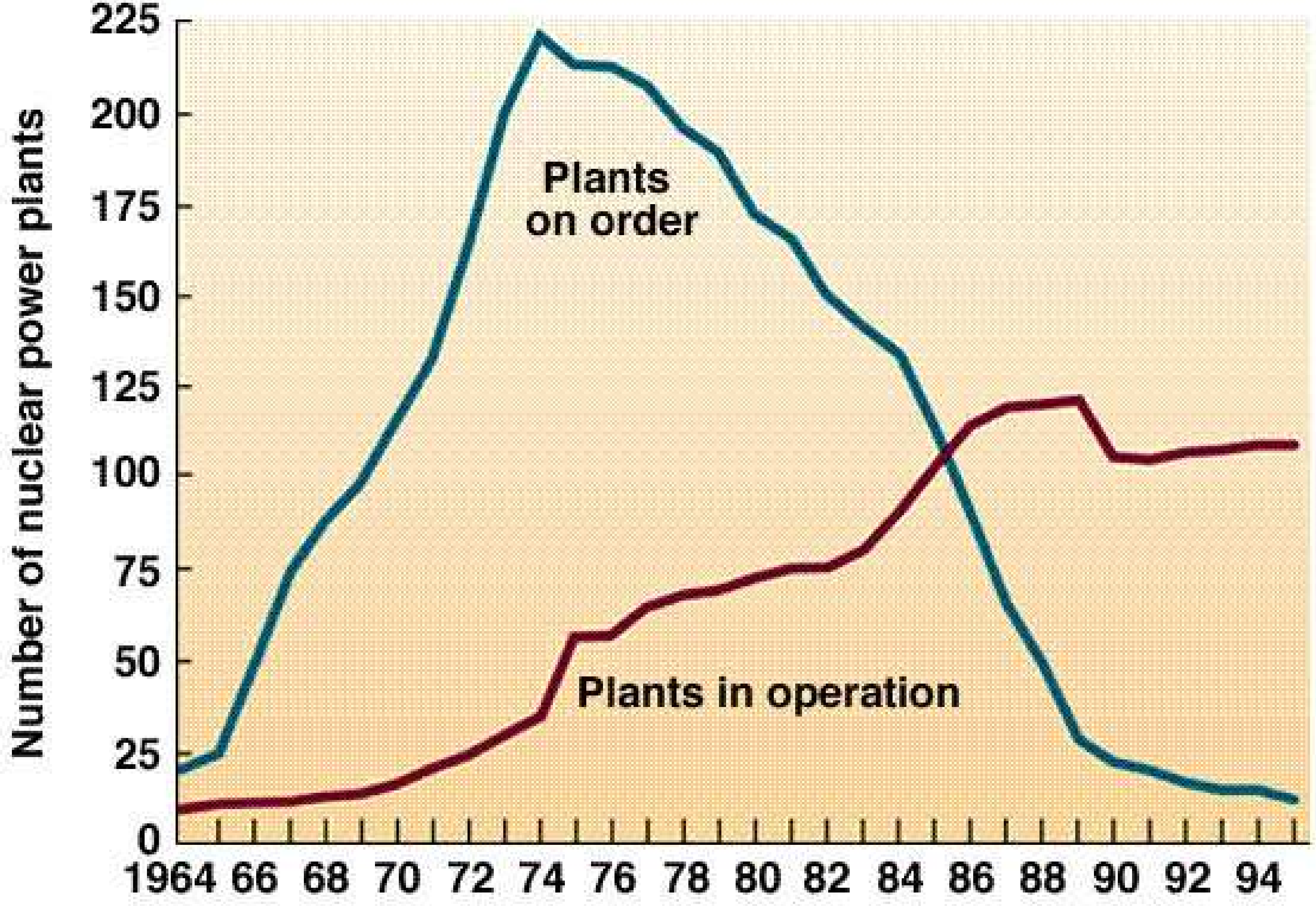
Last Ice Age glaciation
was 10,000 years ago

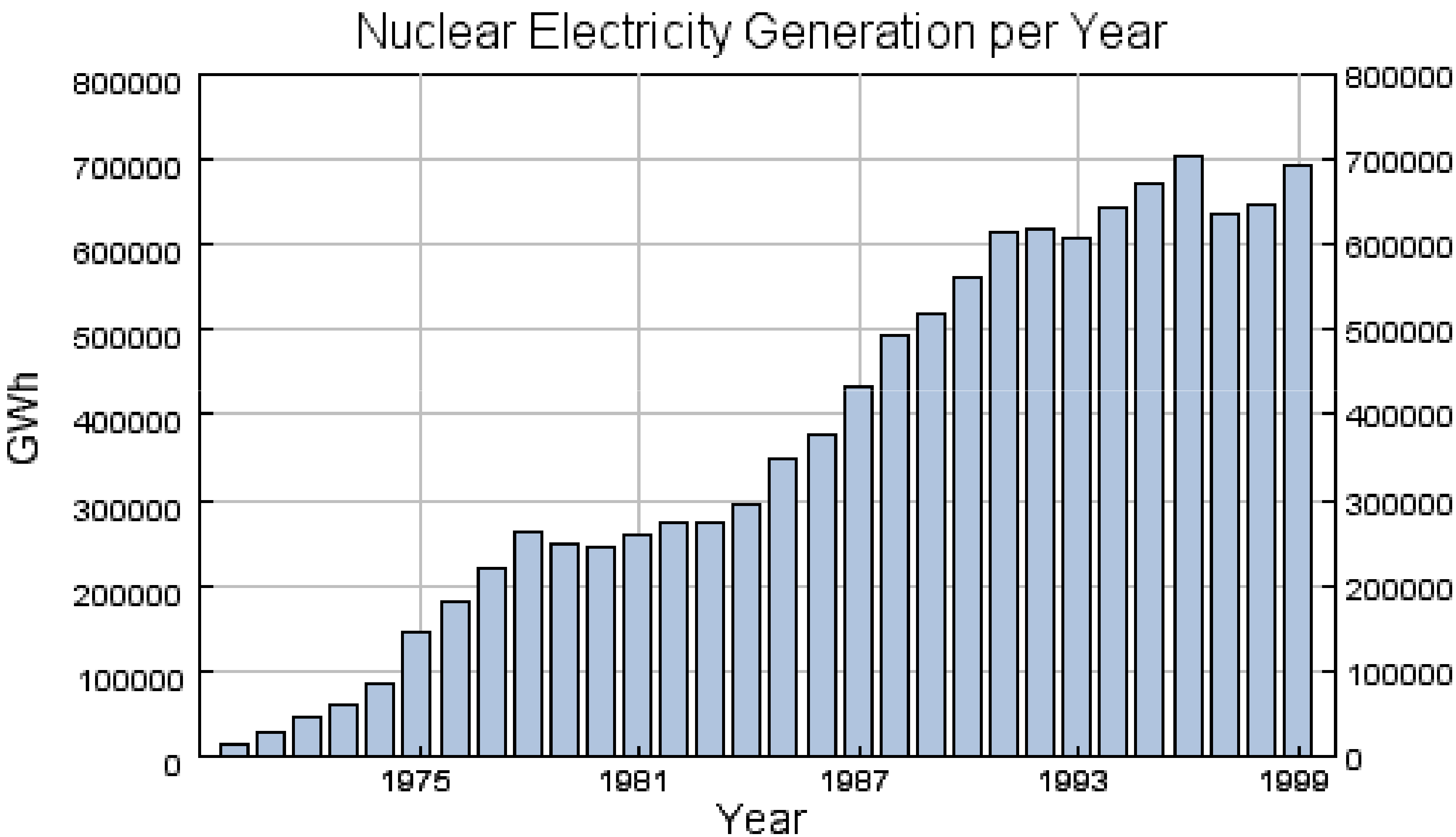
Neanderthal Man died out
30,000 years ago


Containment structure
Steam
Steam generator
Turbine
Generator
Pressurized water reactor
Pump
Fuel rods
Condenser
Water
Pump
Hot water

Technology depends on operators

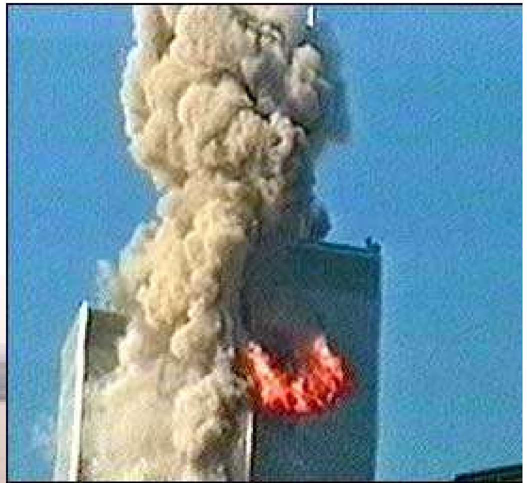
US Nuclear Power

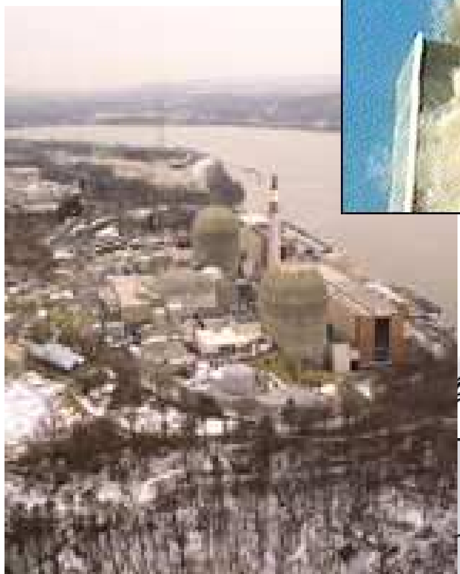


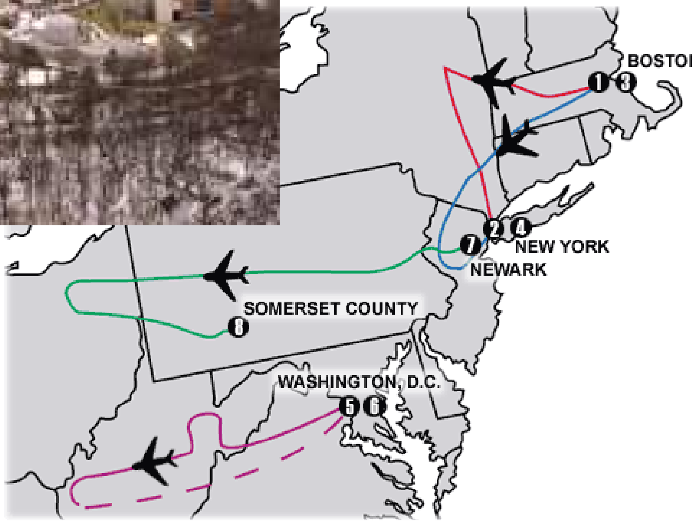


United States

Risk of terrorism
(new challenge to industry)

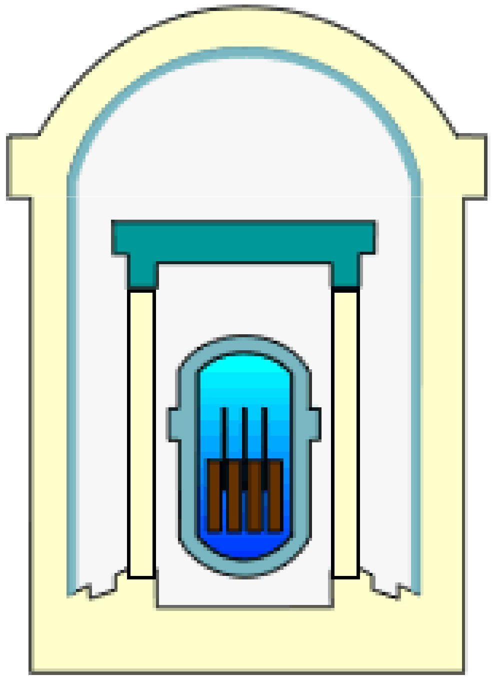




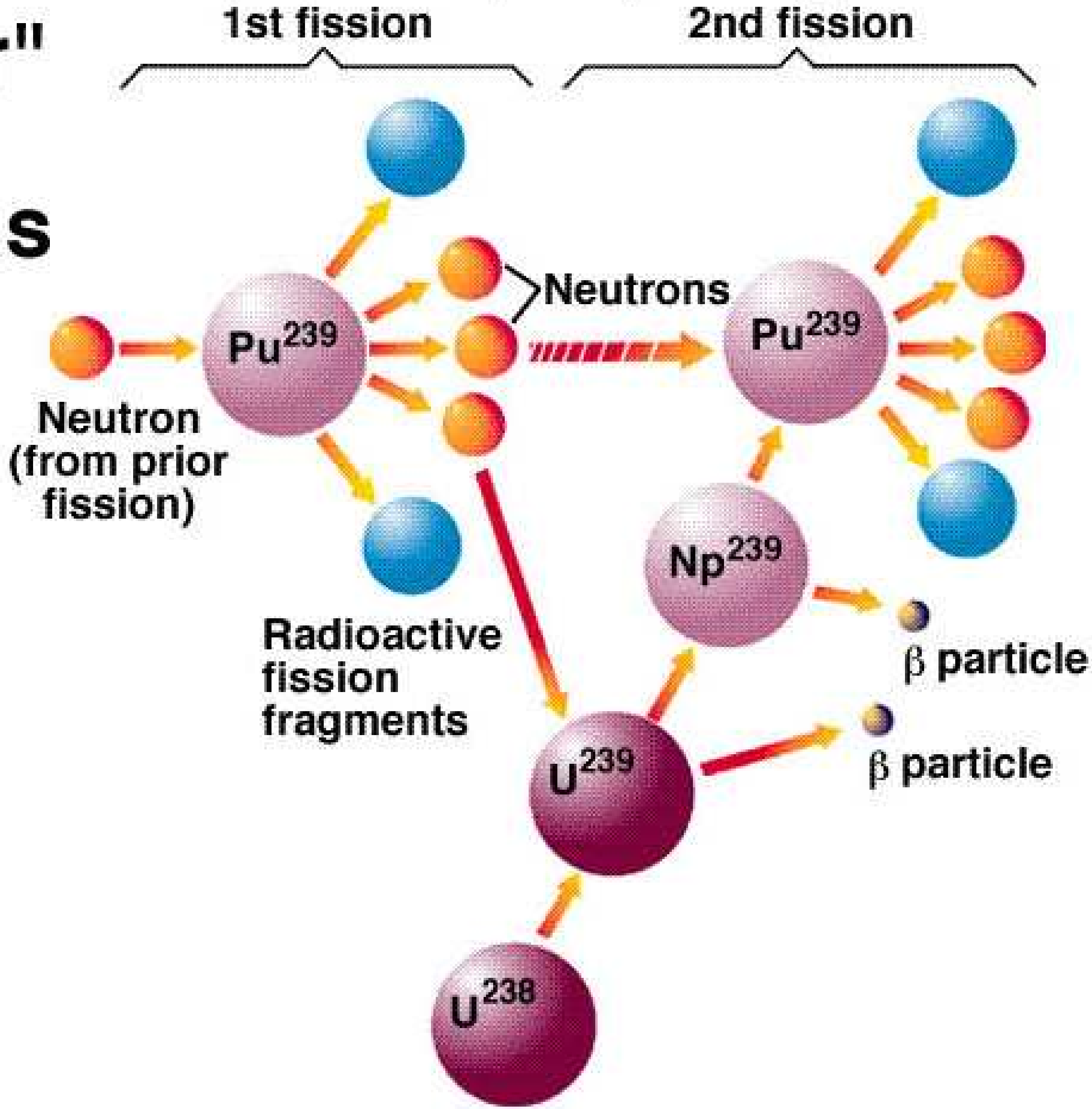


Nuclear Reactor Structure

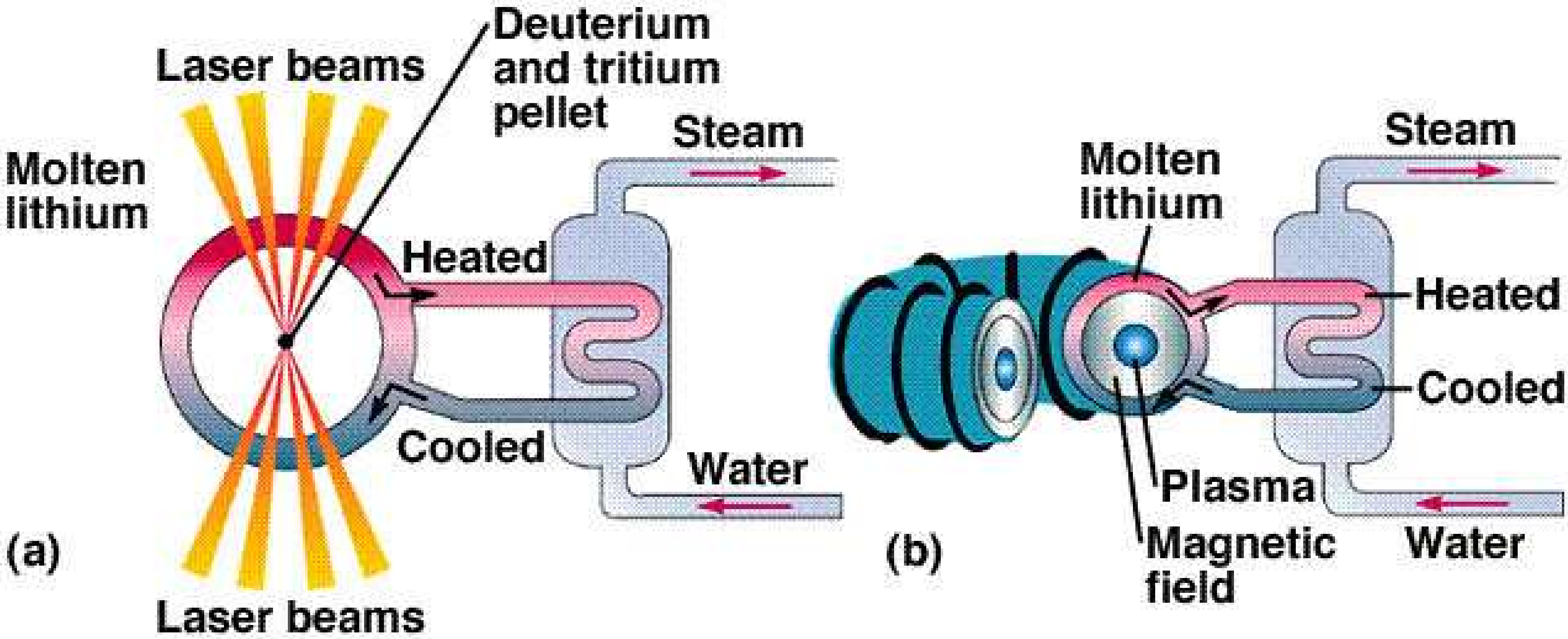
- Reactor's pressure vessel typically housed in 8" of steel
- 36" concrete shielding
- 45" steel reinforced concrete



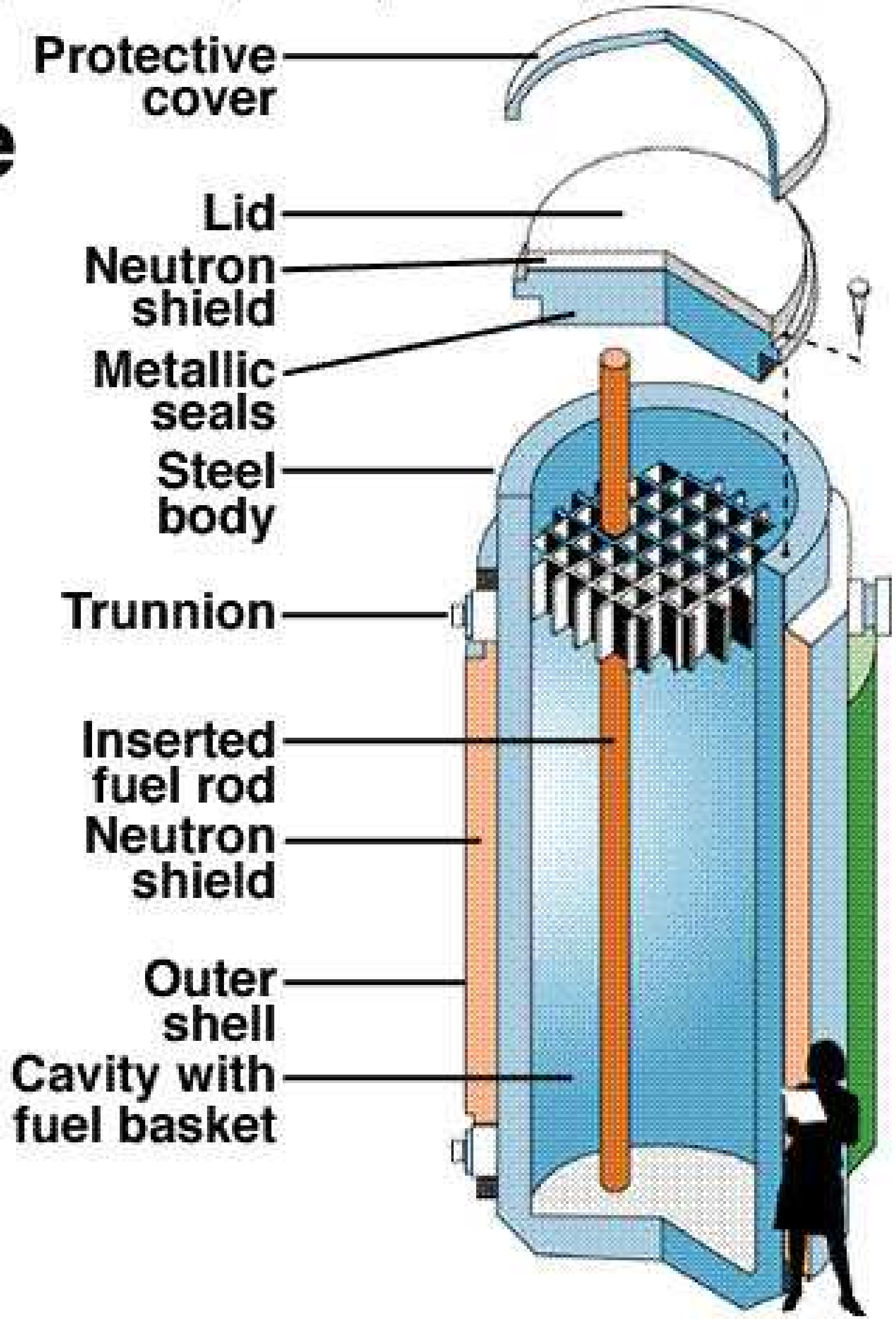
"Breeder" Fission Reactions



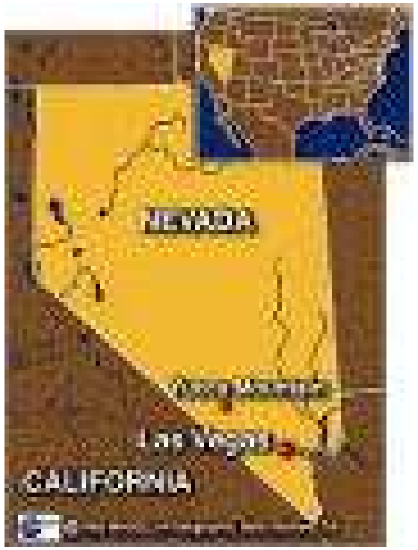
Nuclear Fusion Devices

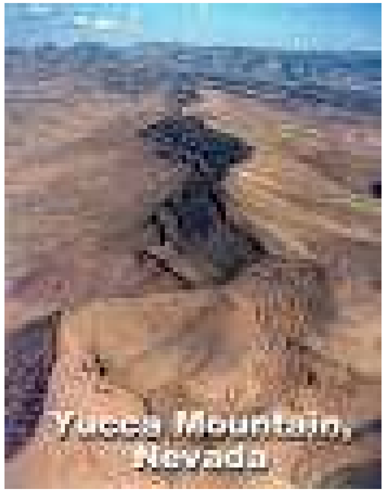


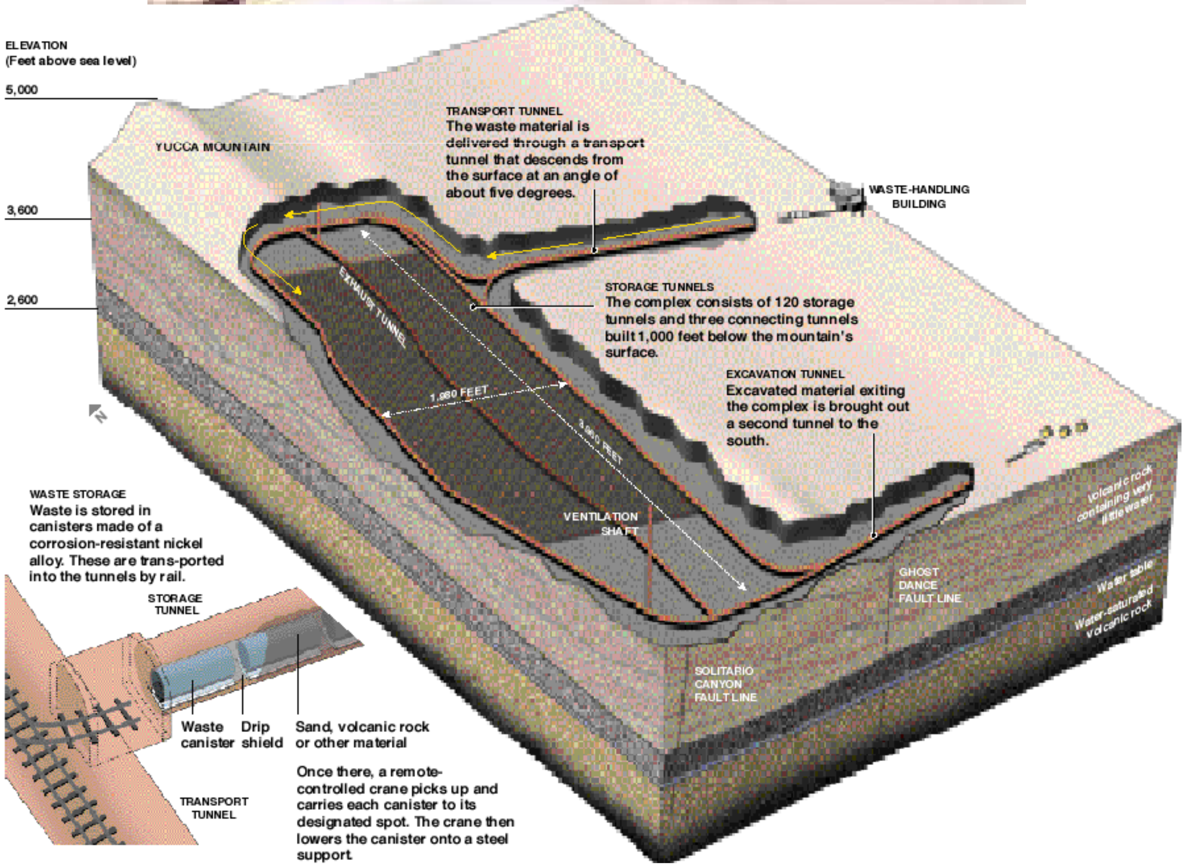
Dry Cask Storage



Yucca Mountain





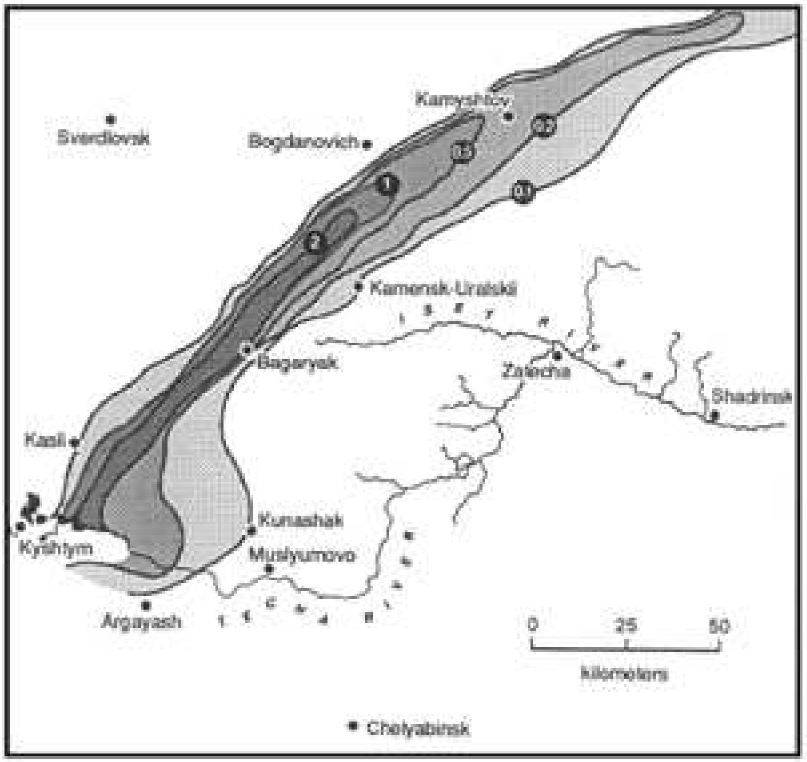


Transportation risks

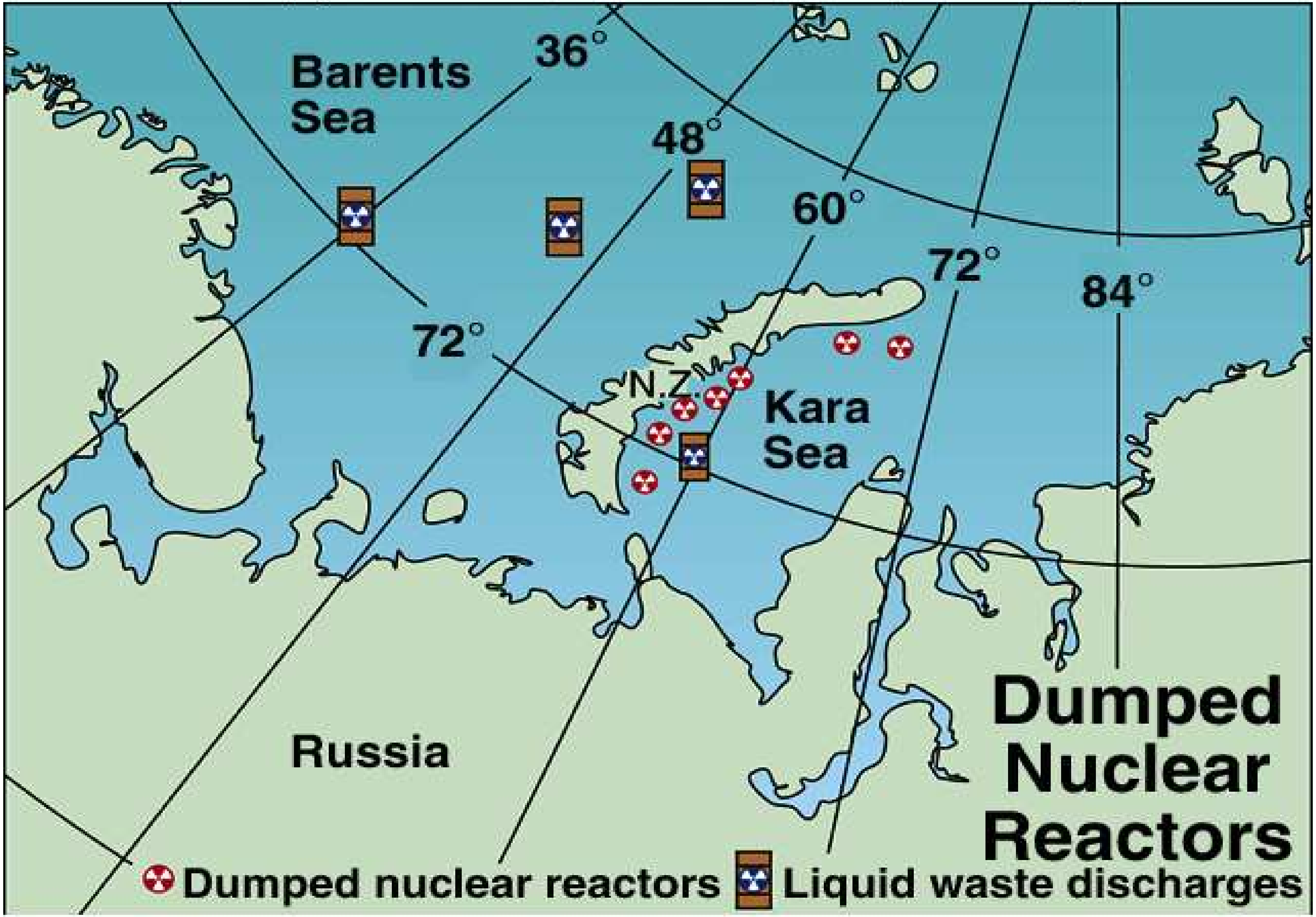
- Fuel rod spills (WI 1981)
- Uranium oxide spills
- Radioactive waste risks

“Mobile Chernobyl” to Yucca Mtn.

Kyshtym waste disaster, 1957



- Explosion at Soviet weapons factory forces evacuation of over 10,000 people in Ural Mts.
- Area size of Rhode Island still uninhabited; thousands of cancers reported


Barents Sea
36°
48°
60°
72°
84°
72°
N.Z.
Kara Sea
Russia
Dumped Nuclear Reactors
Dumped nuclear reactors
Liquid waste discharges