Ion Implantation Laboratory

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Radiation, Contamination and Boiling Water Reactors

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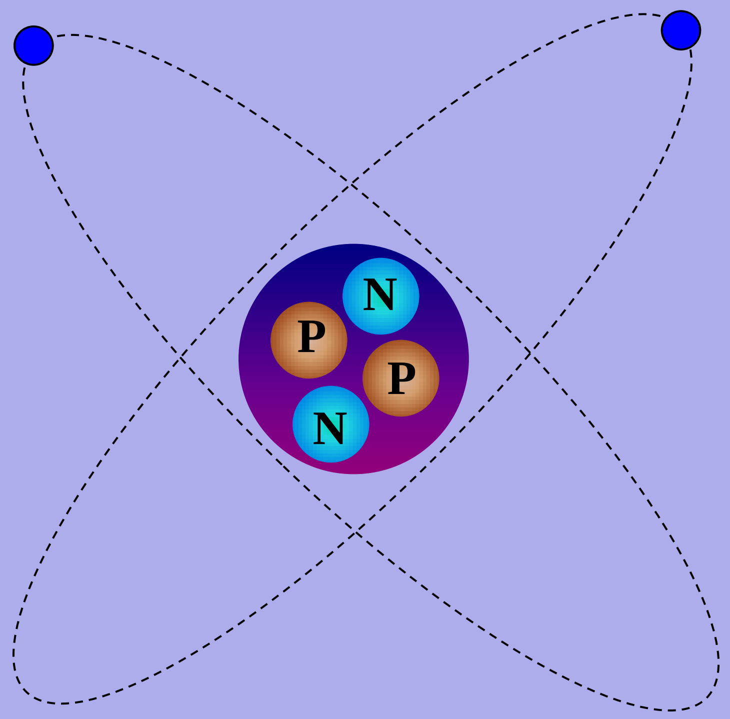
Atomic Model

⇒ N. Bohr (1913): quantization

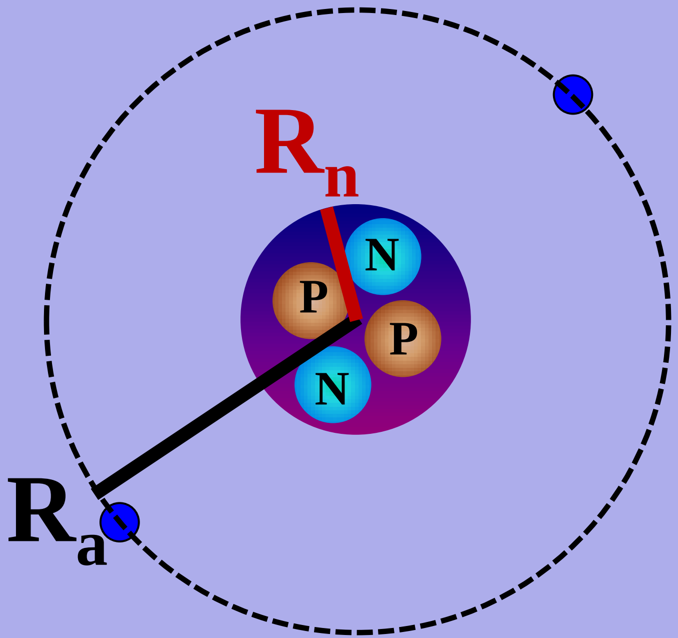
⇒ J. Chadwick (1932): neutron



Helium Atom (He)

- 2 protons (Z=2)
- 2 neutrons (N=2)
- A = Z + N = 4
- 2 electrons

Atomic Radius R_a & Nuclear Radius R_n

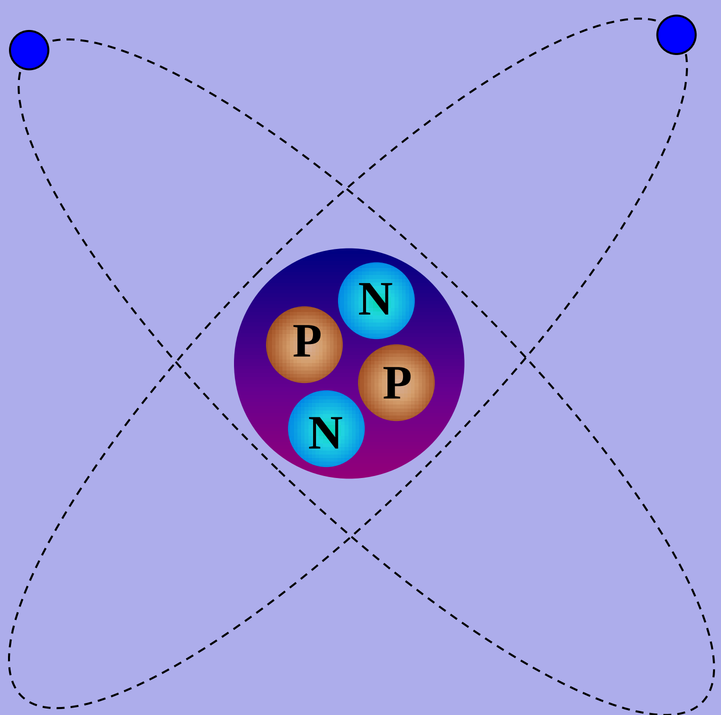


$R_a \approx 10000\ R_n$

Free-Way

School Bus

He Atom
& α particle



A=4

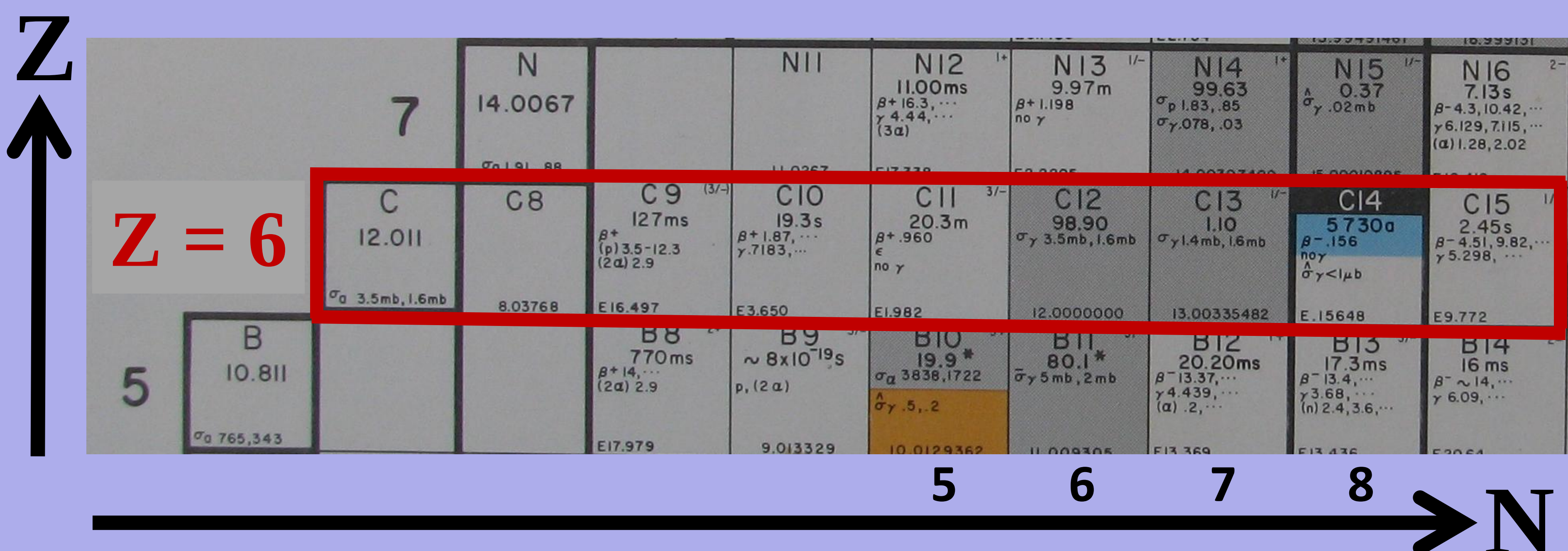
He

Z=2 N=2

Isotope

- Same element (same Z)
- Different N's

  ⇒ Carbon (Z = 6)



Radioactive Decay

Nucleus
Ground State

Stable
(Energetic Balance)

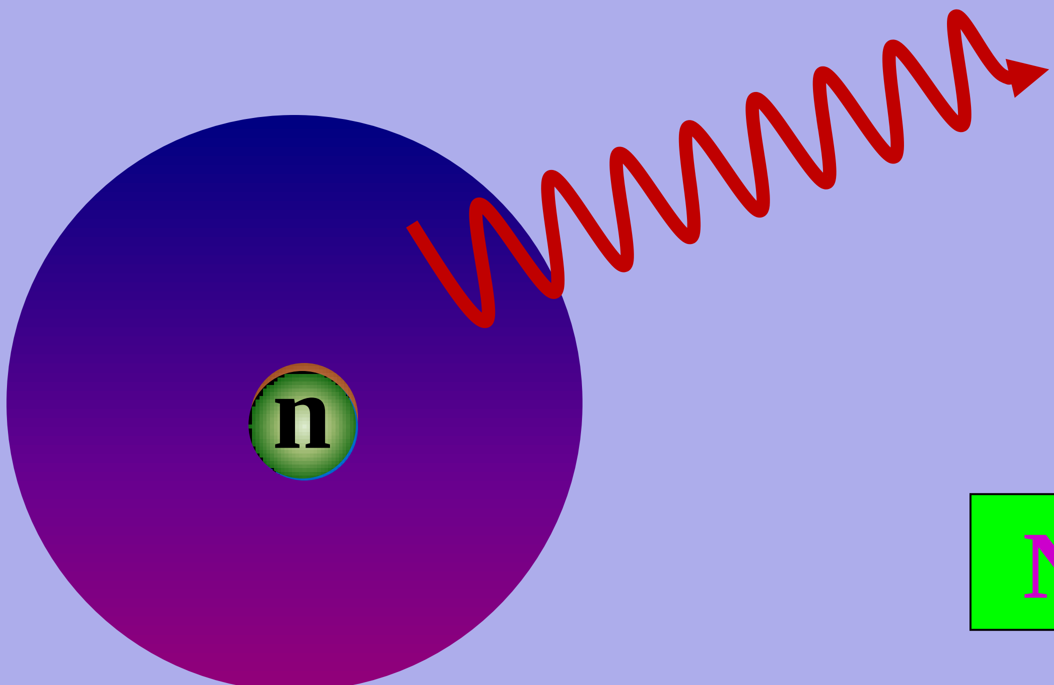
No Changes
(does not decay)

Nucleus
Excited States

Unstable
(Excess of Energy)

Energy Release
(does decay)

Decay



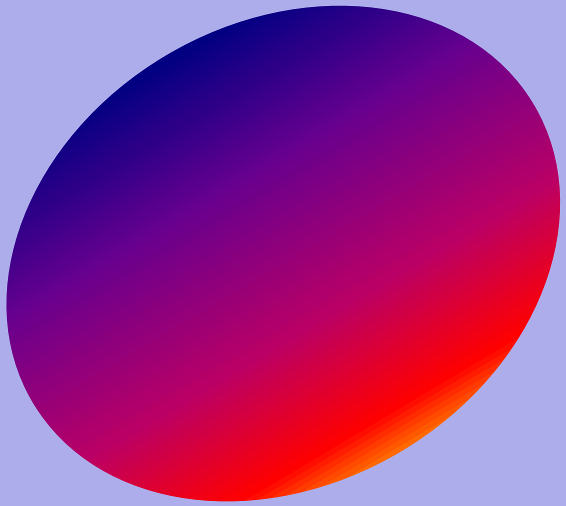
γ Rays

α Particles

Neutrinos ν, $\bar{\nu}$

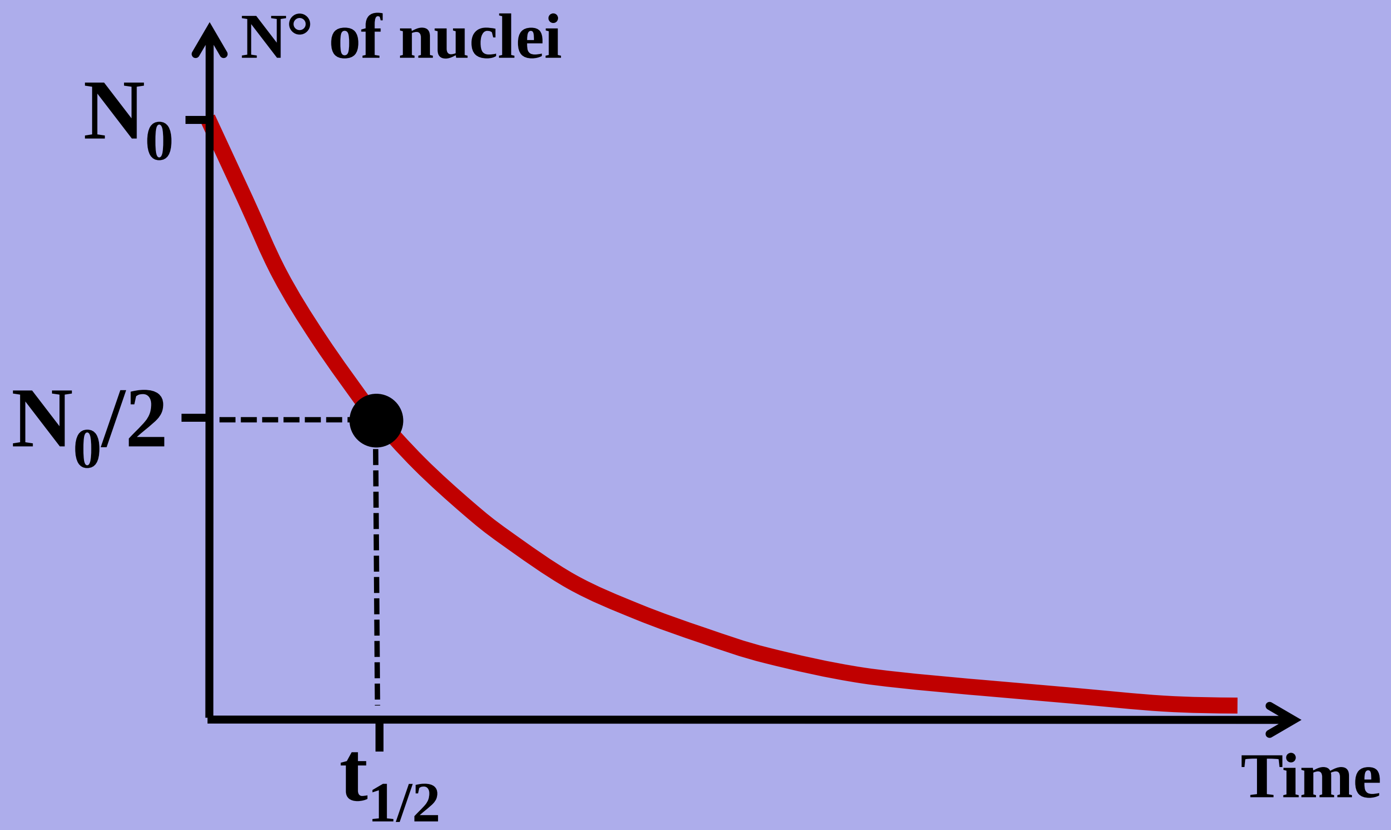
Neutrons

Spontaneous Fission



Half-life $t_{1/2}$

- Time required for half of the nuclei from a sample to decay



Activity

- **Curie**

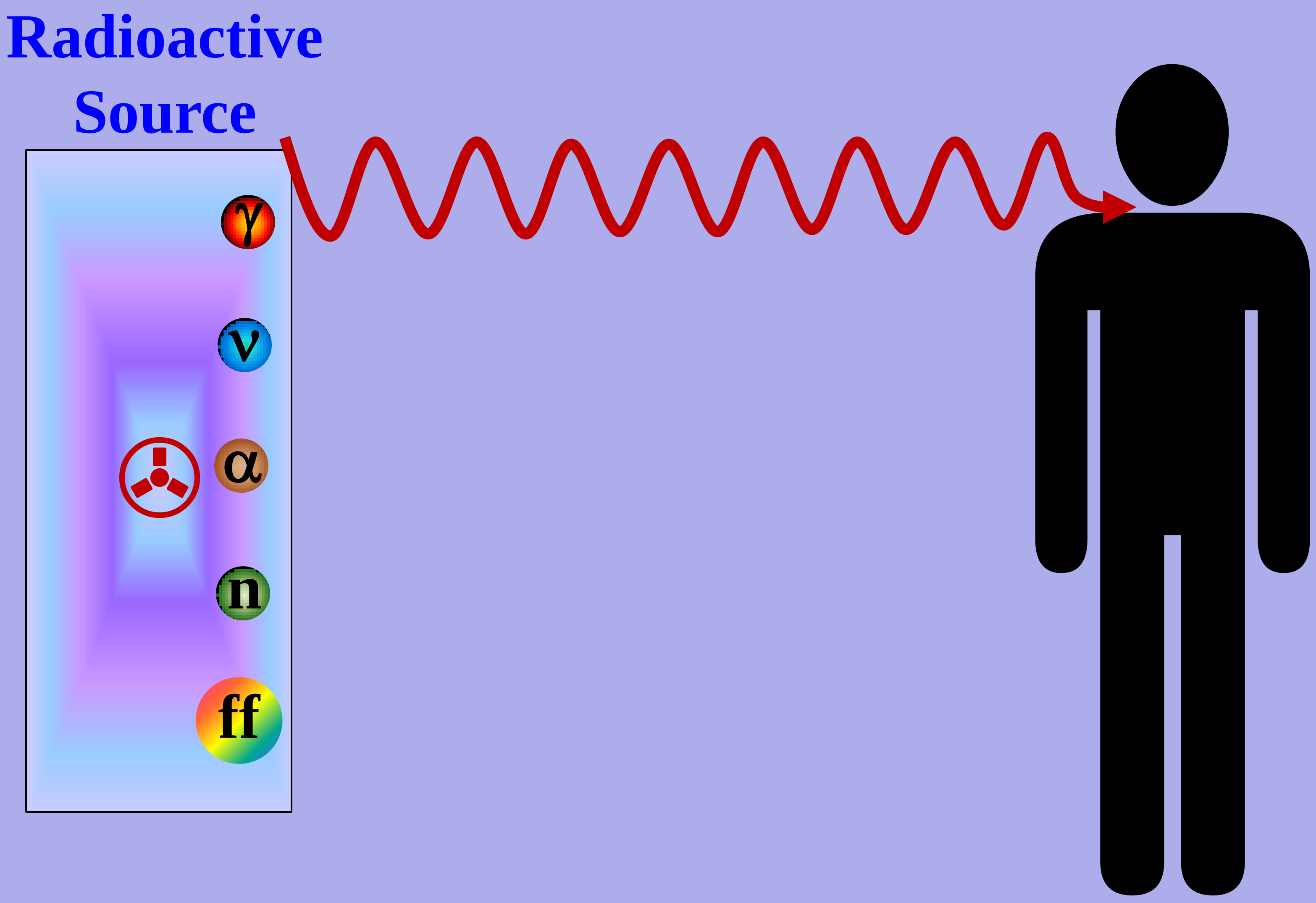
$$1Ci = \frac{3,7 \times 10^{10} \, des.}{1s}$$

Equivalent Dose

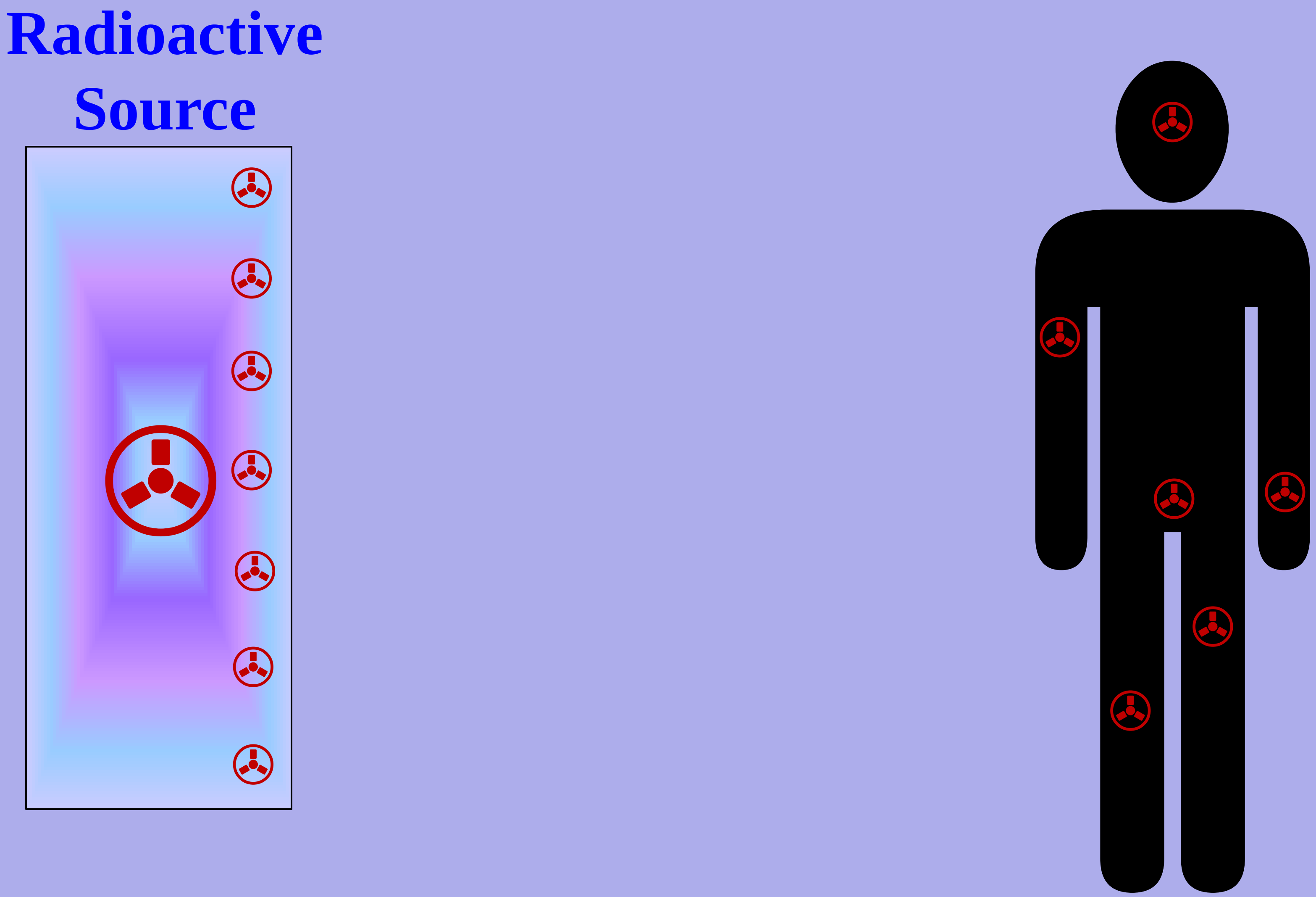
- **Sievert (biological tissues)**

$$1Sv = \frac{1Joule}{1kg}$$

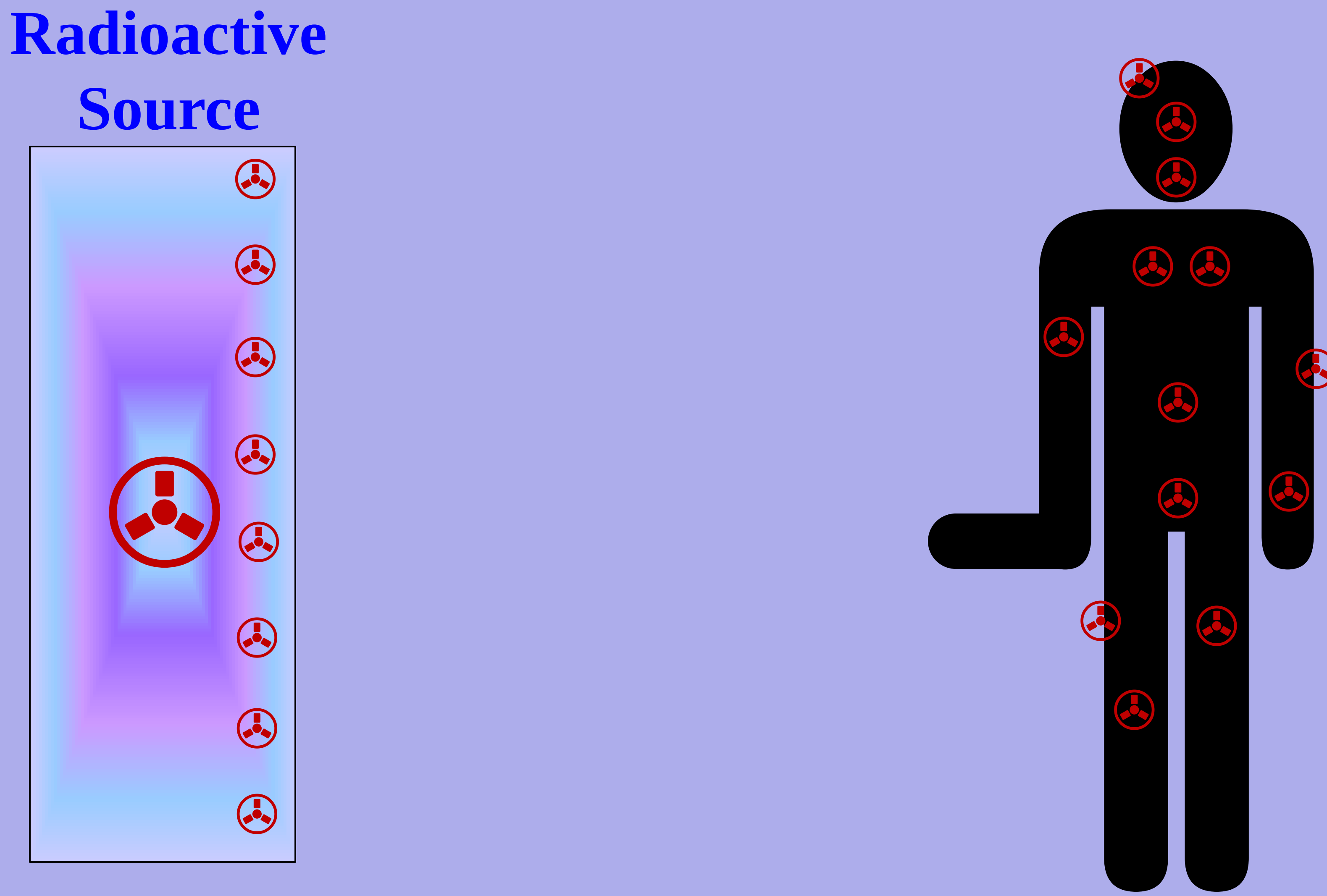
Exposure



Contamination - Air



Contamination - Contact



Radiation Damage

- Cell
  - ⇒ Cromossomes, DNA
- Complex systems
  - ⇒ Bone tissues, organs
- Simptoms
  - ⇒ Vomit, diarrhea, skin burns
  - ⇒ Hair loss, infections, hemorrhage, fatigue
- Tumor, Cancer
- Death

Nuclear Power

Fuel: Uranium

"Stable" Isotopes: ^{234}U (0.0054%)
^{235}U (0.7204%)
^{238}U (99.2742%)

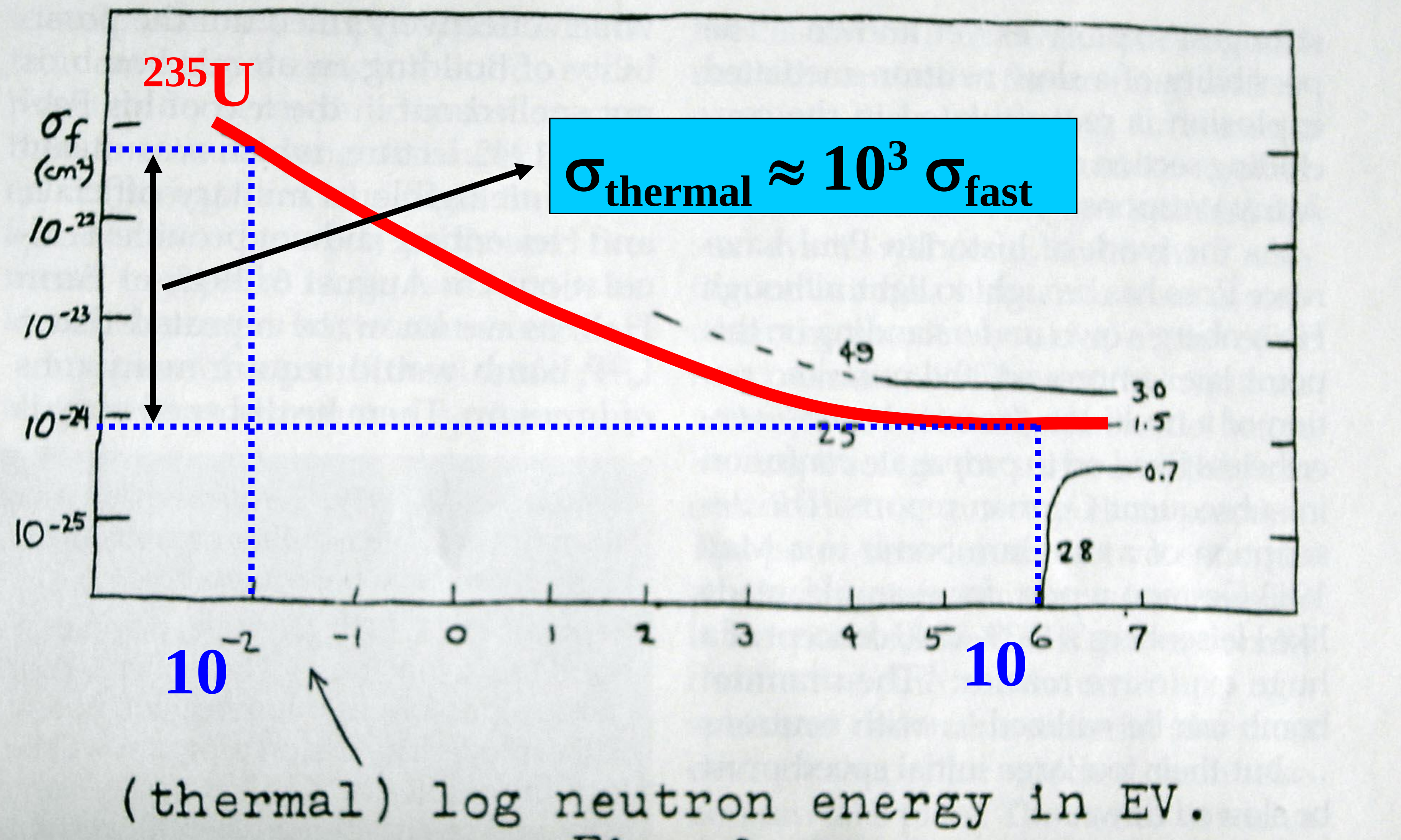
$$^{235}U + n \rightarrow {}^{236}U^* \rightarrow {}^{92}Kr + {}^{142}Ba + n + n$$

Thermal
$\approx 2\times10^{-2}$ eV

Fast
$\approx 2\times10^{6}$ eV

$E_{released} \approx 2\times10^{8}$ eV ☺

Neutron-Induced Fission Reaction



235U
σthermal ≈ 10³ σfast
σf
(cm²)
10-22
10-23
10-24
10-25
49
3.0
1.5
25
0.7
28
-2
-1
0
1
2
3
4
5
6
7
10
10
(thermal) log neutron energy in EV.

Fig. 1

Moderator

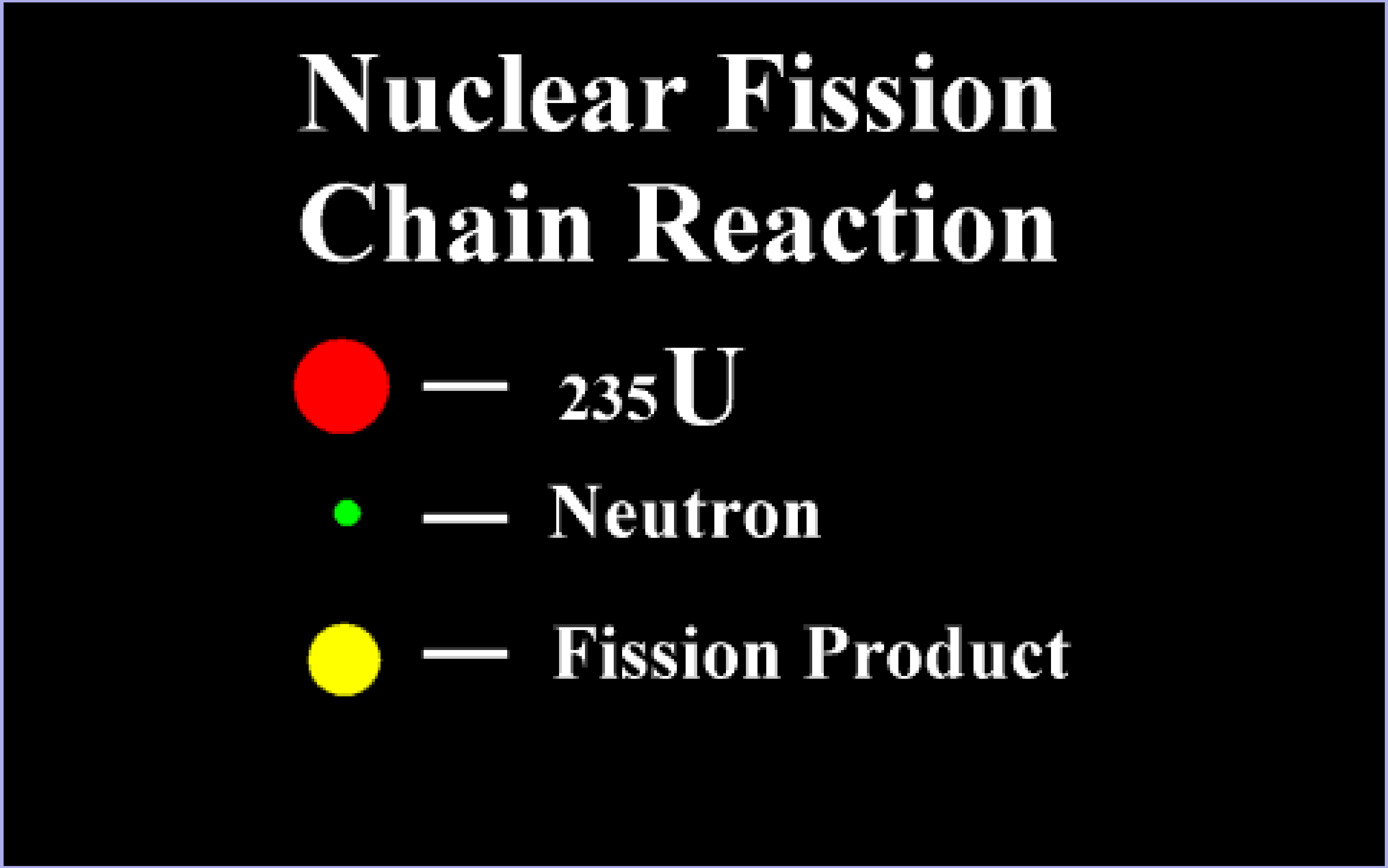
Fast Neutrons
$\approx 2\times10^{6}$ eV

→

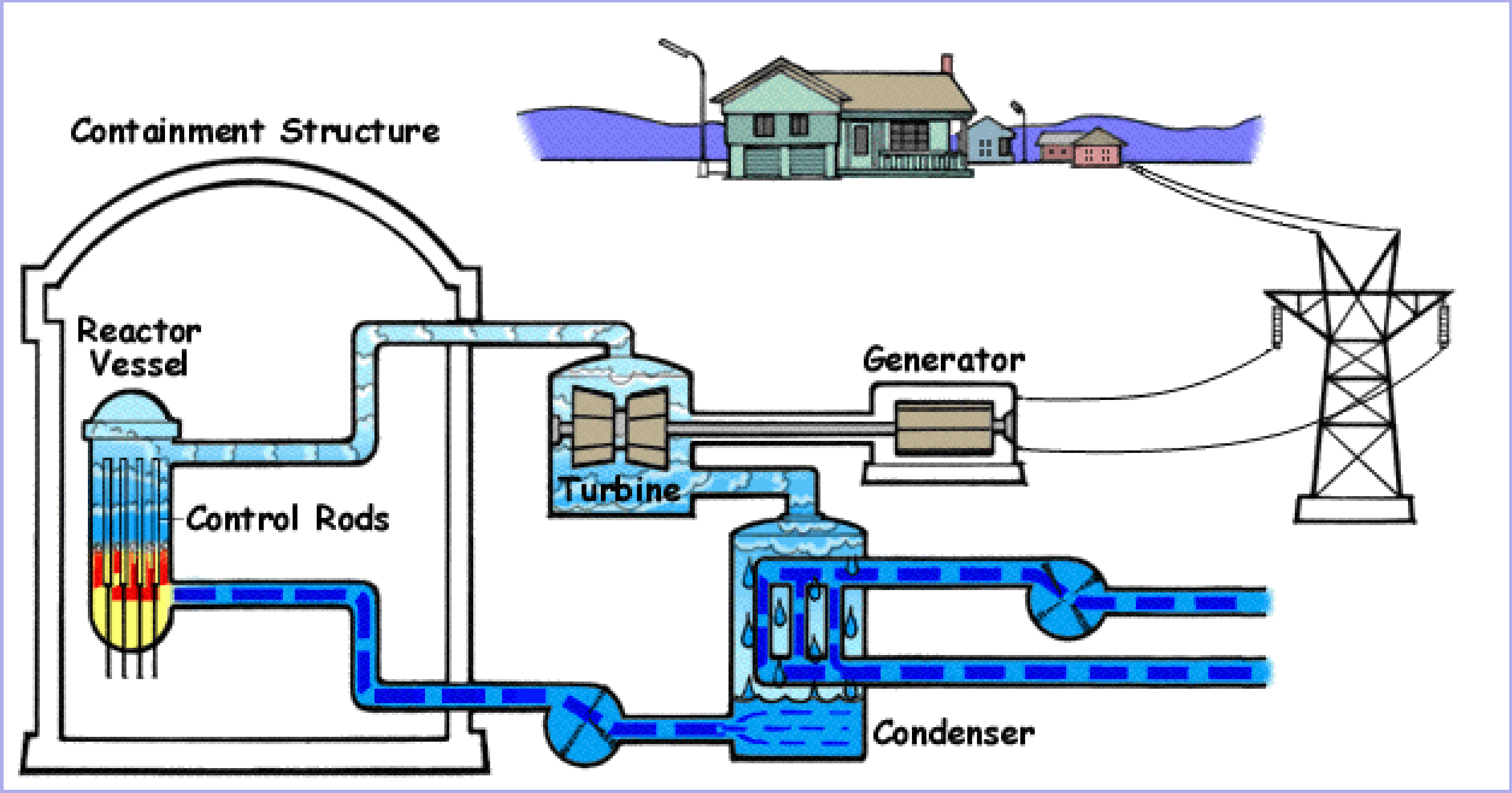
Thermal Neutrons
$\approx 2\times10^{-2}$ eV

- **H_2O**
- **Pure Graffite**

Chain Reaction



Nuclear Power Plant

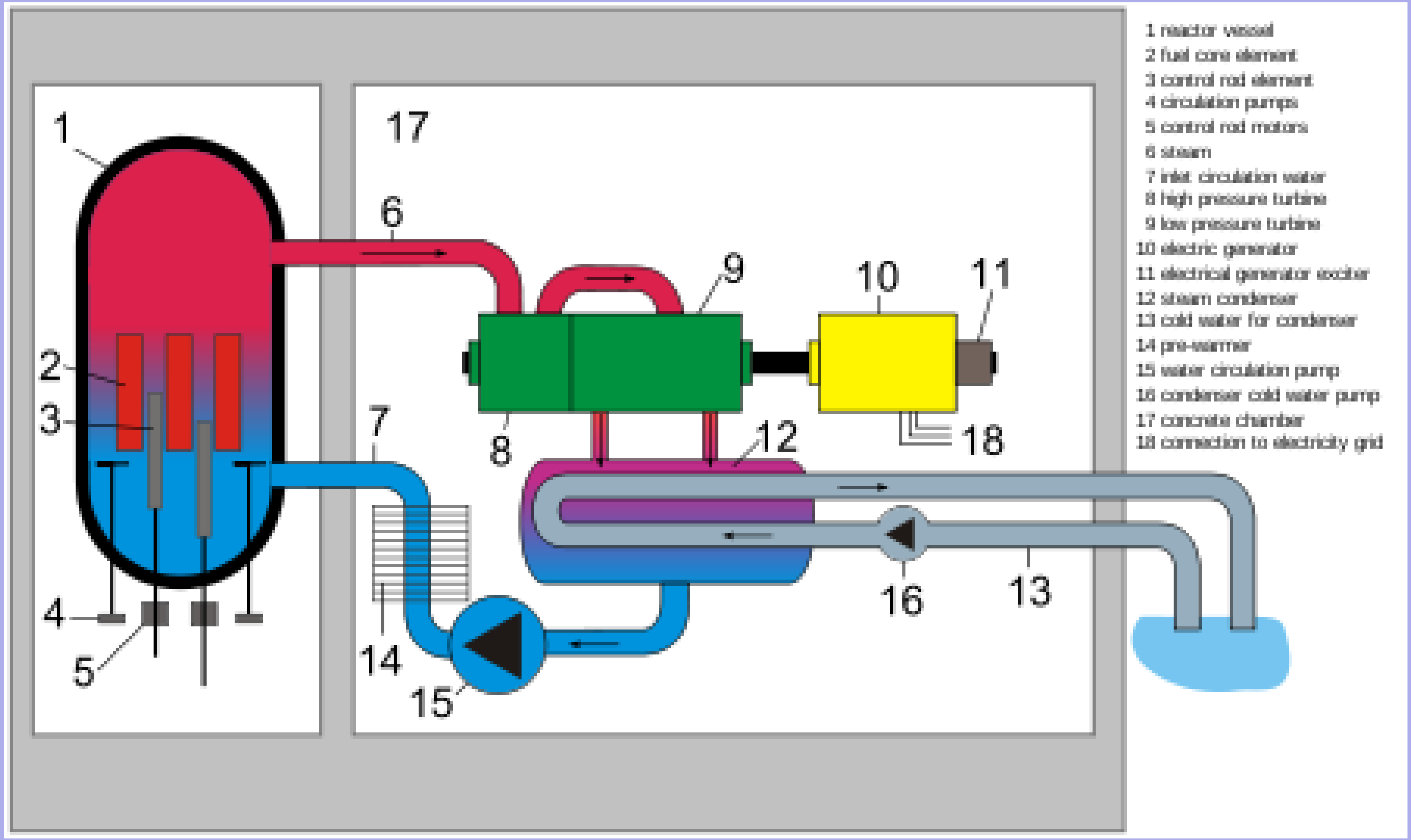


Boiling Water Reactor (BWR)

- **Moderator:** H_2O
- **Reactor core surrounded by** H_2O **for the production of steam**
- **Enrichment:** $^{235}U \Rightarrow \approx 3\%$

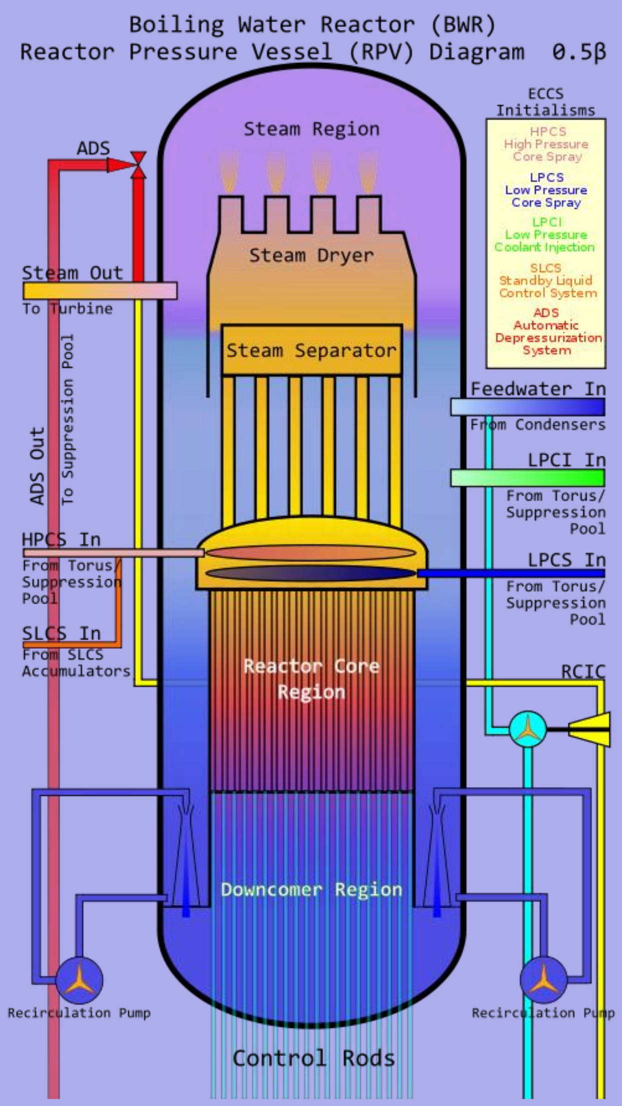
  $^{238}U \Rightarrow \approx 97\%$

BWR



1
17
6
9
10
11
2
3
7
8
12
18
4
5
14
15
16
13
1 reactor vessel
2 fuel core element
3 control rod element
4 circulation pumps
5 control rod motors
6 steam
7 inlet circulation water
8 high pressure turbine
9 low pressure turbine
10 electric generator
11 electrical generator exciter
12 steam condenser
13 cold water for condenser
14 pre-warmer
15 water circulation pump
16 condenser cold water pump
17 concrete chamber
18 connection to electricity grid

BWR



Boiling Water Reactor (BWR)
Reactor Pressure Vessel (RPV) Diagram 0.5β
Steam Region
ECCS Initialisms
HPCS High Pressure Core Spray
LPCS Low Pressure Core Spray
LPCI Low Pressure Coolant Injection
SLCS Standby Liquid Control System
ADS Automatic Depressurization System
ADS
Steam Dryer
Steam Out
To Turbine
Steam Separator
ADS Out
To Suppression Pool
Feedwater In
From Condensers
LPCI In
From Torus/ Suppression Pool
HPCS In
From Torus/ Suppression Pool
LPCS In
From Torus/ Suppression Pool
SLCS In
From SLCS Accumulators
Reactor Core Region
RCIC
Downcomer Region
Recirculation Pump
Recirculation Pump
Control Rods

Fuel: UO_2 Pellets

Fuel Rods

- Zirconium alloys
  - ⇒ Metal
  - ⇒ Relatively low neutron absorption cross section: Zr ⇒ $\sigma_{abs} \approx 0.18$ b

Control Rods

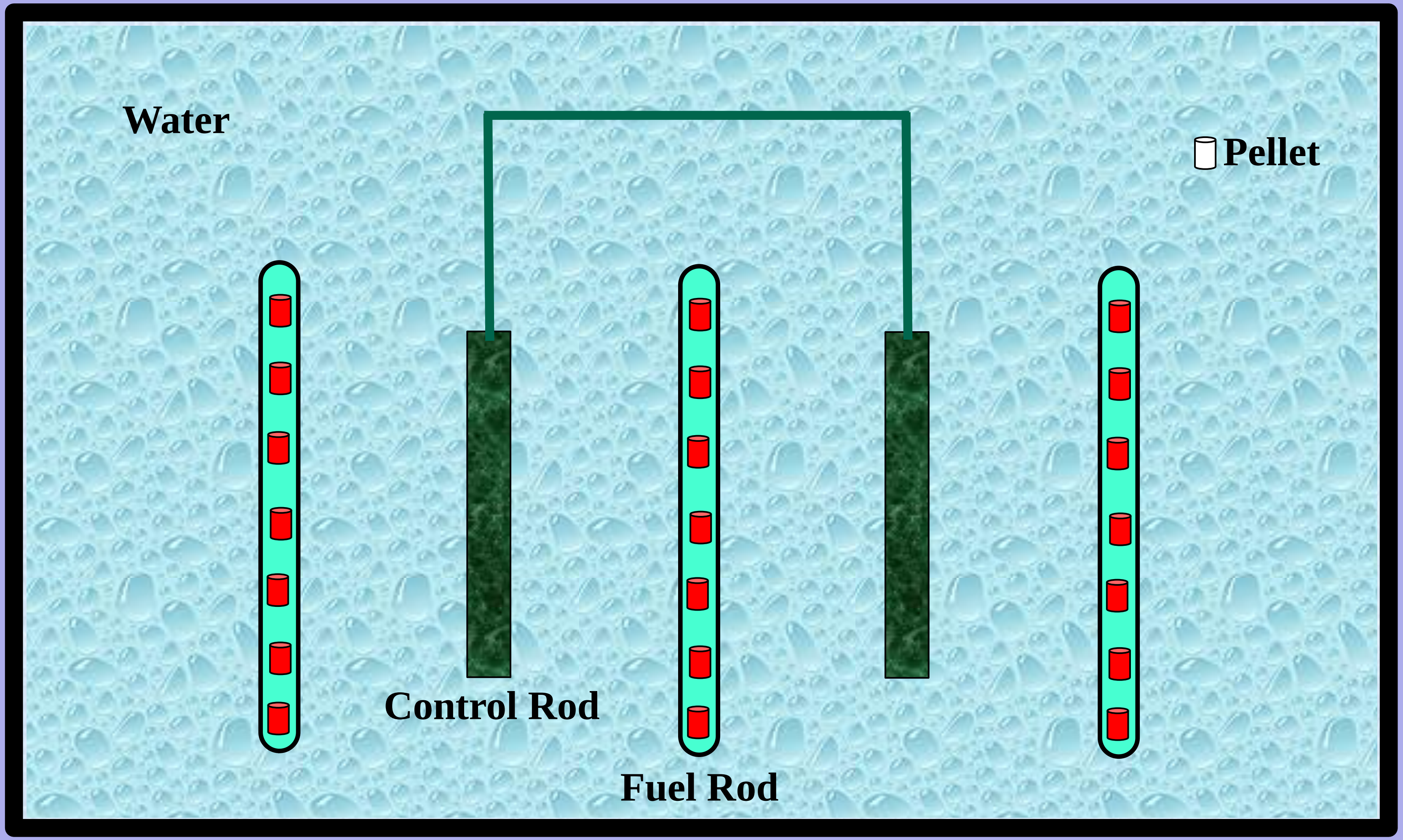
- Ag-In-Cd alloys
  - ⇒ Metal
  - ⇒ Relatively high neutron absorption cross section

Ag ⇒ $\sigma_{abs} \approx 63.3$ b

In ⇒ $\sigma_{abs} \approx 193.8$ b

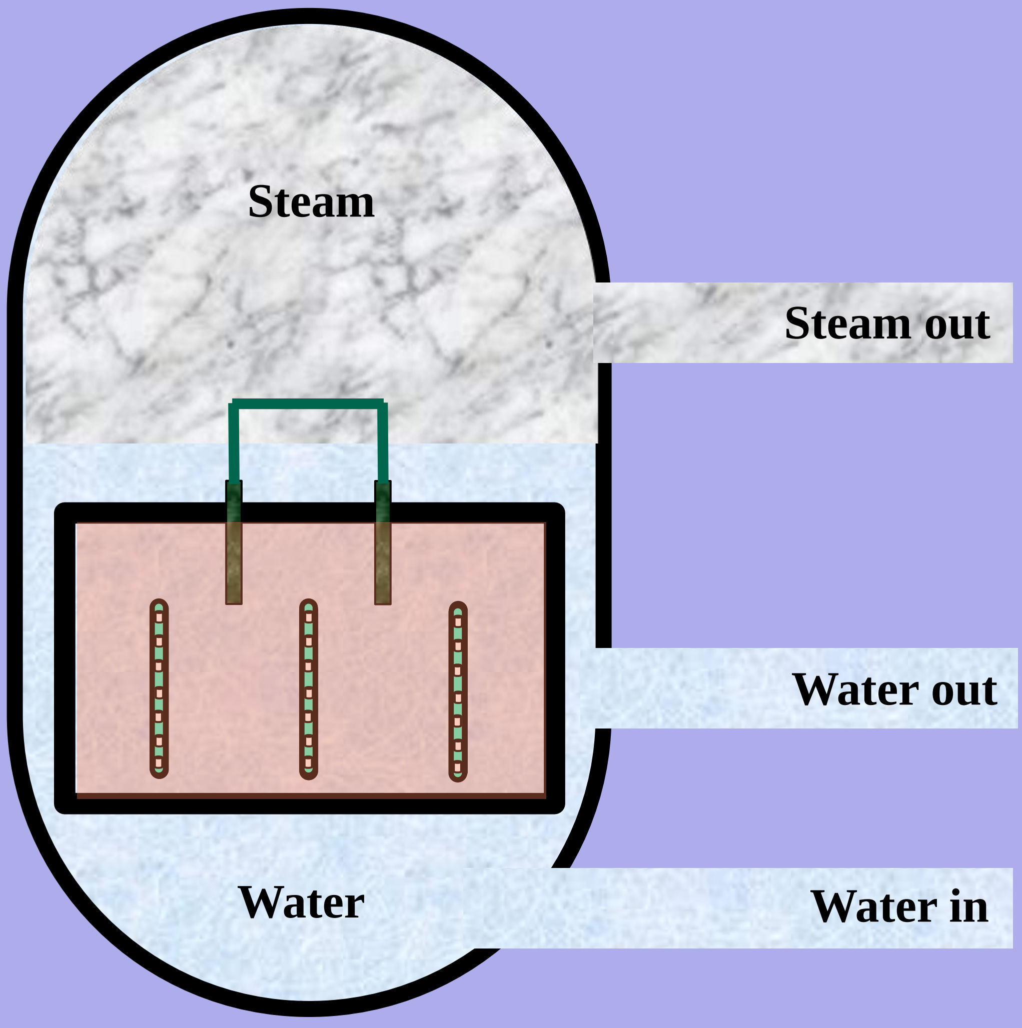
Cd ⇒ $\sigma_{abs} \approx 2520$ b

Reactor Core



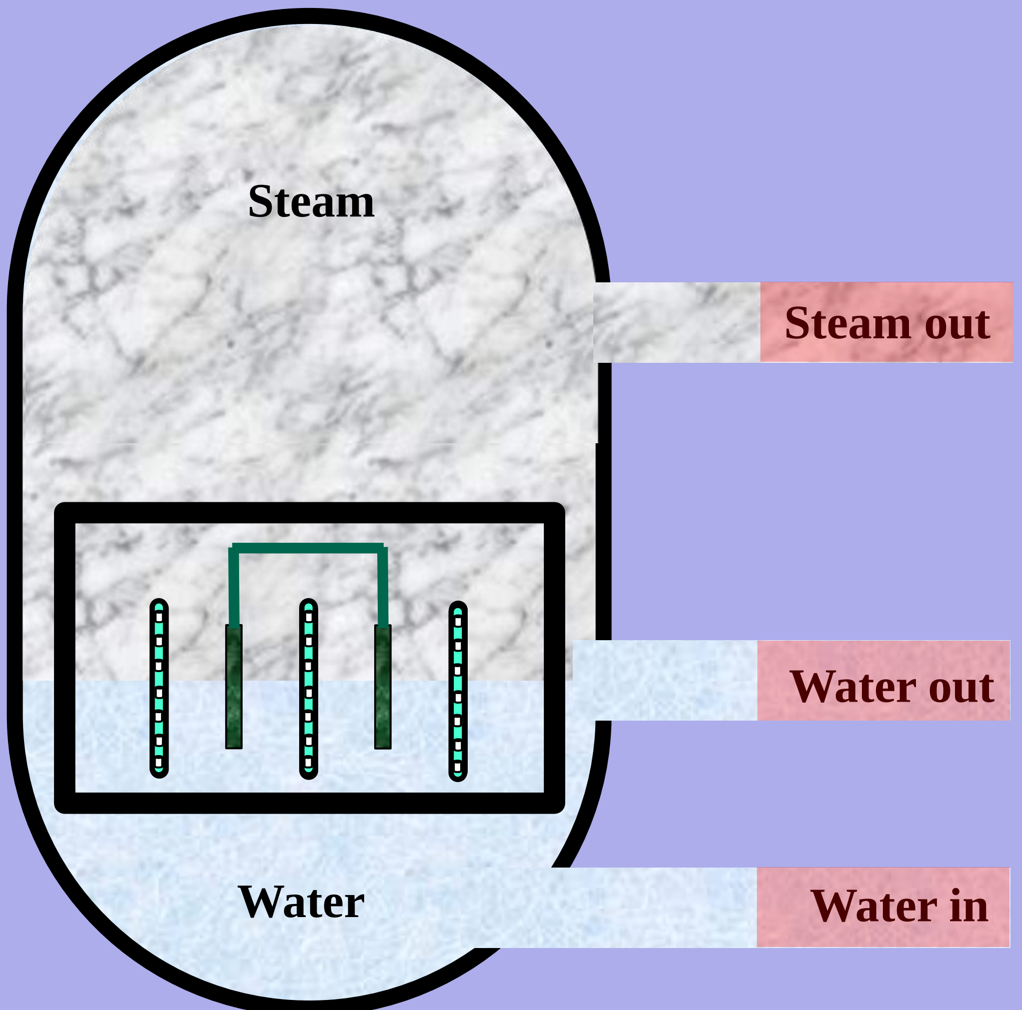
Accident

- Earthquake + tsunami = shutdown



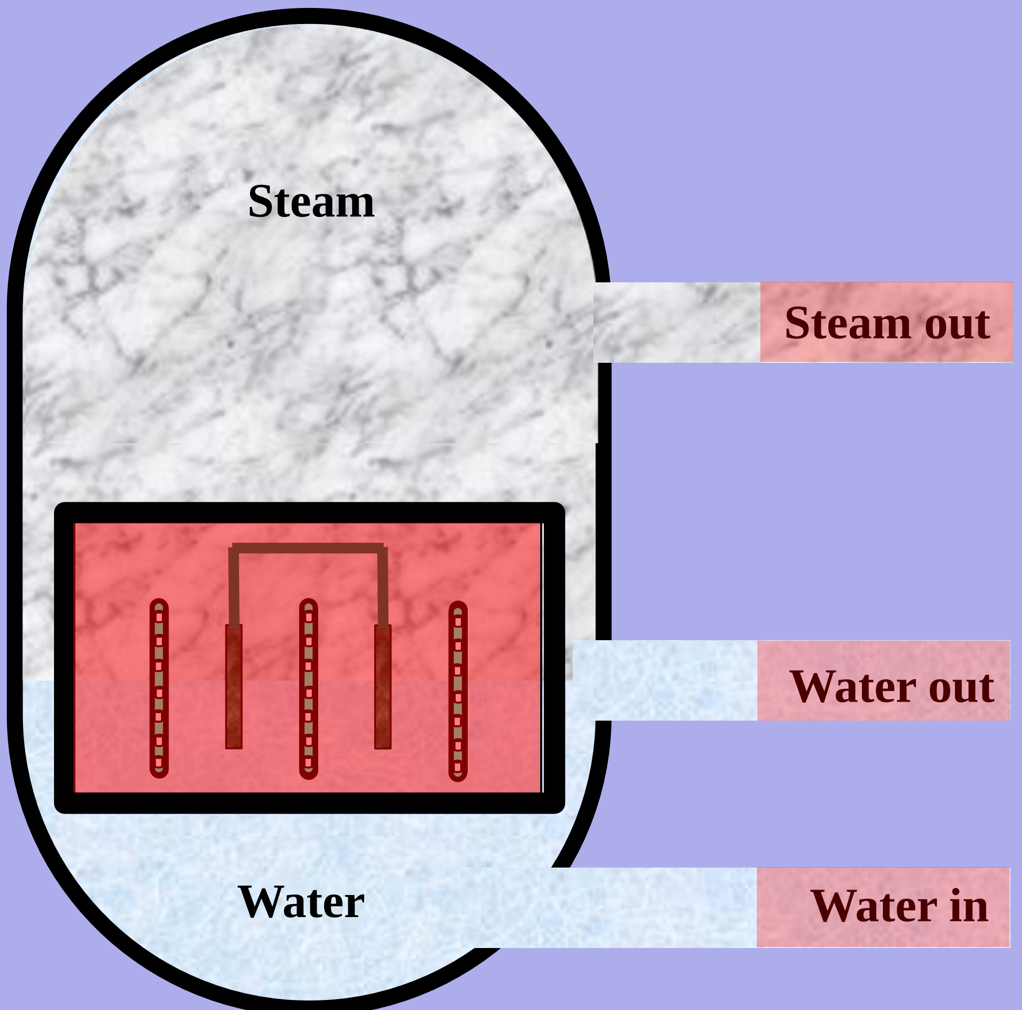
Accident

- ☢ **Problems with generators ⇒ pumps**



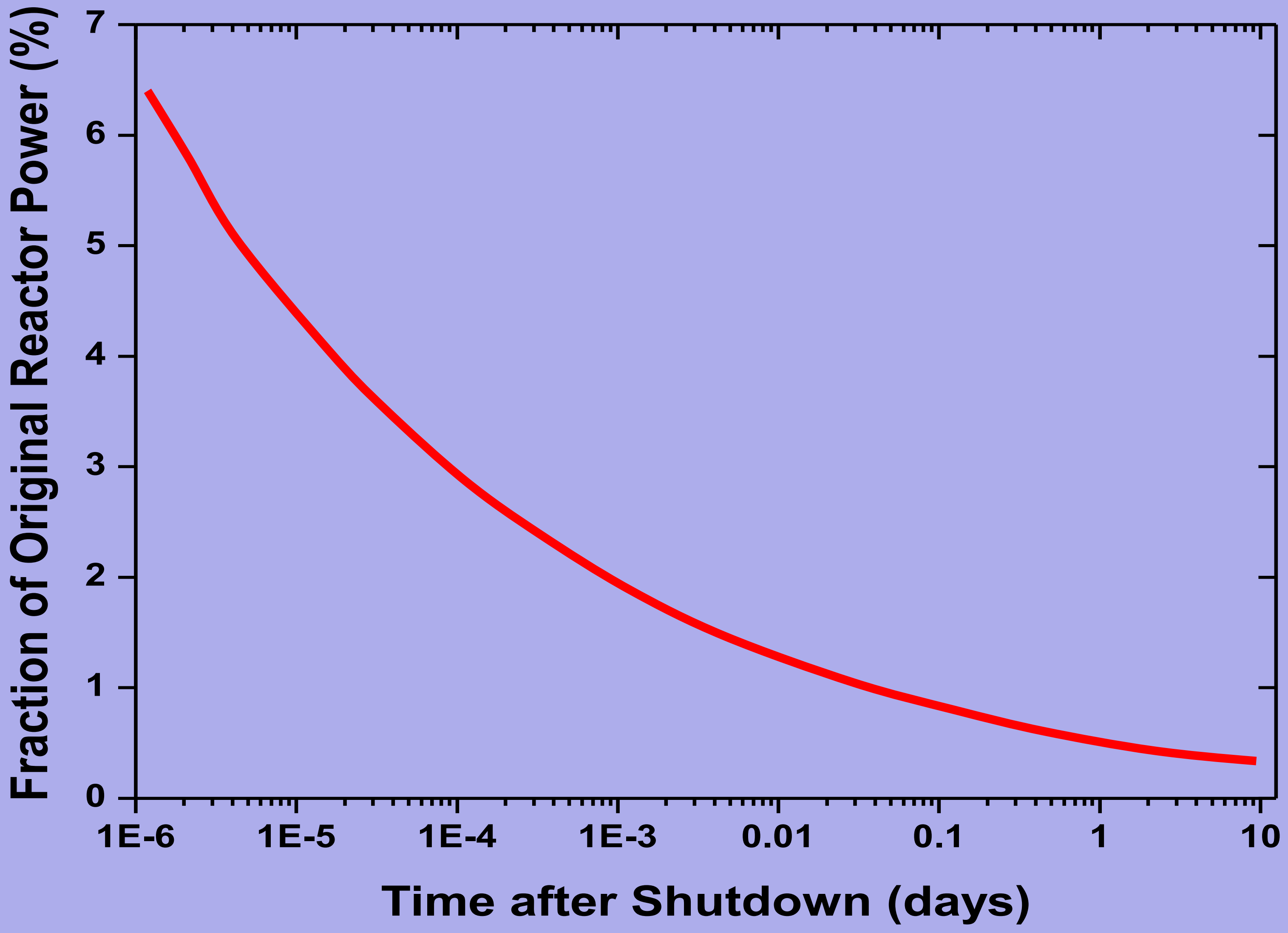
Accident

- Core heats up



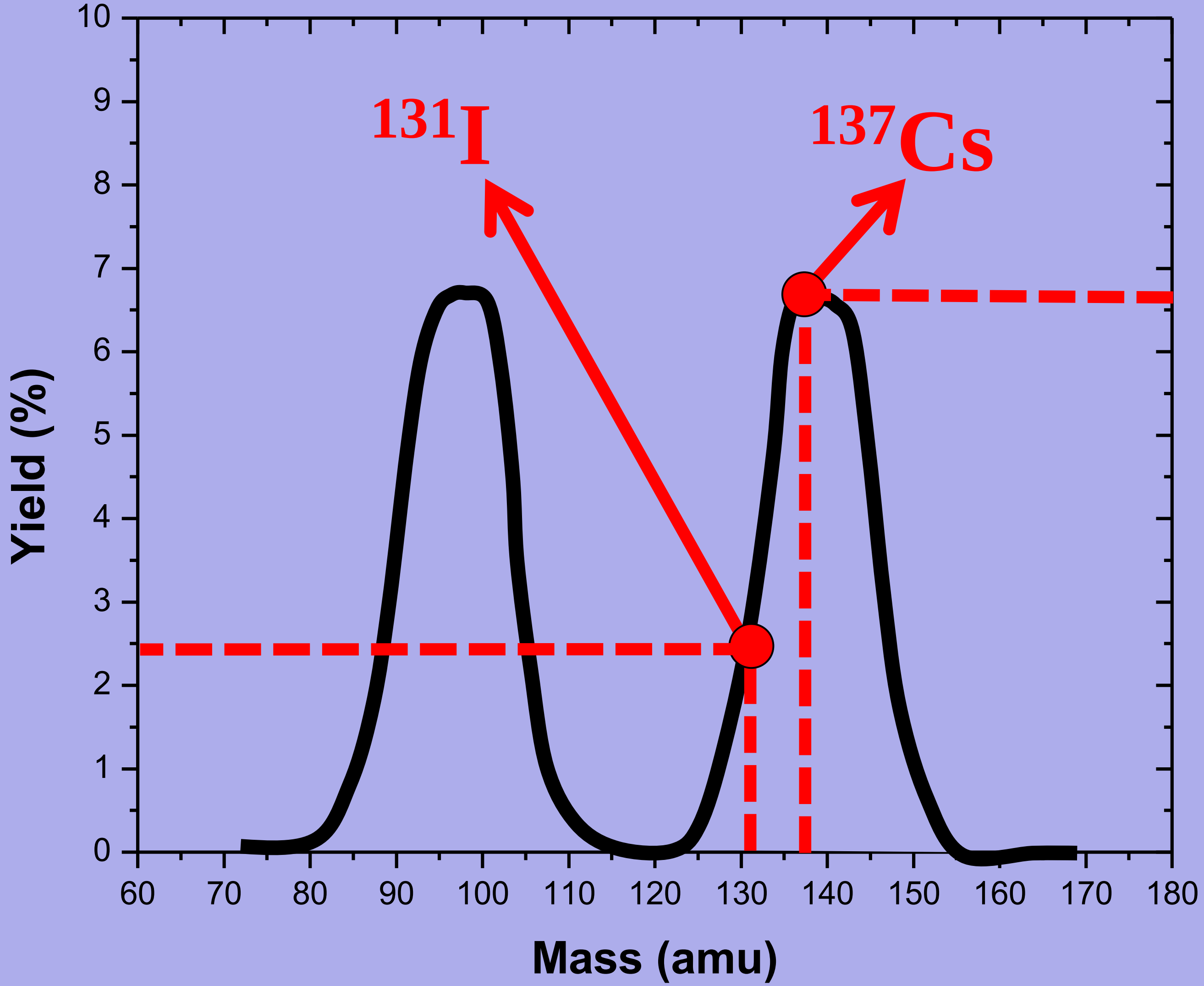
Heat

- ☢ Core materials are overheated
- ☢ Decay heat
  - ⇒ Fission (chain reaction) has stopped
  - ⇒ Fission products are still decaying, thus generating heat



Fraction of Original Reactor Power (%)
7
6
5
4
3
2
1
0
1E-6
1E-5
1E-4
1E-3
0.01
0.1
1
10
Time after Shutdown (days)

^{235}U Fission
Fragment Mass Distribution



Beta Decay (β^-)

$^{131}I \rightarrow {}^{131}Xe + e^- + \bar{\upsilon}$

$t_{1/2}$ = 8.04 days

e^-: 0.61 MeV

γ: 0.36 MeV

$^{137}Cs \rightarrow {}^{137}Ba + e^- + \bar{\upsilon}$

$t_{1/2}$ = 30.17 years

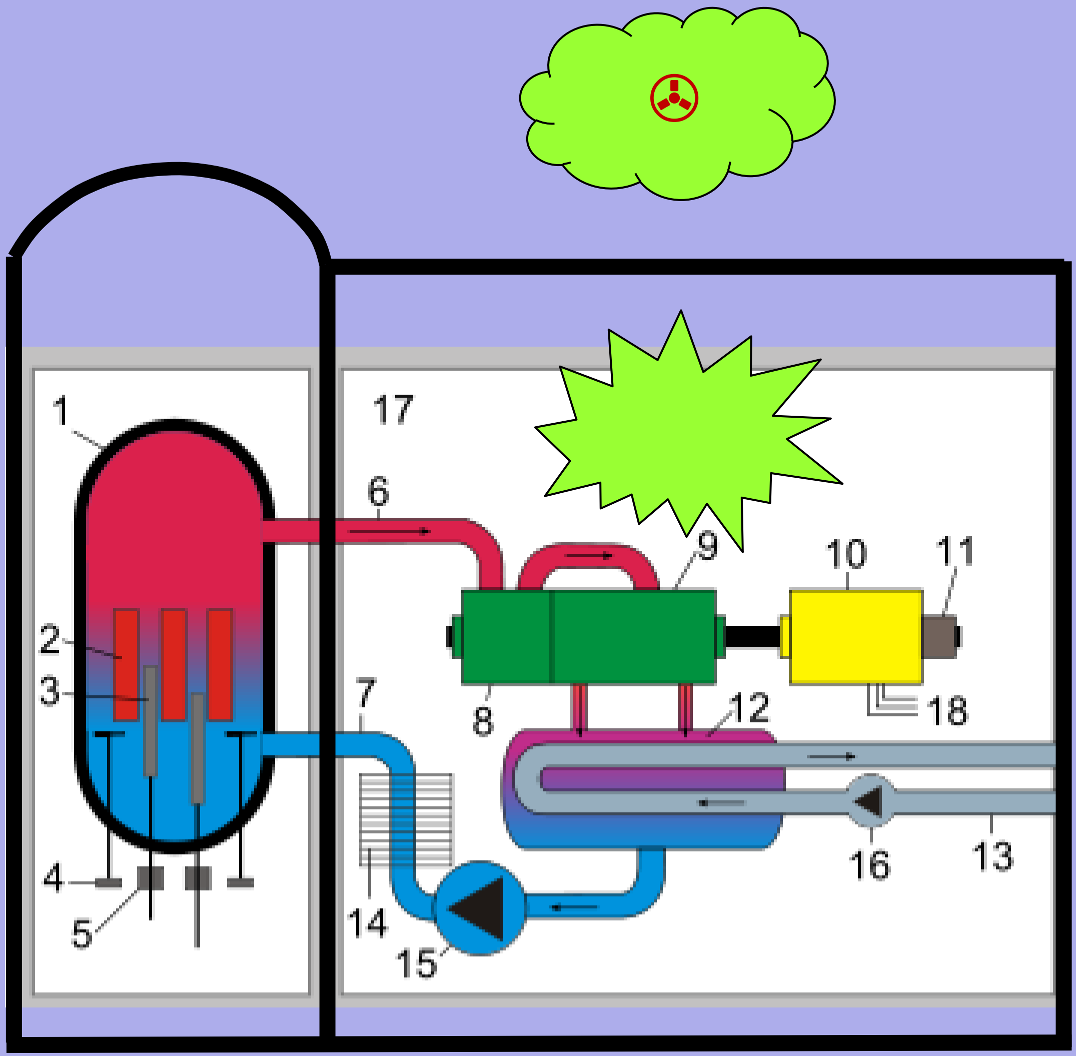
e^-: 0.51 MeV

γ: 0.66 MeV

Hydrogen

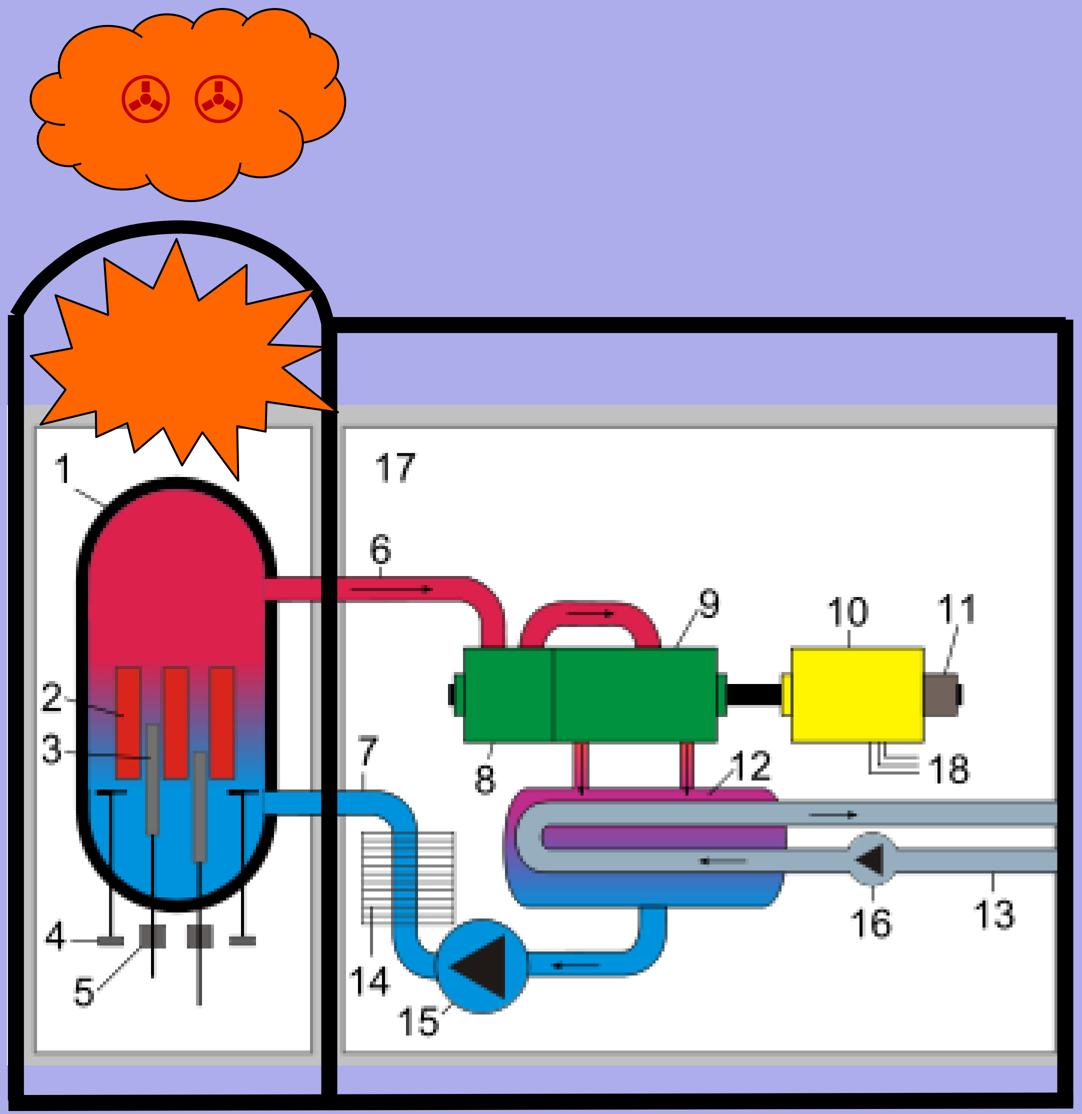
- ☢ **Thermal dissociation of water**
  - $\Rightarrow$ **High temperatures (> 2000°C)**
  - $\Rightarrow H_2O \rightarrow 2H + O$
- ☢ **Reaction with zirconium**
  - $\Rightarrow Zr + 2H_2O \rightarrow ZrO_2 + 2H_2$
- ☢ **Flammable compounds $\Rightarrow$ explosion**

Explosion Scenario 1



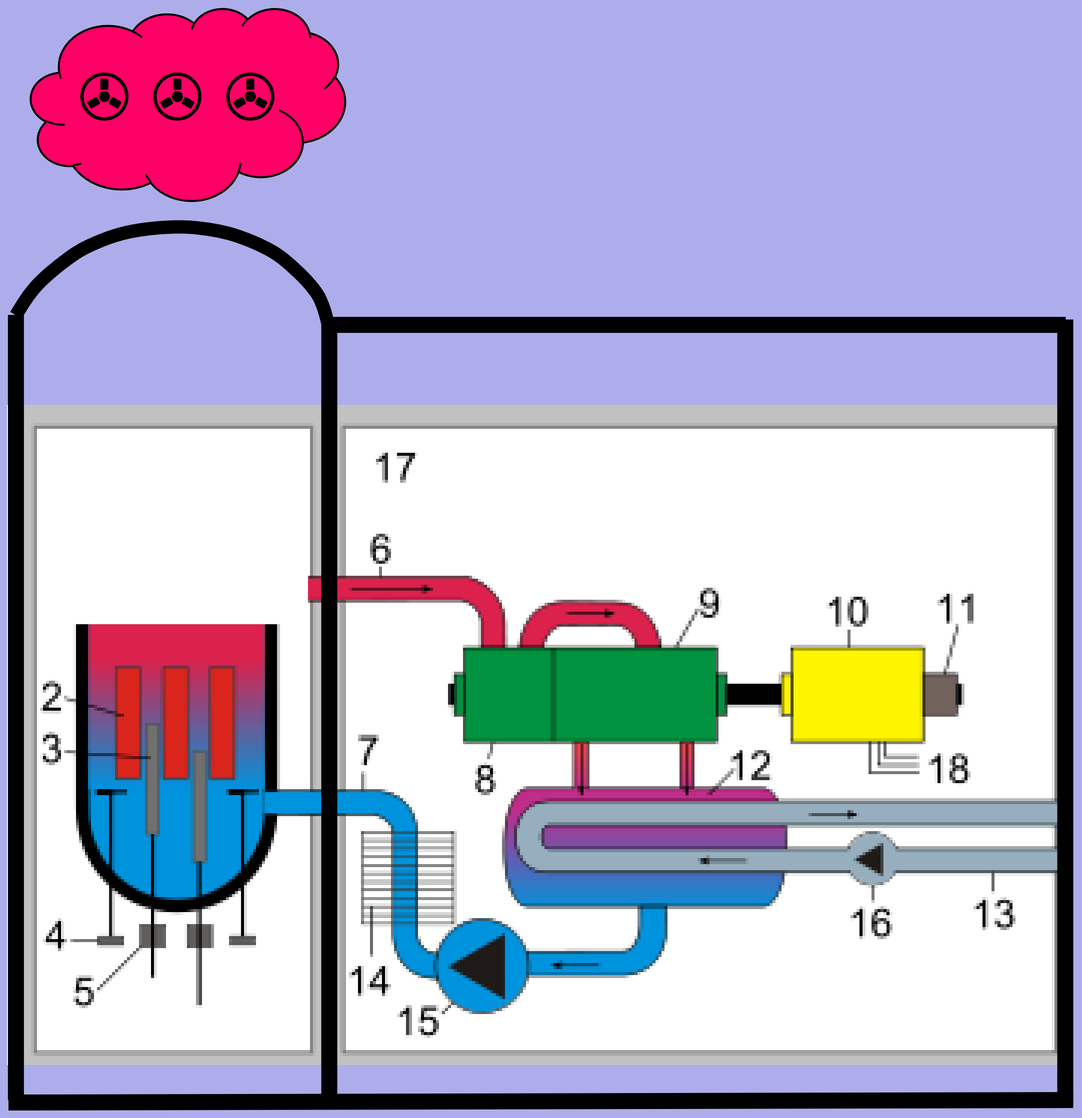
International Nuclear Radiological Event Scale

Explosion Scenario 2



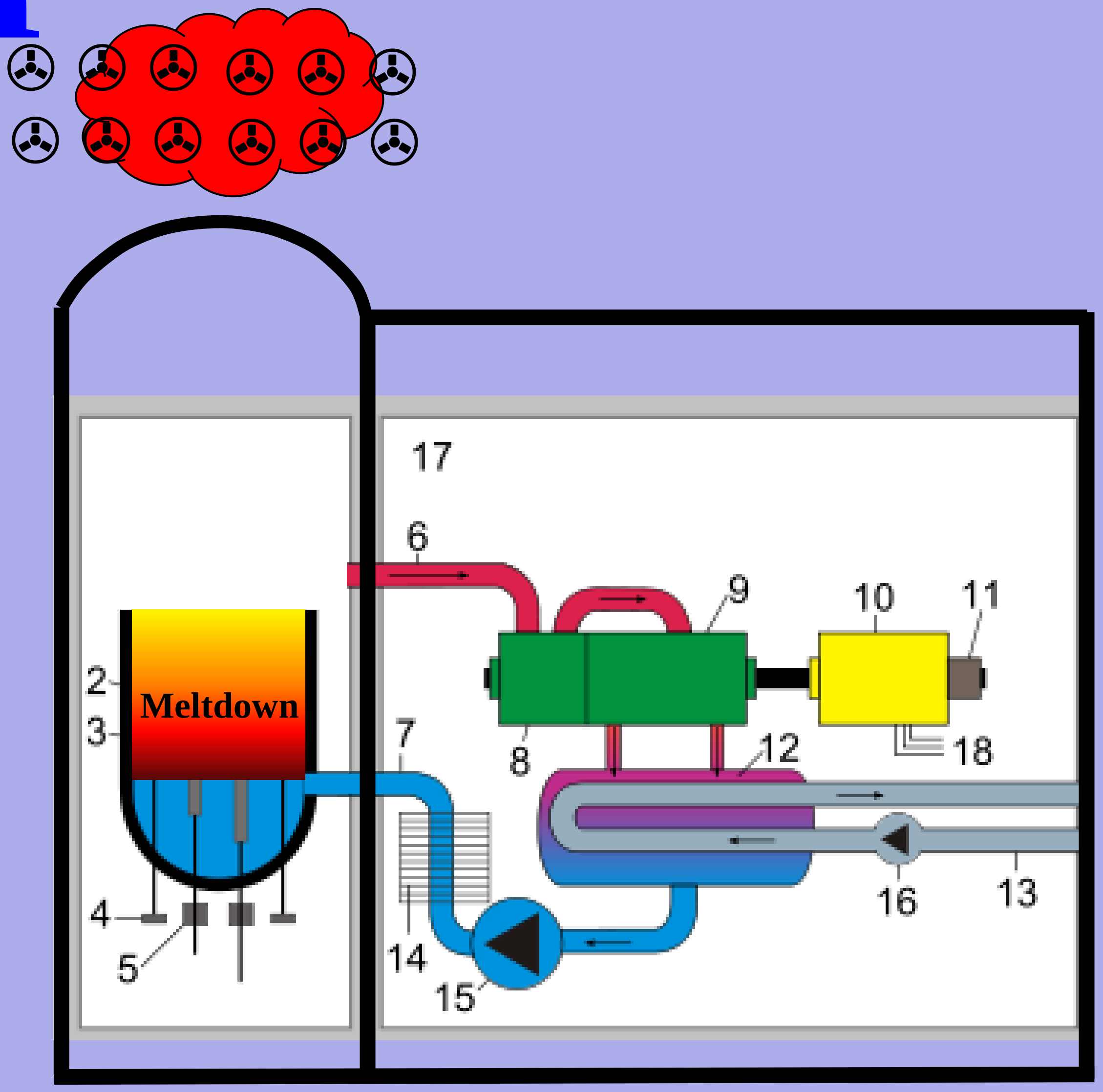
International Nuclear Radiological Event Scale

Explosion Scenario 3



International Nuclear Radiological Event Scale

Explosion Scenario 4



International Nuclear Radiological Event Scale

Brazilian Nuclear Power Plants

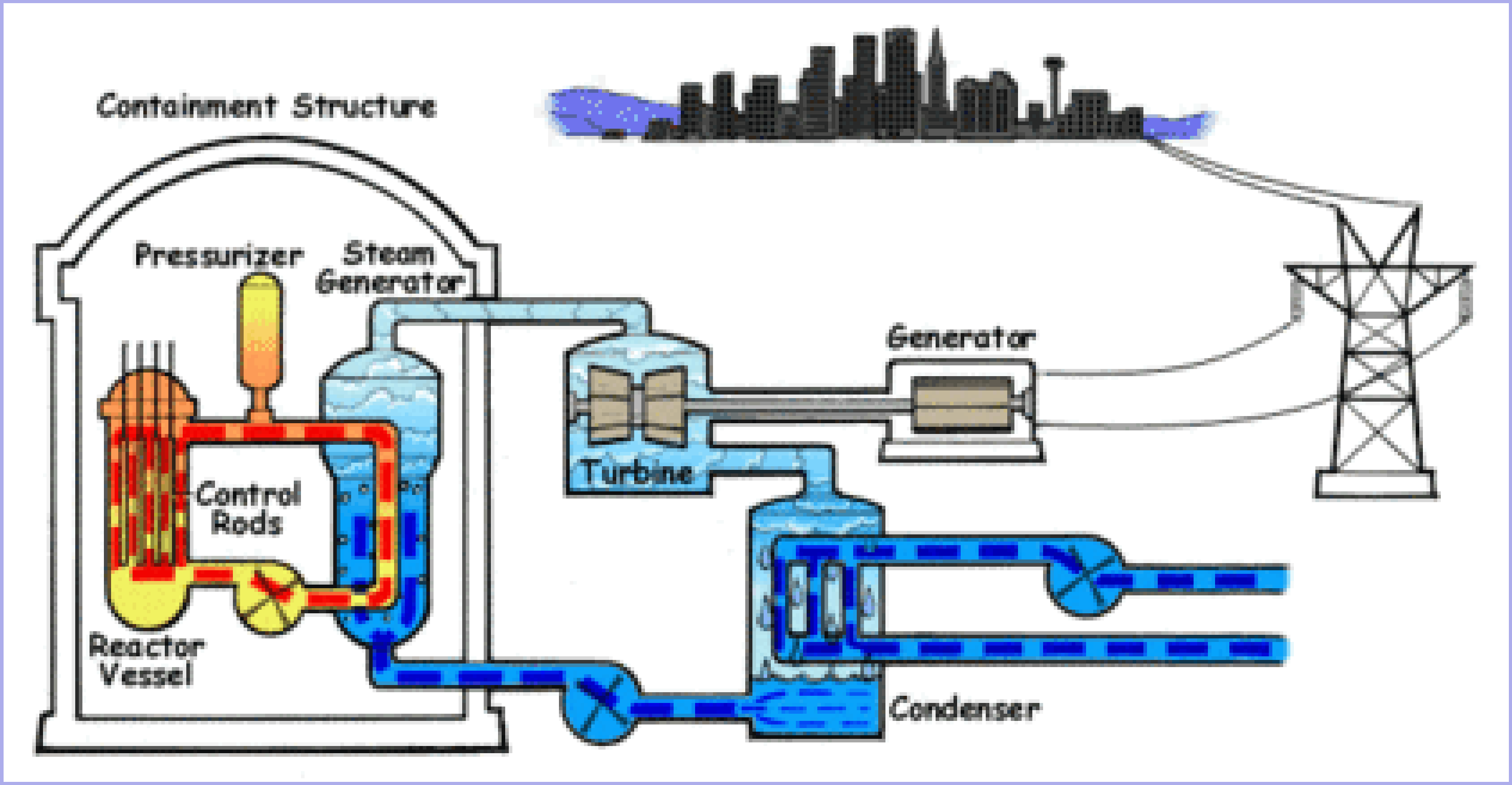
- Angra dos Reis (RJ)
- Angra I
  - ⇒ Westinghouse (USA)
  - ⇒ 657 MW

Brazilian Nuclear Power Plants

- ☢ Angra II
  - ⇒ German technology
  - ⇒ 1350 MW
- ☢ Angra III
  - ⇒ 1270 MW (due 2015)

Angra Nuclear Power Plant

Pressurized Water Reactor



Conclusion

- What do we learn?
- Nuclear Power: benefit x risk
- Can we afford going free of any nuclear power?