A.I.F. - XLVI CORSO DI AGGIORNAMENTO IN FISICA

ENERGIA NUCLEARE

PAOLO MONTAGNA
JACOPO BRAGHIERI

16-10-2024

Introduzione

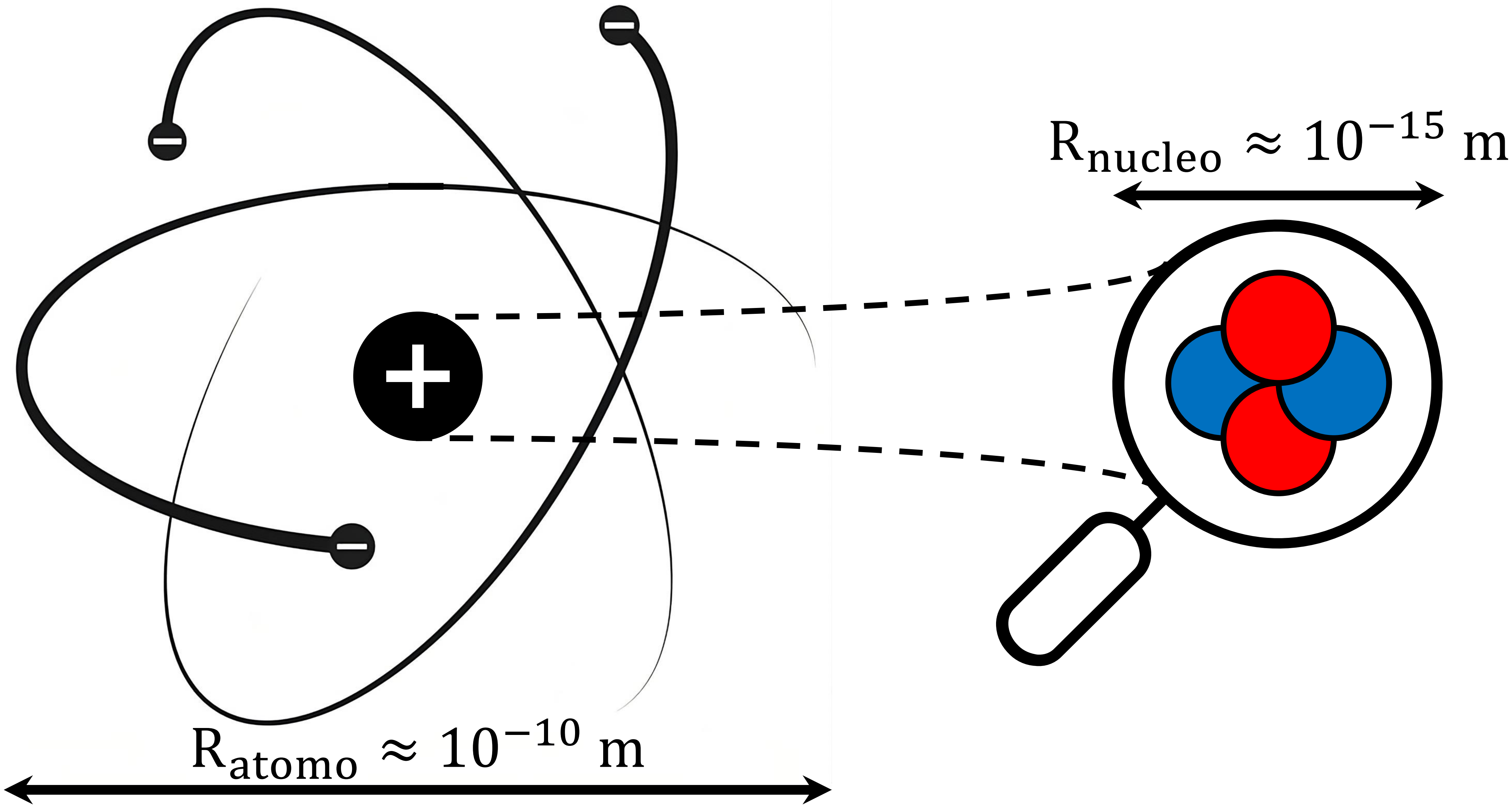
Fusione e fissione

Neutrone

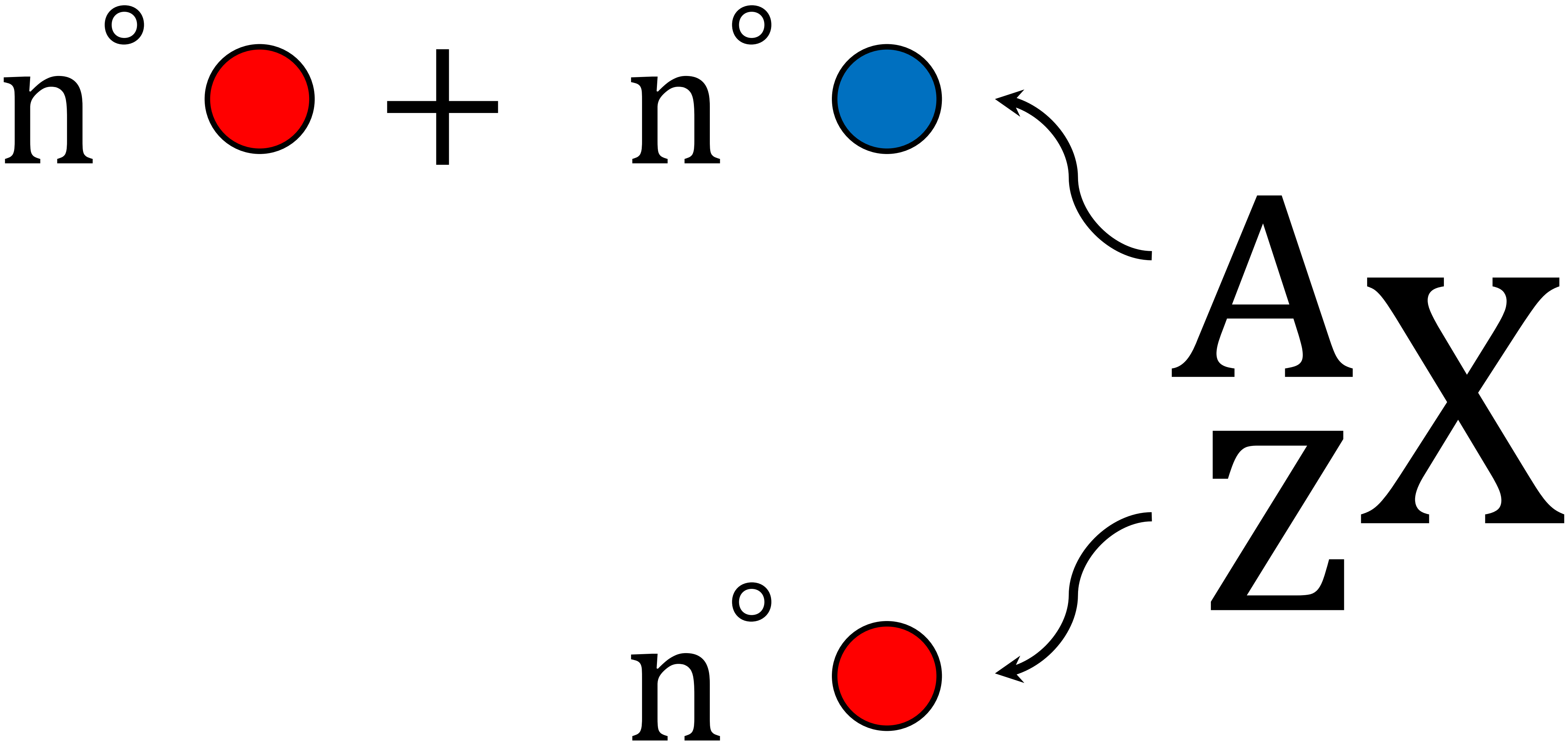
Reattori e centrali

Bomba atomica

NUCLEO ATOMICO



	Protone	Neutrone	Elettrone
Carica (C)	$+1.6 \cdot 10^{-19}$	0	$-1.6 \cdot 10^{-19}$
Massa (kg)	$1.673 \cdot 10^{-27}$	$1.675 \cdot 10^{-27}$	$9.109 \cdot 10^{-31}$

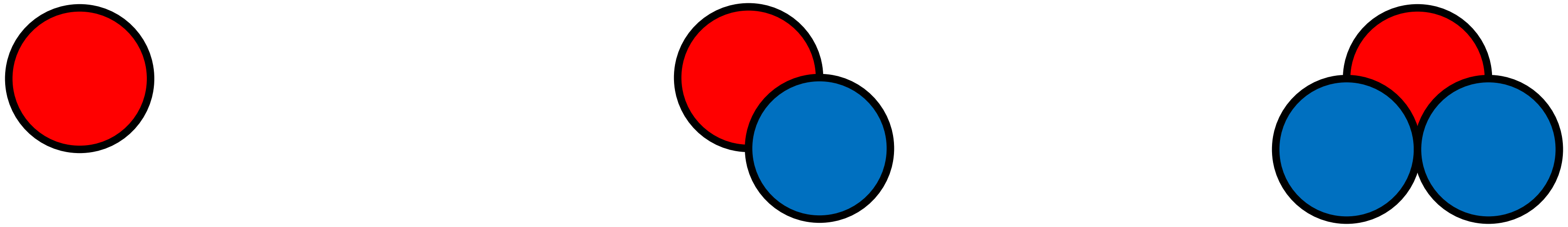

n°
+
n°
n°
A
Z
X

Atomic Number → 1
Symbol ← H
Name → Hydrogen
Atomic Weight ← 1.008

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.008																	2 He Helium 4.002602
3 Li Lithium 6.94	4 Be Beryllium 9.0121831											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998403163	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.305											13 Al Aluminium 26.9815385	14 Si Silicon 28.085	15 P Phosphorus 30.973761998	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955908	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933194	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.921595	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90637	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.90545196	56 Ba Barium 137.327	57 - 71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 - 103 Actinoids	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (269)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)
		57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93422	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.9668	
		89 Ac Actinium (227)	90 Th Thorium 232.0377	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (266)	

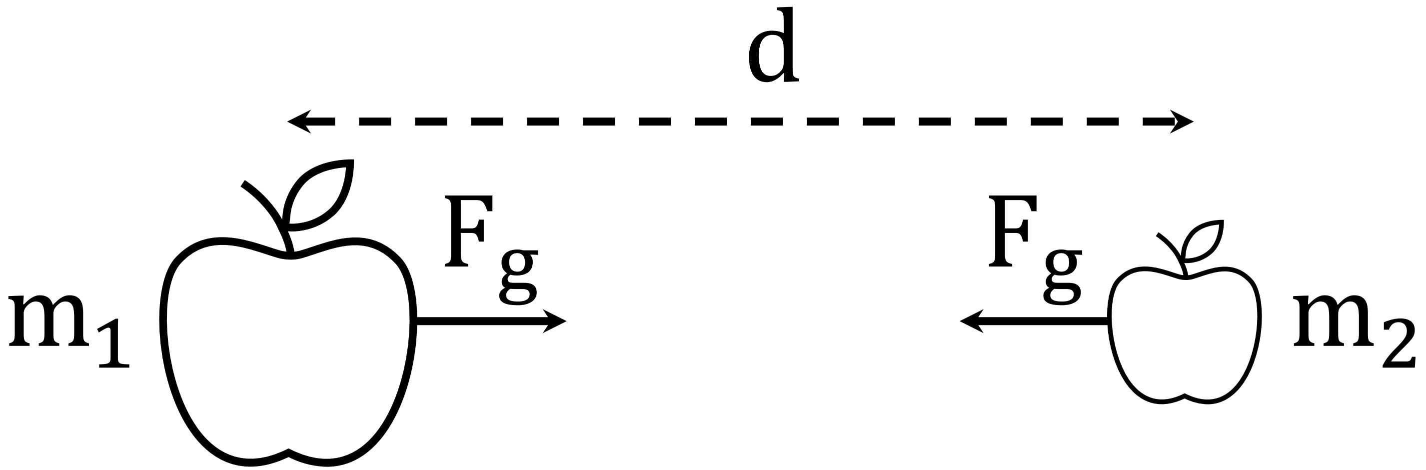
ISOTOPI

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$



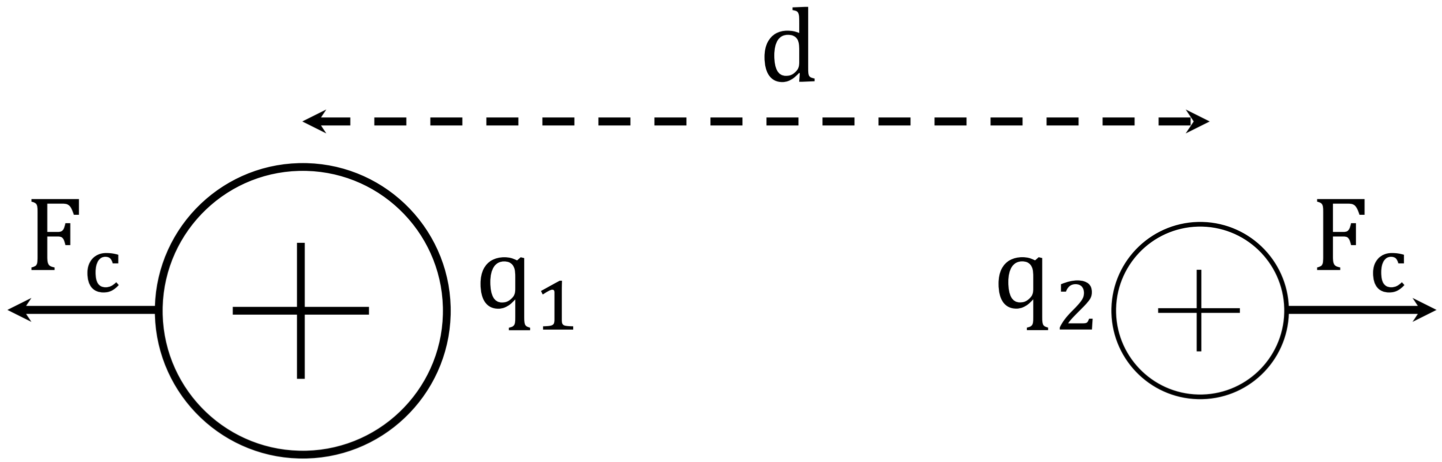
$= Z$ $\neq A$

FORZA GRAVITAZIONALE



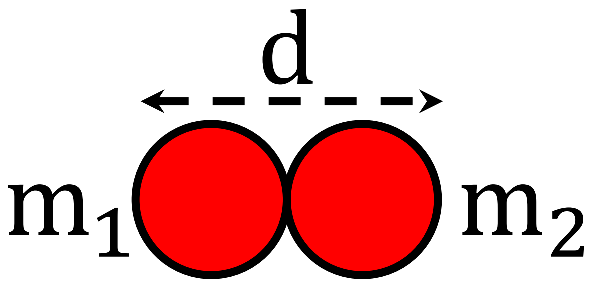
$$F_g = G\frac{m_1 m_2}{d^2}$$

FORZA ELETTROMAGNETICA



$$F_c = k\frac{q_1 q_2}{d^2}$$

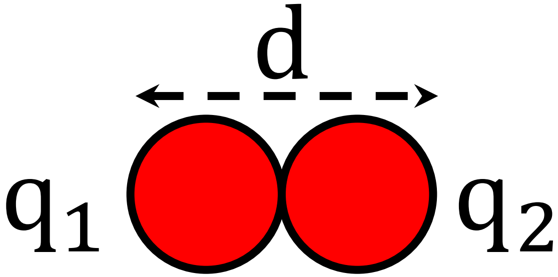
FORZA GRAVITAZIONALE



$$m_1 = m_2 = 1.673 \cdot 10^{-27}\ \text{kg} \qquad d = 2 \cdot 10^{-15}\ \text{m}$$

$$F_g \approx 4.65 \cdot 10^{-35}\ \text{N}$$

FORZA ELETTROMAGNETICA



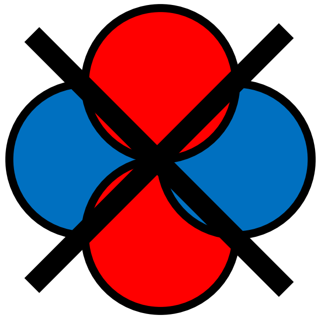
$$q_1 = q_2 = 1.6 \cdot 10^{-19}\ \mathrm{C}$$

$$d = 2 \cdot 10^{-15}\ \mathrm{m}$$

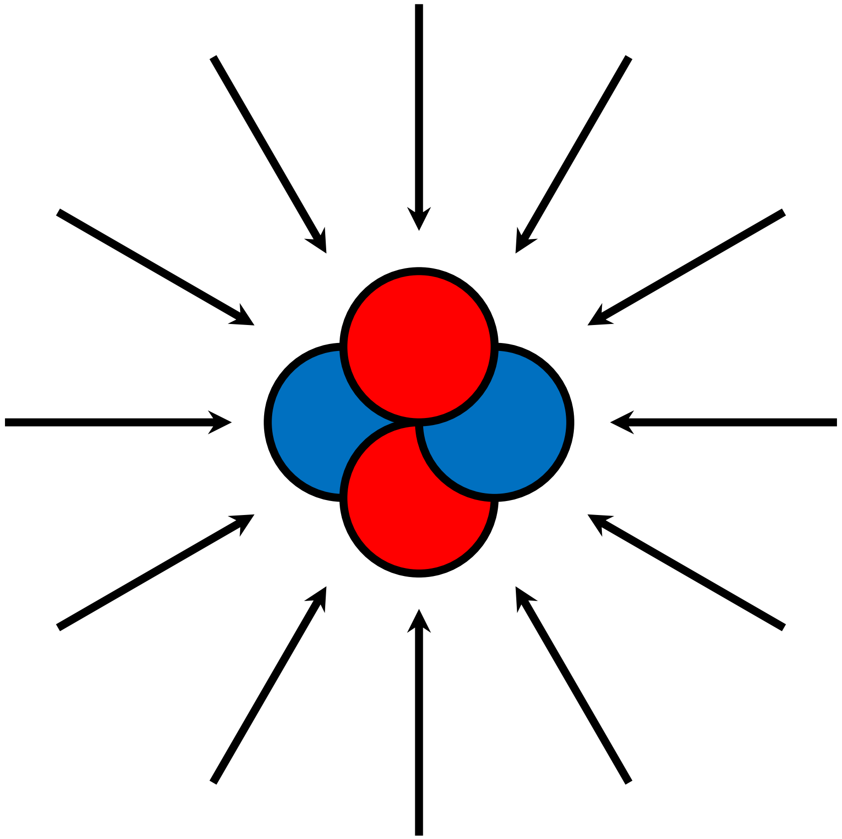
$$F_c \approx 57.6\ \mathrm{N}$$

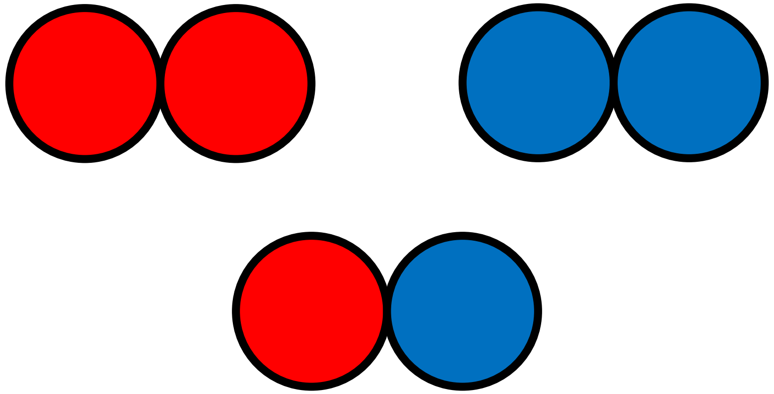
$$F_c \gg F_g$$

$$\Downarrow$$



FORZA NUCLEARE FORTE

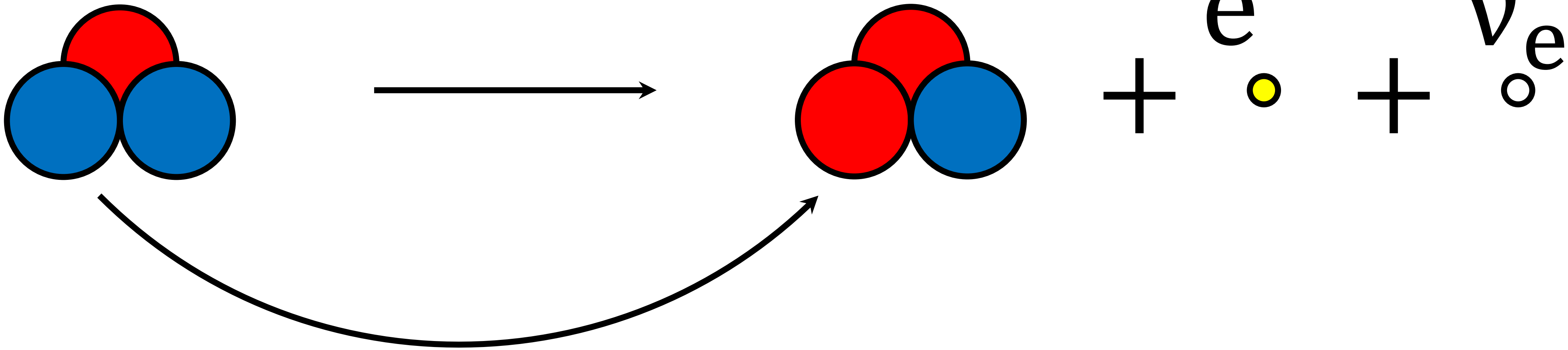




$$10^{-15}\ \mathrm{m}$$

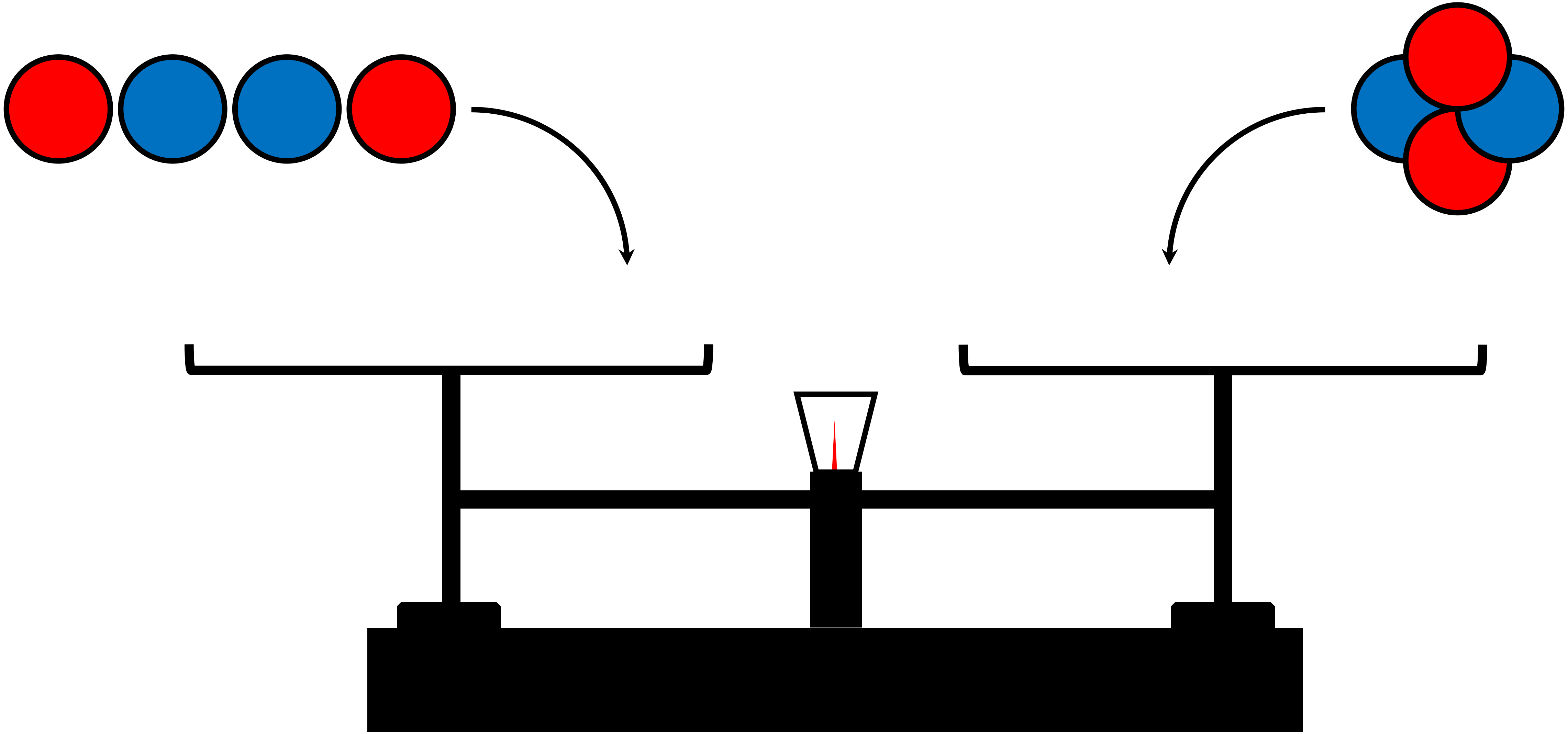
FORZA NUCLEARE DEBOLE

$$^{3}_{1}H \longrightarrow {}^{3}_{2}He + e^{-} + \overline{\nu}_e$$

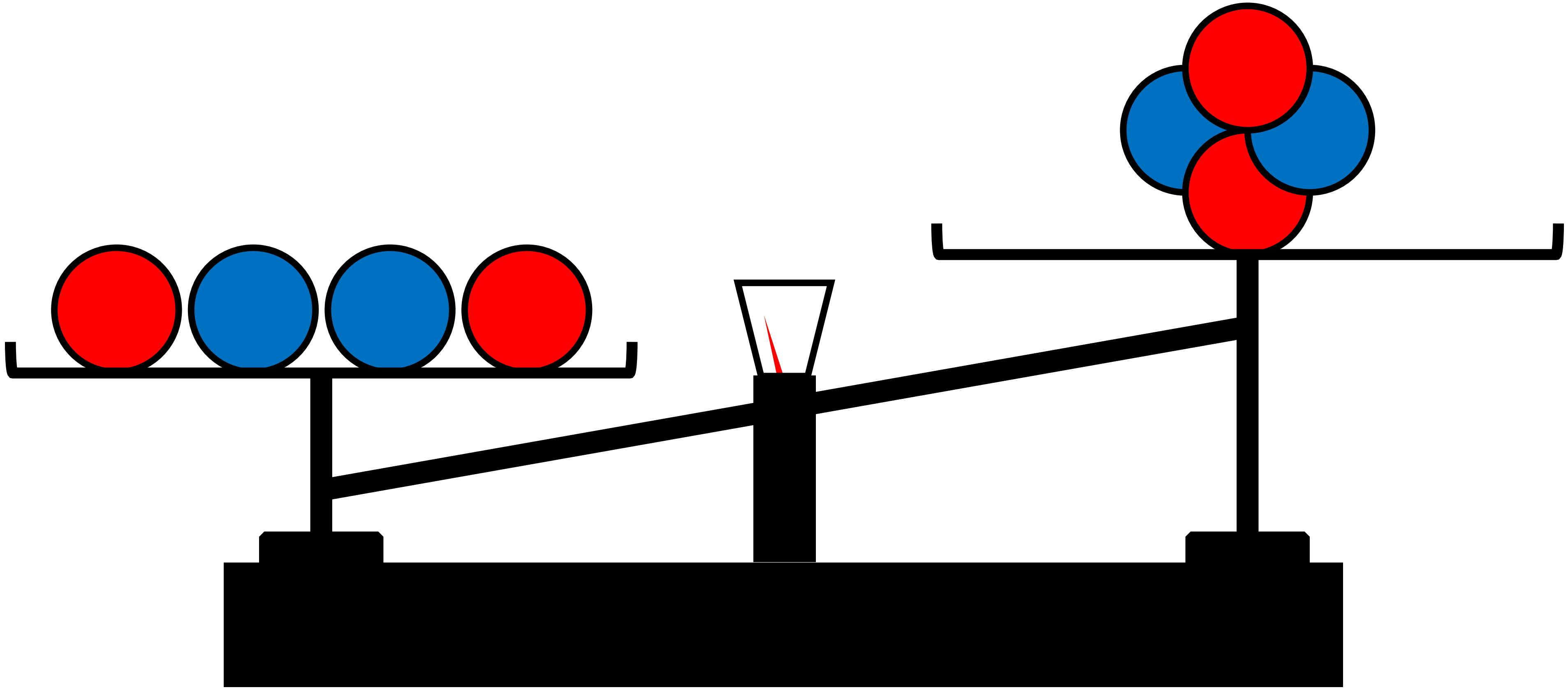


Interazione	Intensità relativa	Range (m)
Forte	10^{38}	10^{-15}
Elettromagnetica	10^{36}	∞
Debole	10^{25}	10^{-15}
Gravitazionale	1	∞

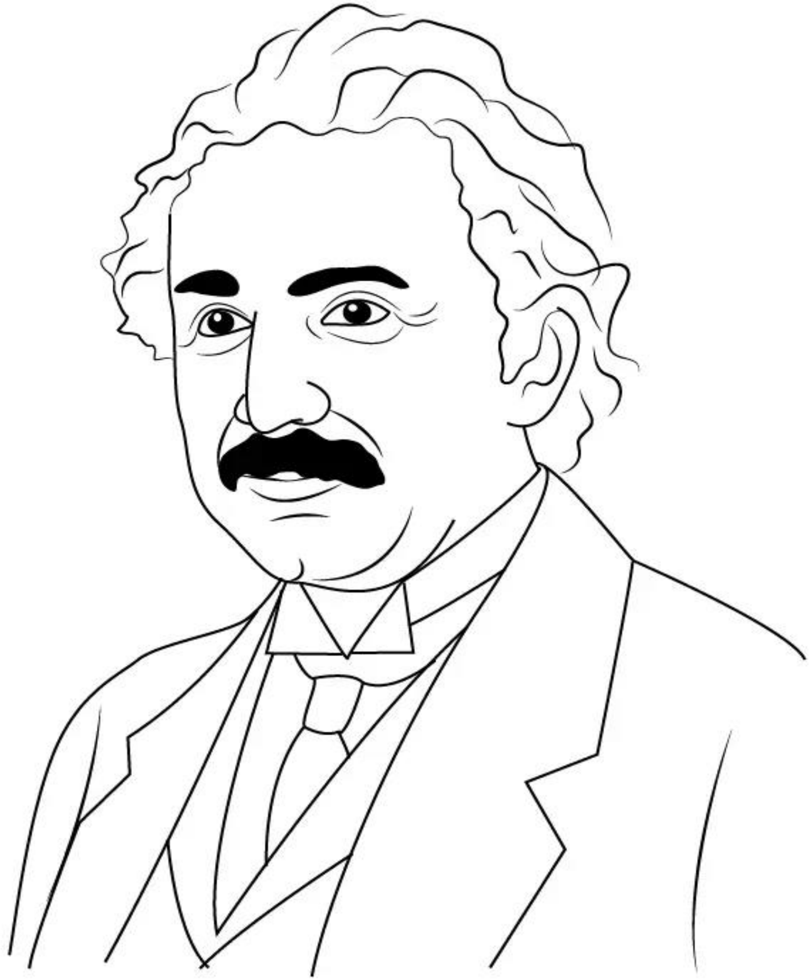
DIFETTO DI MASSA



DIFETTO DI MASSA



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



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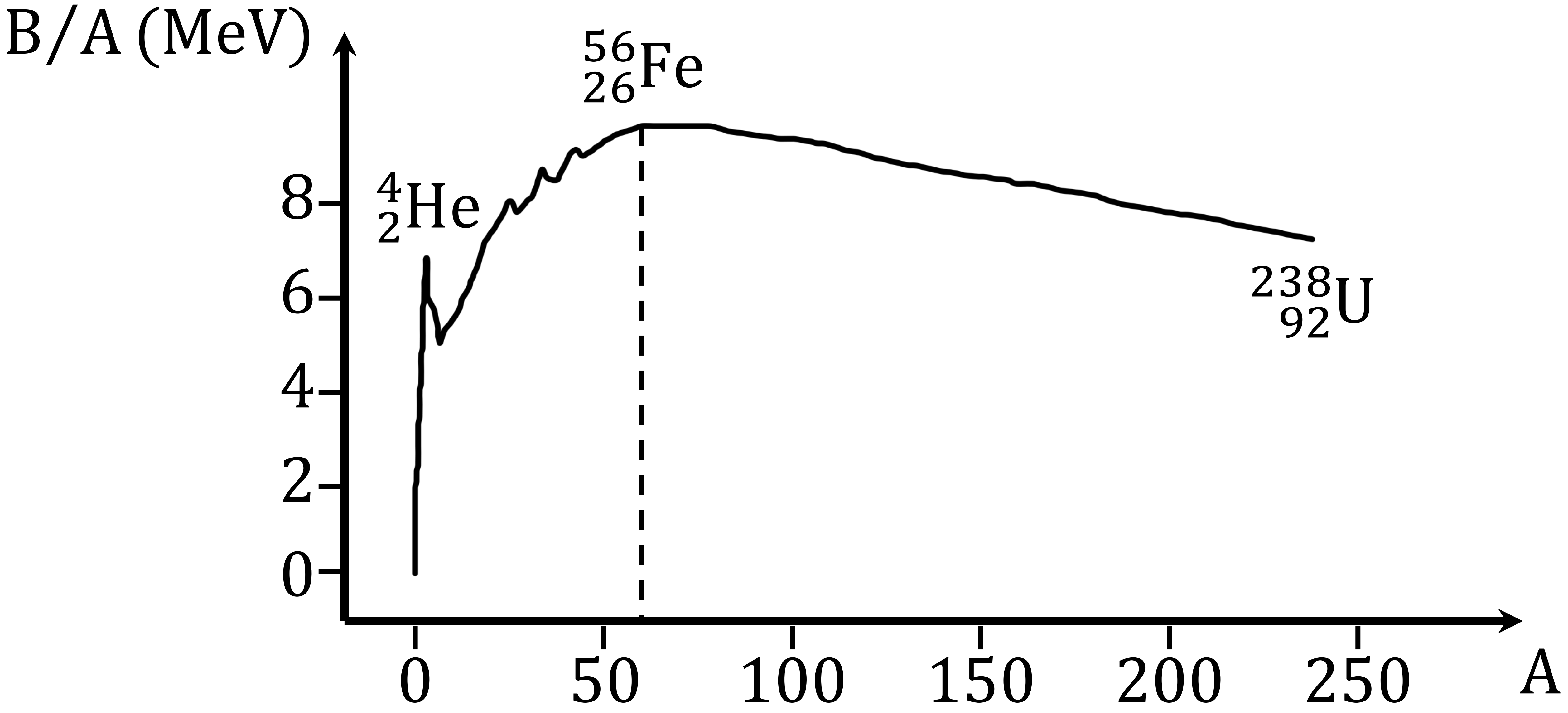
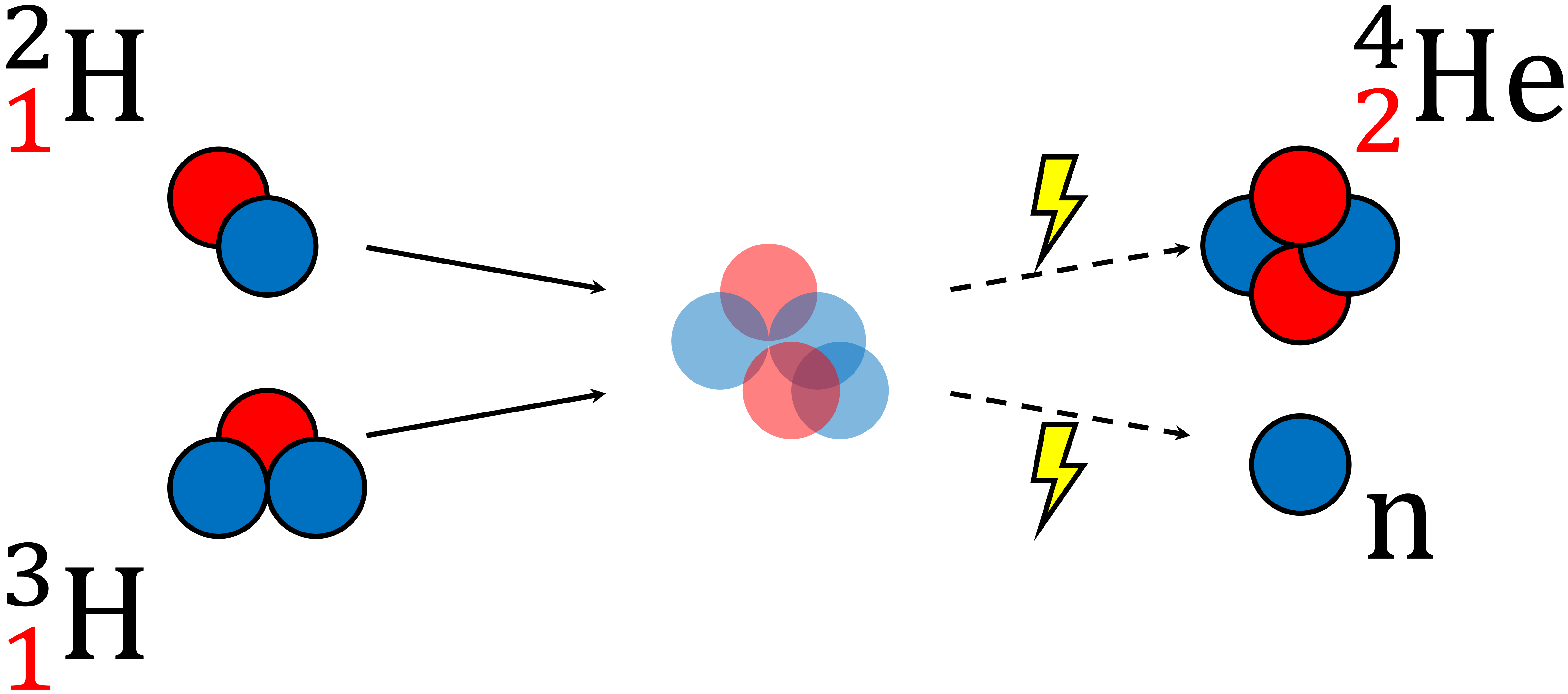
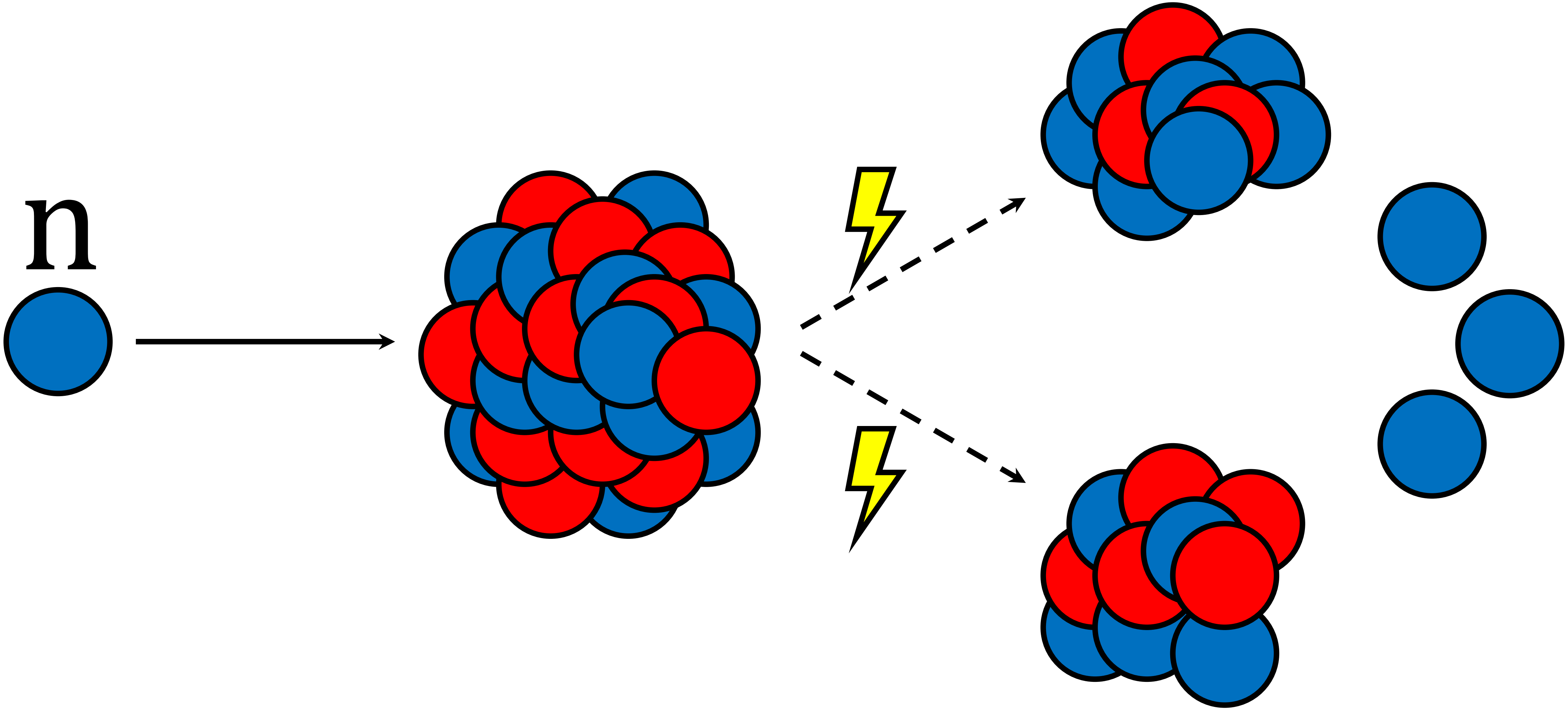
ENERGIA DI LEGAME



FUSIONE NUCLEARE



FISSIONE NUCLEARE



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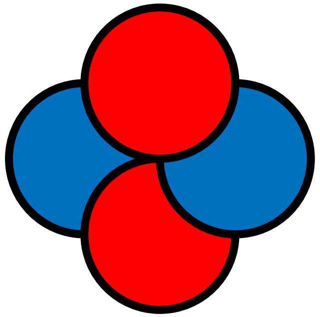
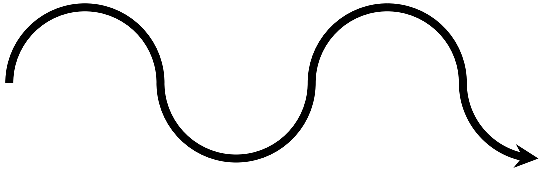
DECADIMENTI RADIOATTIVI

α β γ



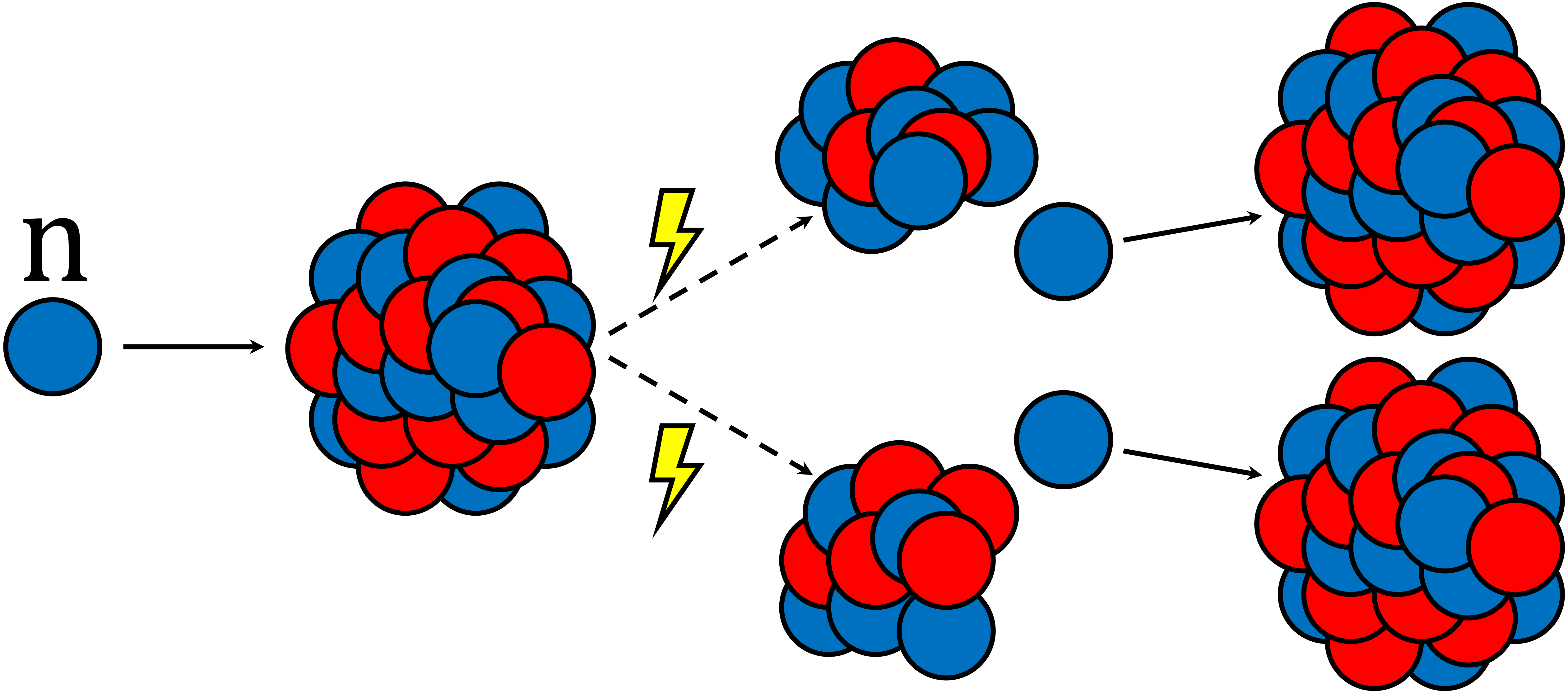


James Chadwick

1932

~~F_c~~

REAZIONE A CATENA



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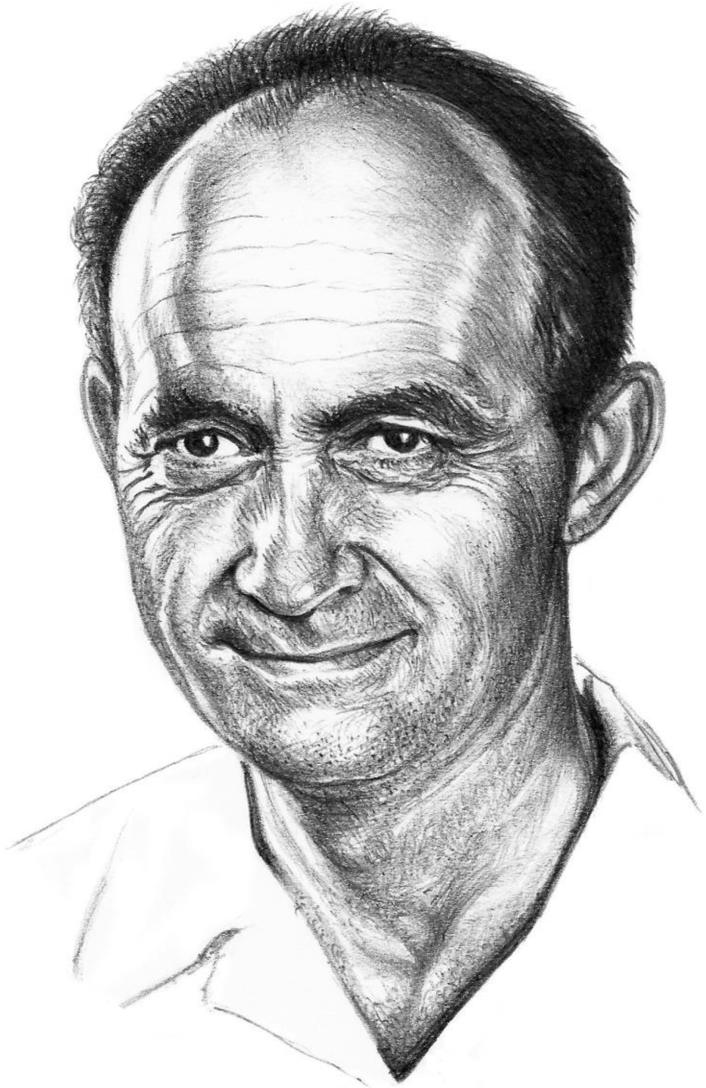
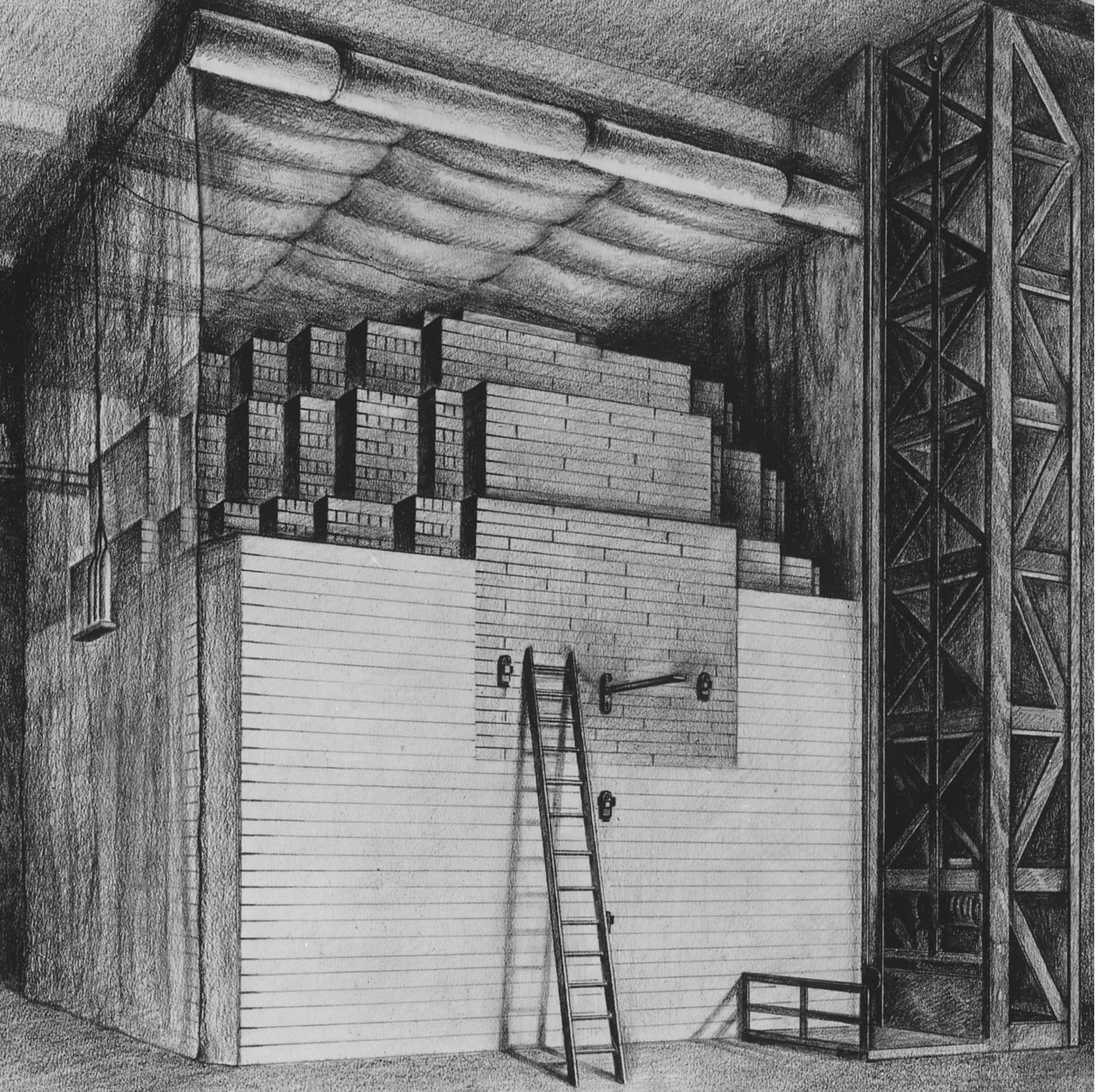
Enrico Fermi

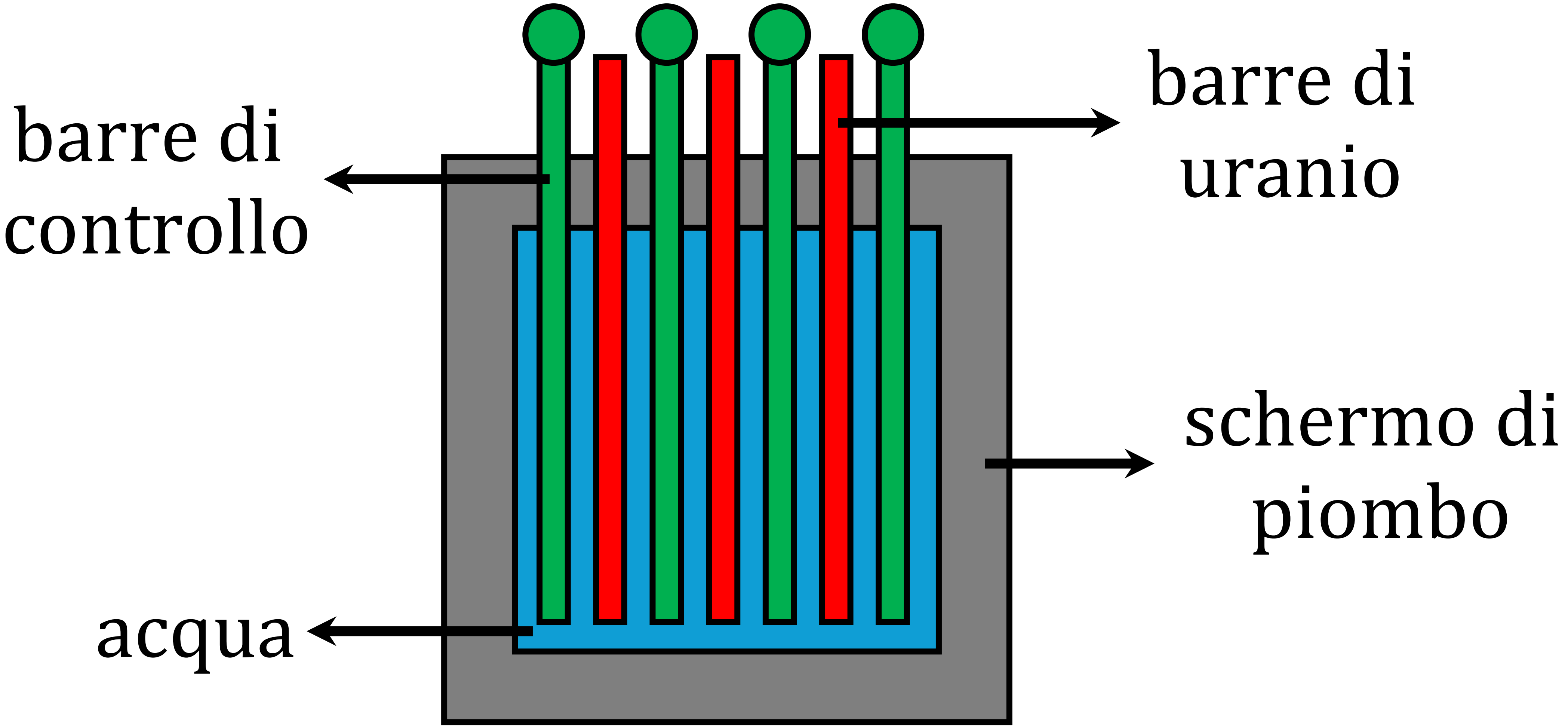
1942



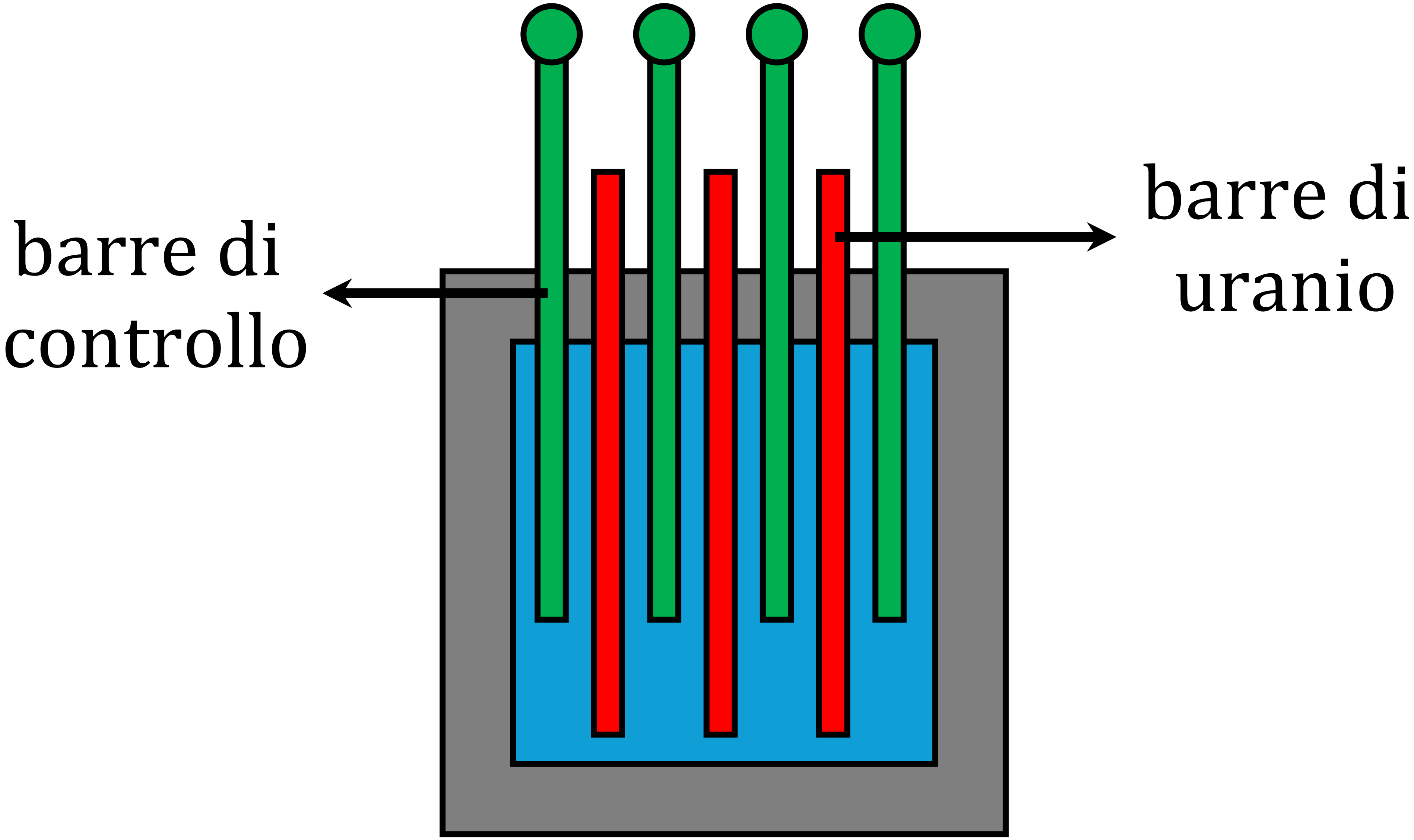


Chicago

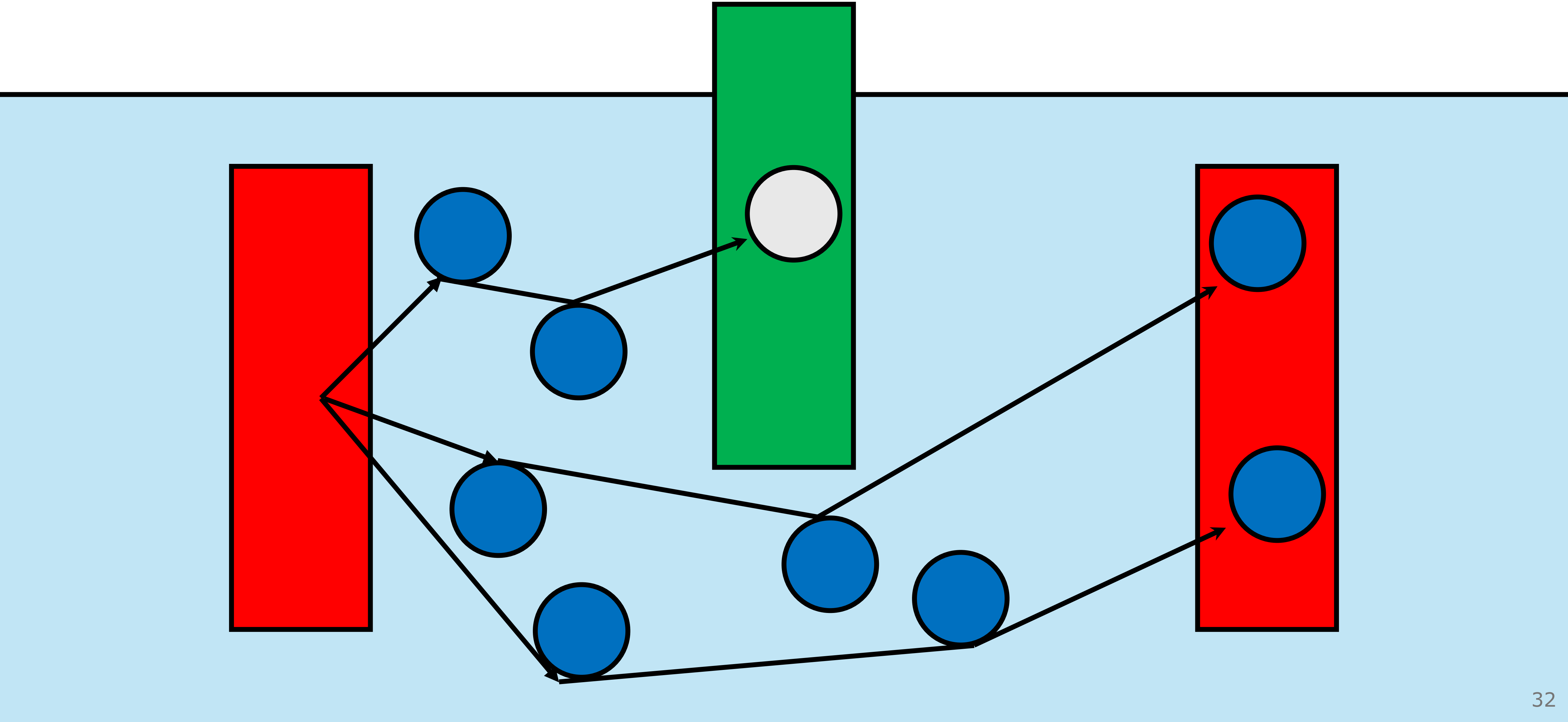
REATTORE NUCLEARE



REATTORE NUCLEARE



REATTORE NUCLEARE



PARAMETRO DI CRITICITÀ

$$k = \frac{P}{A + F}$$

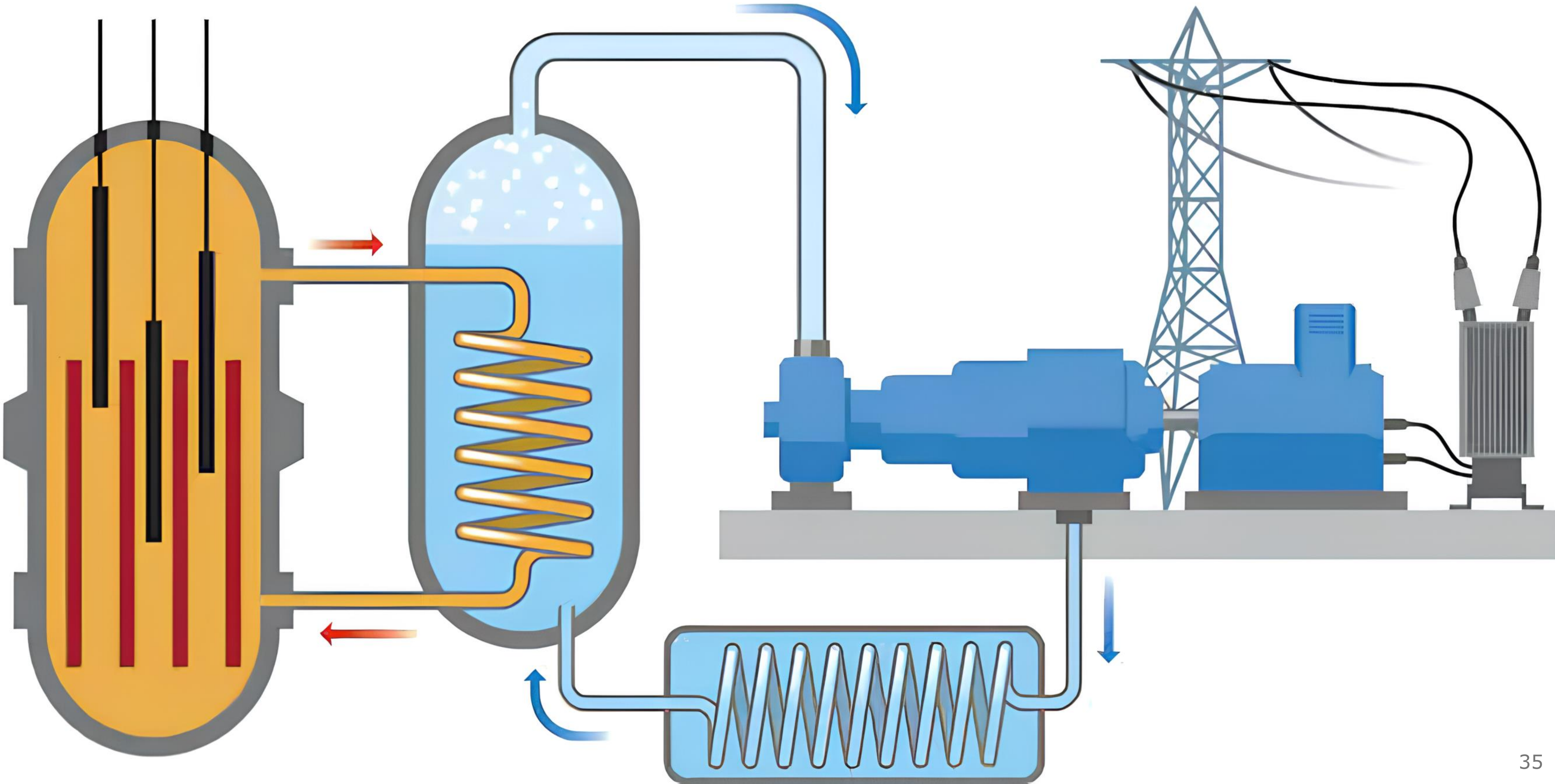
P = ● prodotti

A = ● assorbiti   F = ● fissione

$$P = A + F \Rightarrow k = 1$$

$$P < A + F \Rightarrow k < 1$$

$$P > A + F \Rightarrow k > 1$$



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Chernobyl
Fukushima
Situazione attuale


Chernobyl
Fukushima
Situazione attuale


Chernobyl
Fukushima
Situazione attuale

- Centrale Latina: Latina (LT)
- Centrale Garigliano: Sessa Aurunca (CE)
- Centrale Enrico Fermi: Trino Vercellese (VC)
- Centrale Caorso: Caorso (PC)

- Centrale Alto Lazio: Montalto di Castro (VT)

REFERENDUM 1987

1. Vietare la costruzione di nuove centrali?

Sì	80.57 %
No	19.43 %

2. Eliminare i contributi per incentivare le centrali nucleari?

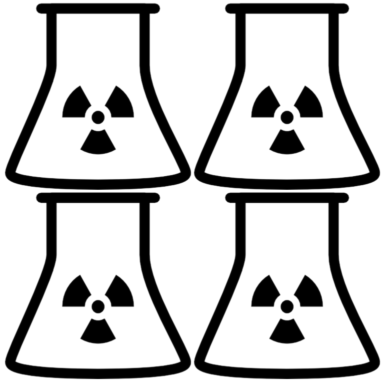
Sì	79.71 %
No	20.29 %

3. Impedire la partecipazione dell’Enel a impianti nucleari all’estero?

Sì	71.86 %
No	28.14 %

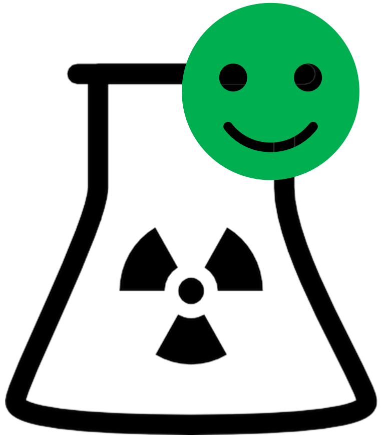
REFERENDUM 2011

1. Eliminare la realizzazione sul territorio nazionale di impianti di produzione di energia nucleare?



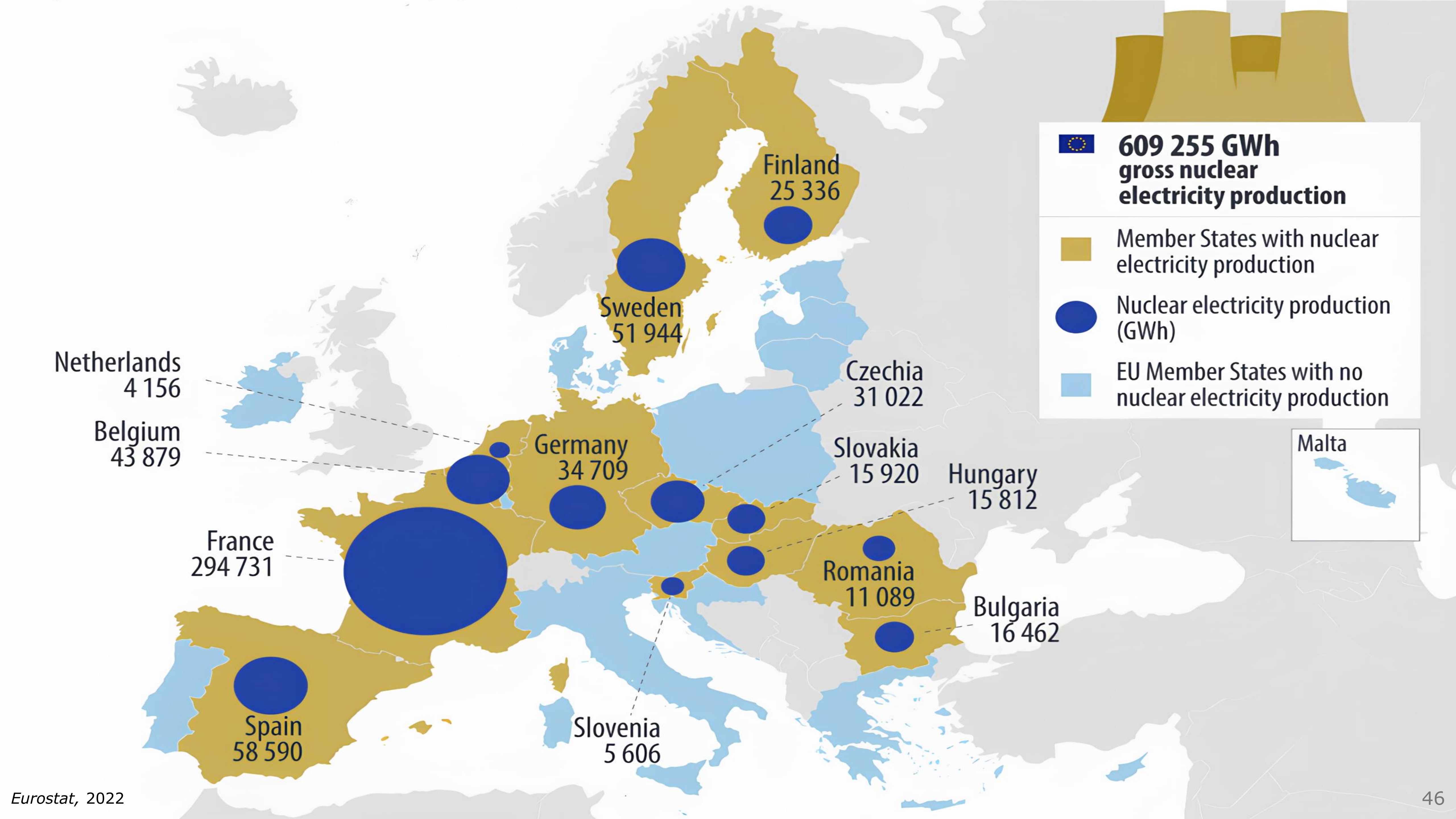
1959

1987

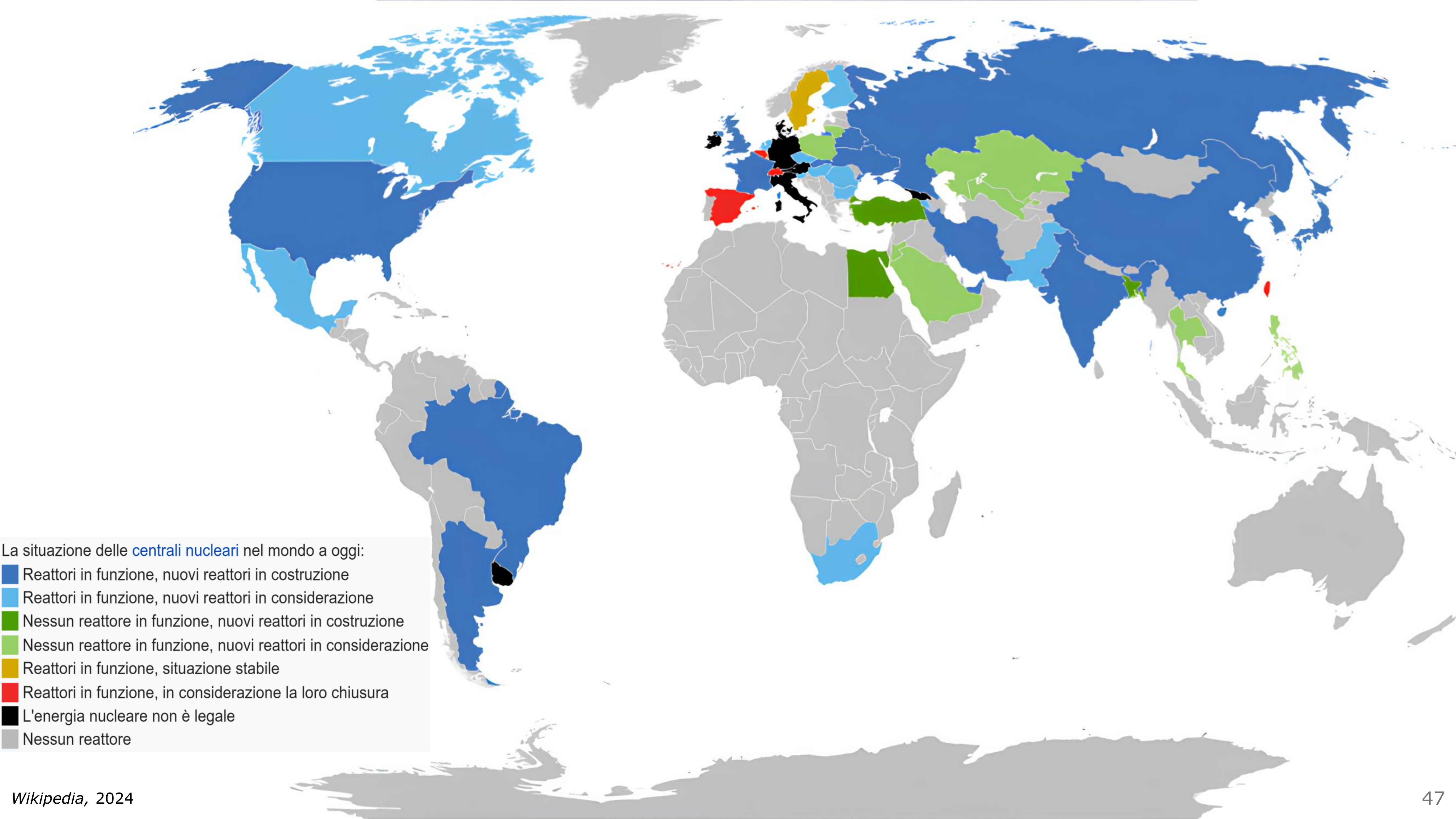


2008

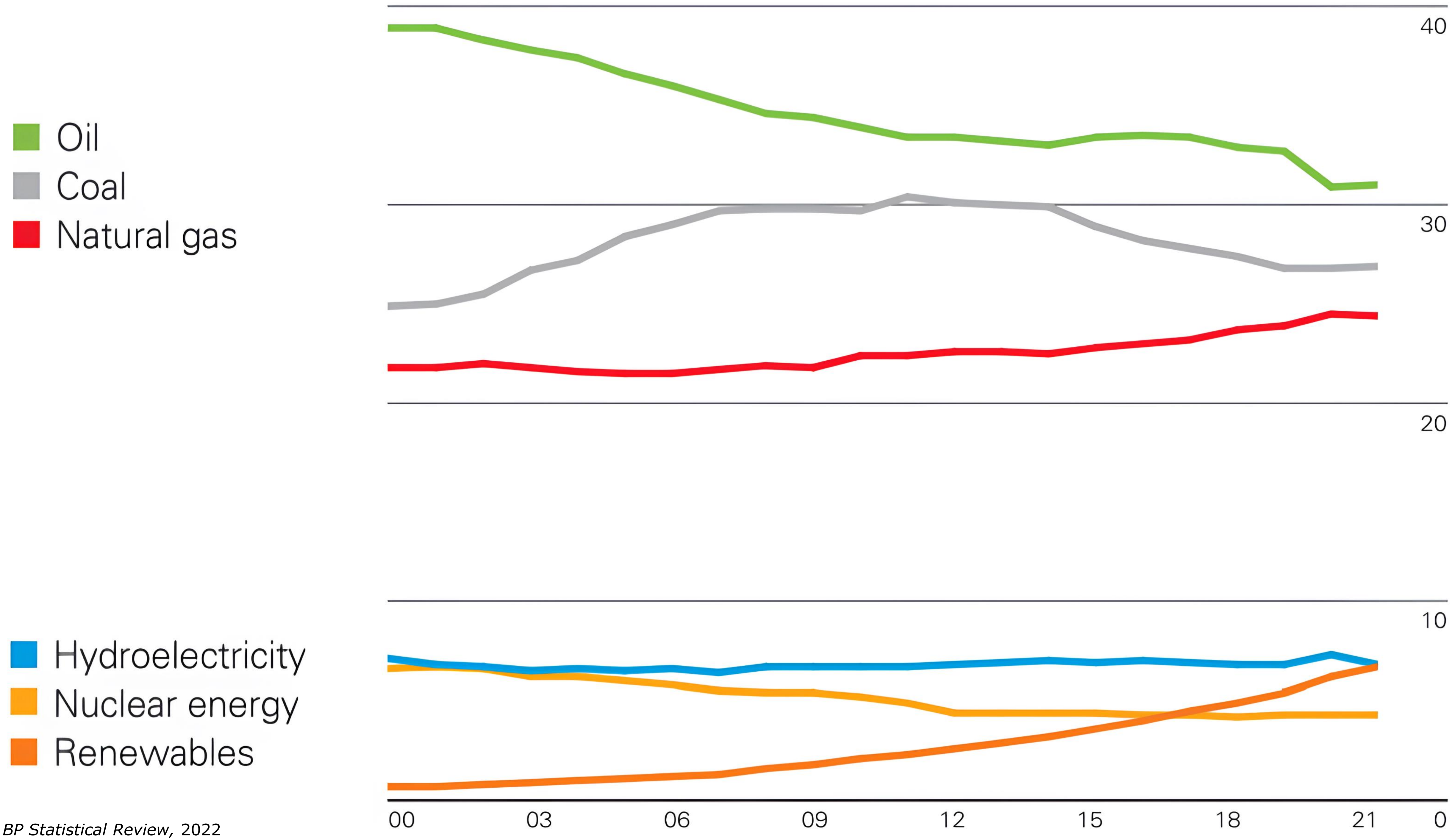
2011



Eurostat, 2022



Wikipedia, 2024



BP Statistical Review, 2022


Sicurezza e affidabilità
Rischio
Basso impatto ambientale
Tempi lunghi
Costi
Scorie

Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power, 2013

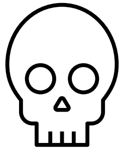
Goddard Institute for Space Studies

James E. Hansen

Pushker A. Kharecha

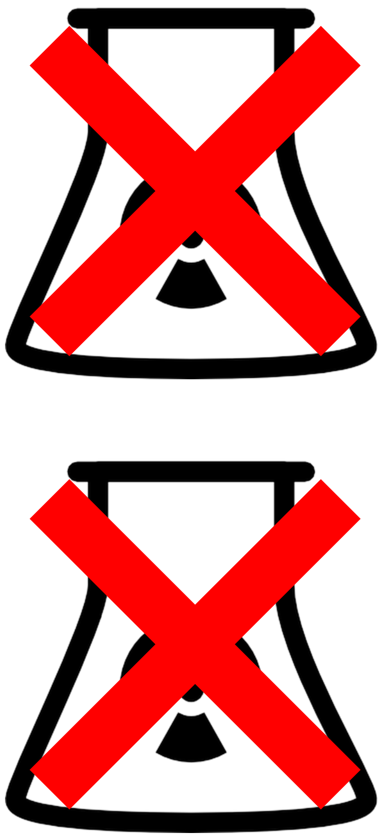
1971 — 2009

-2 milioni

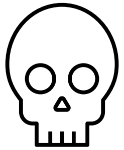


James E. Hansen e Pushker A. Kharecha, *Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power*, 2013

2010 2050



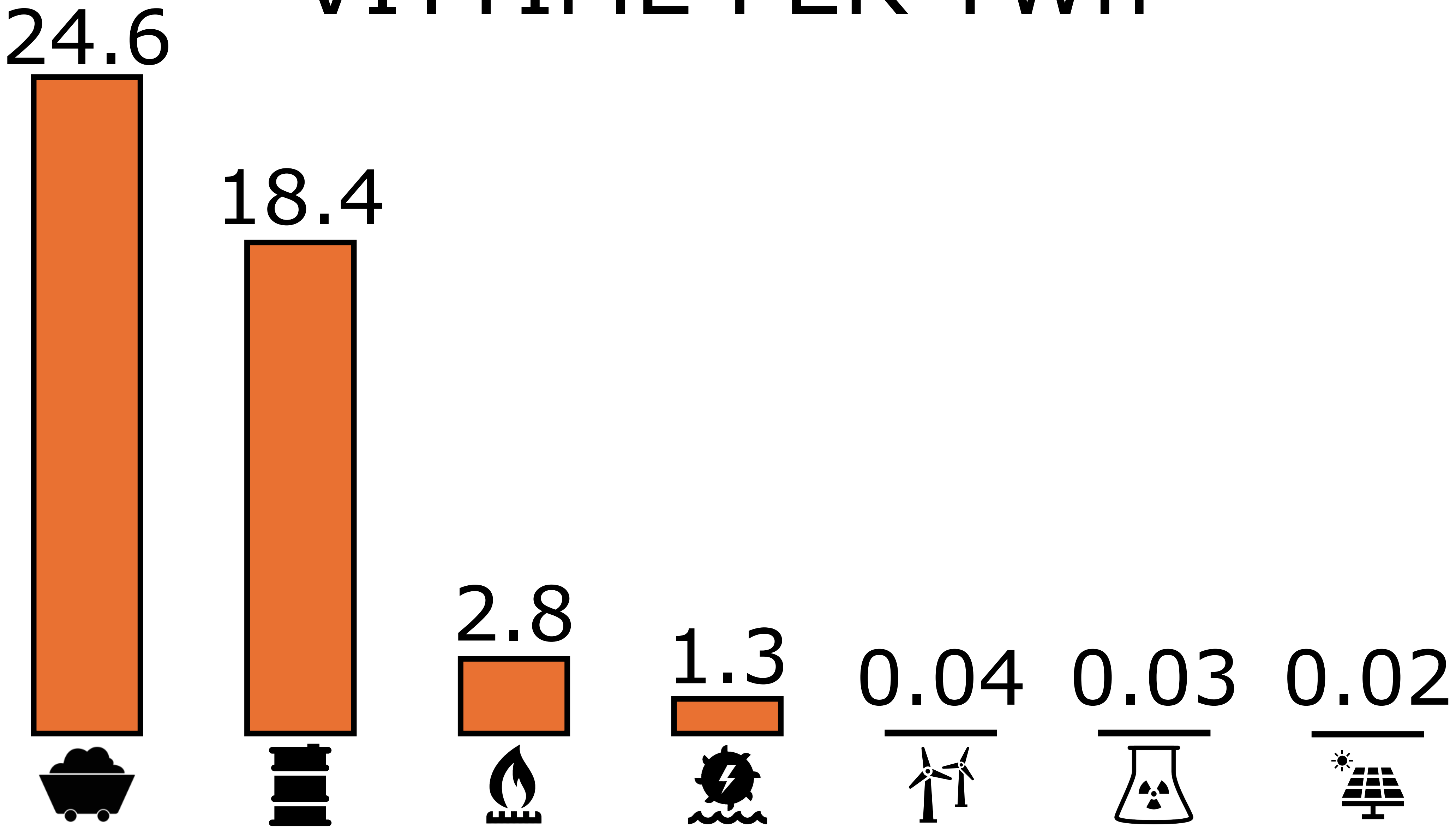
+420 mila



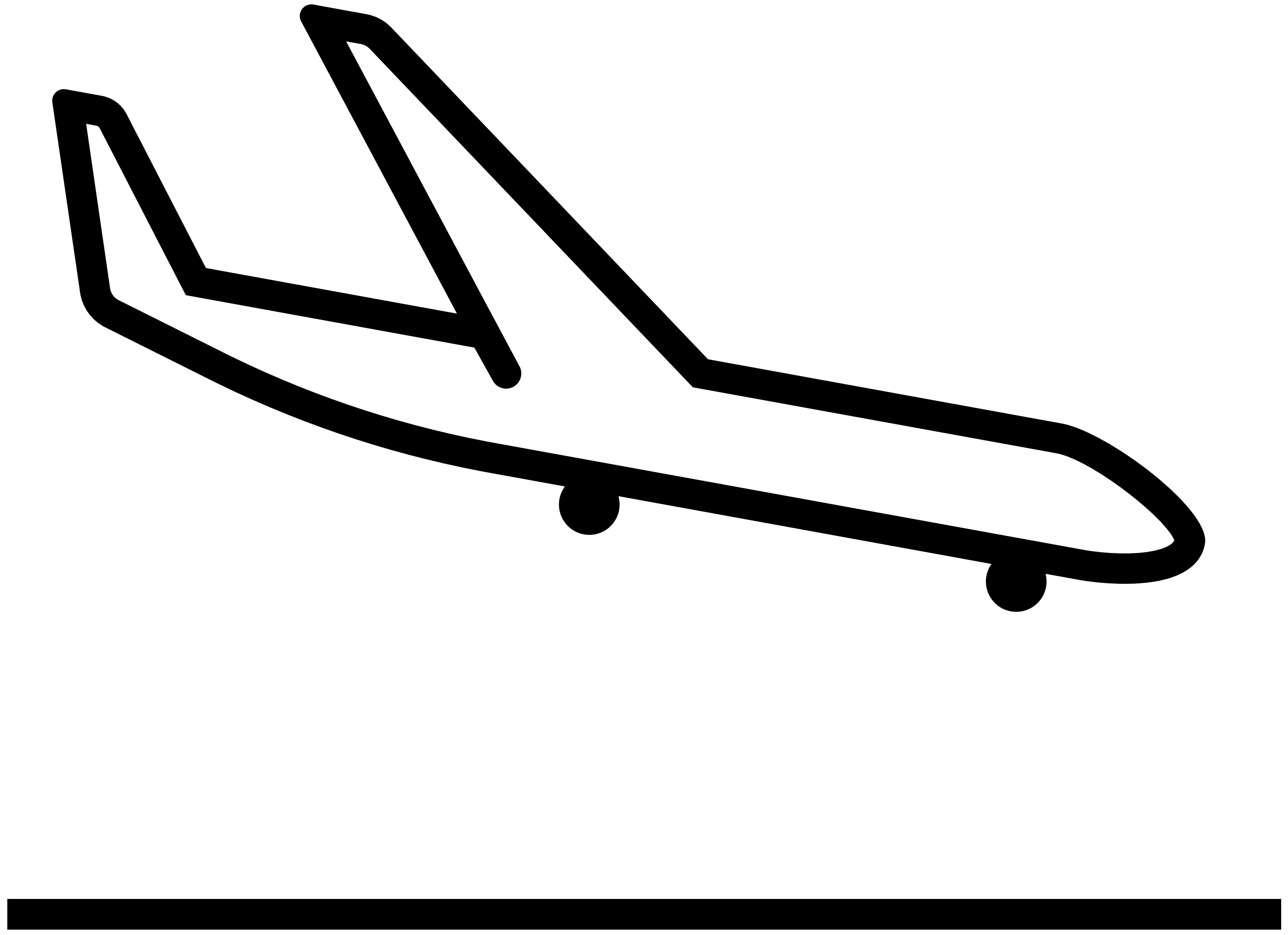
+7 milioni

James E. Hansen e Pushker A. Kharecha, *Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power*, 2013

VITTIME PER TWh



Hannah Ritchie, *What are the safest and cleanest sources of energy?*, 2020

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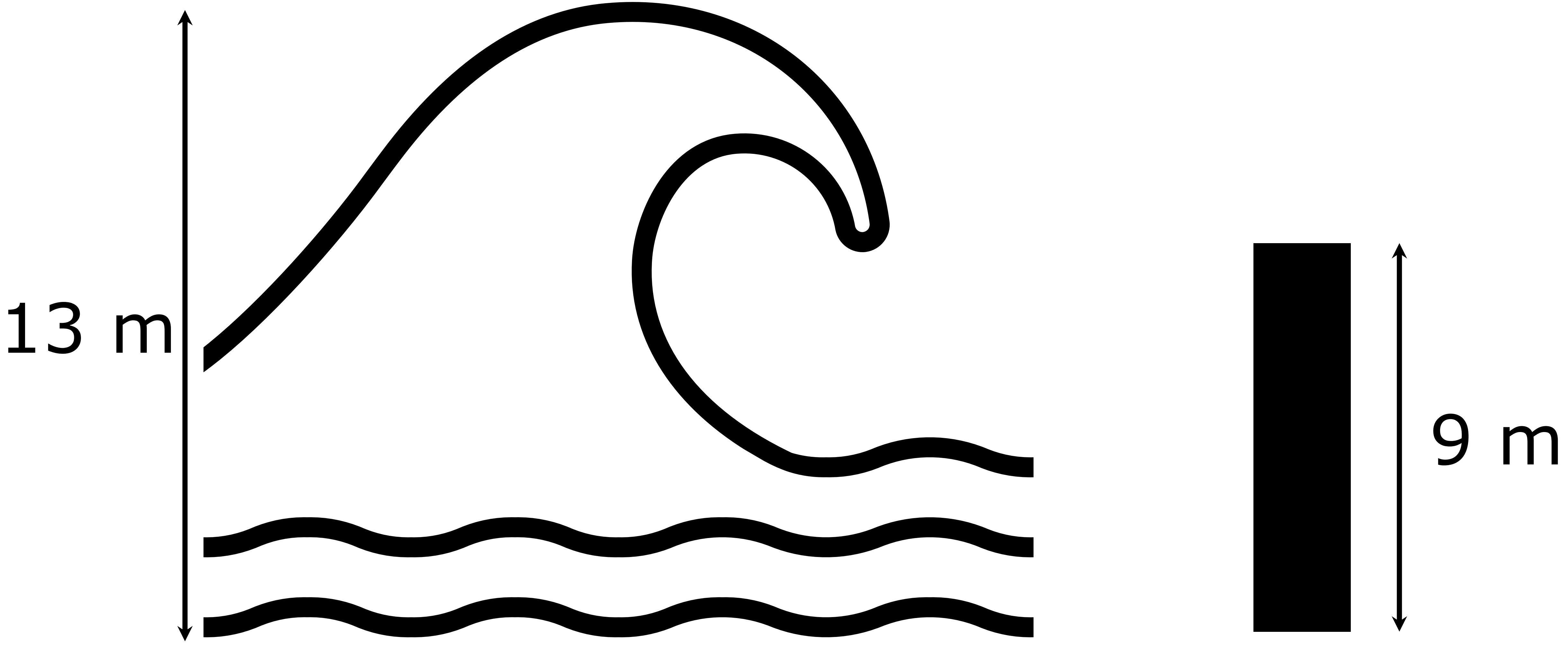
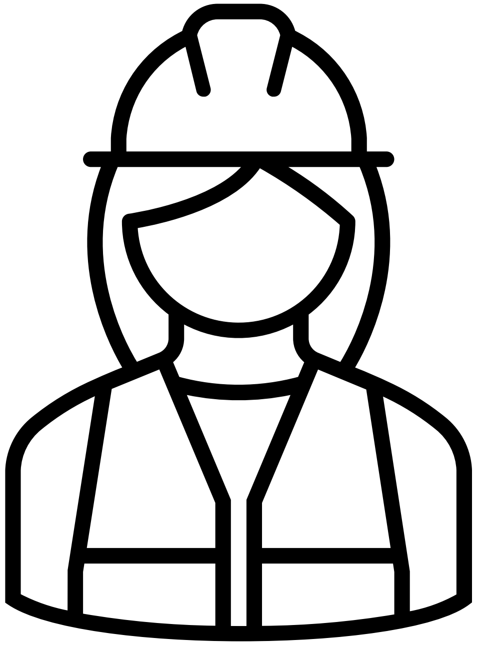
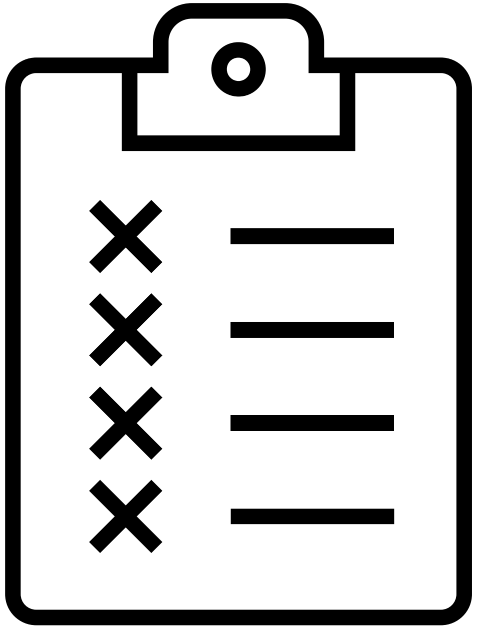
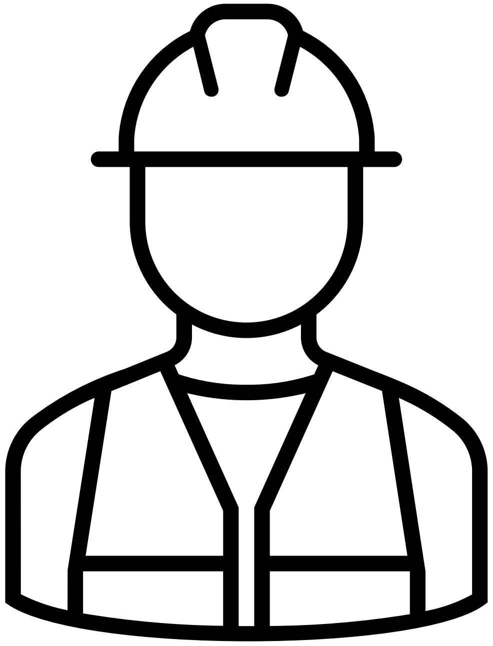

13 m
9 m


Three Mile Island

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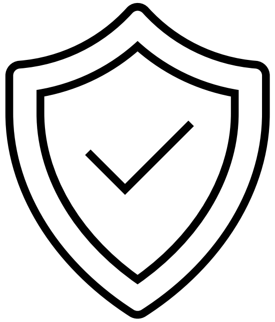


Sicurezza e affidabilità
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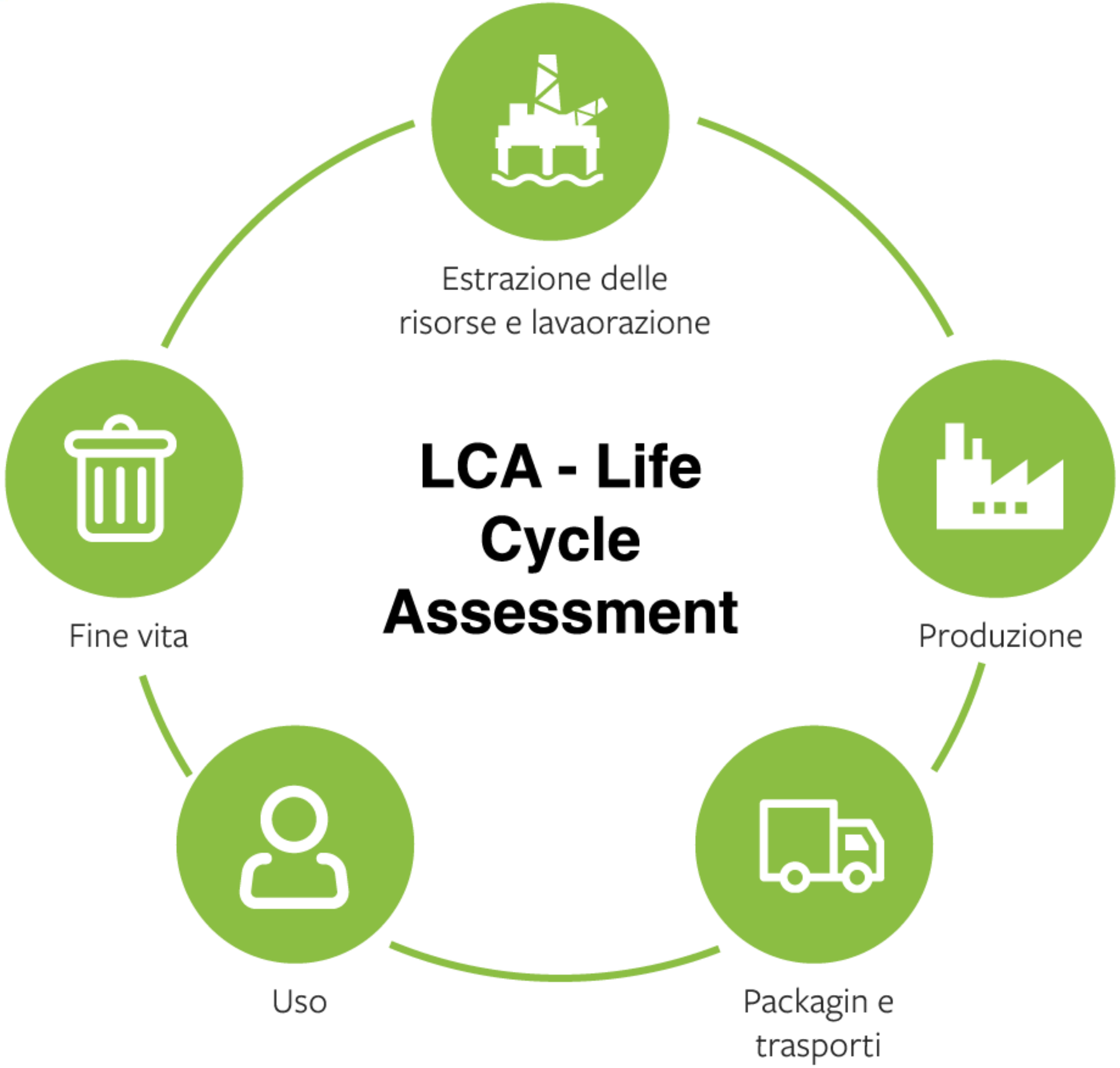
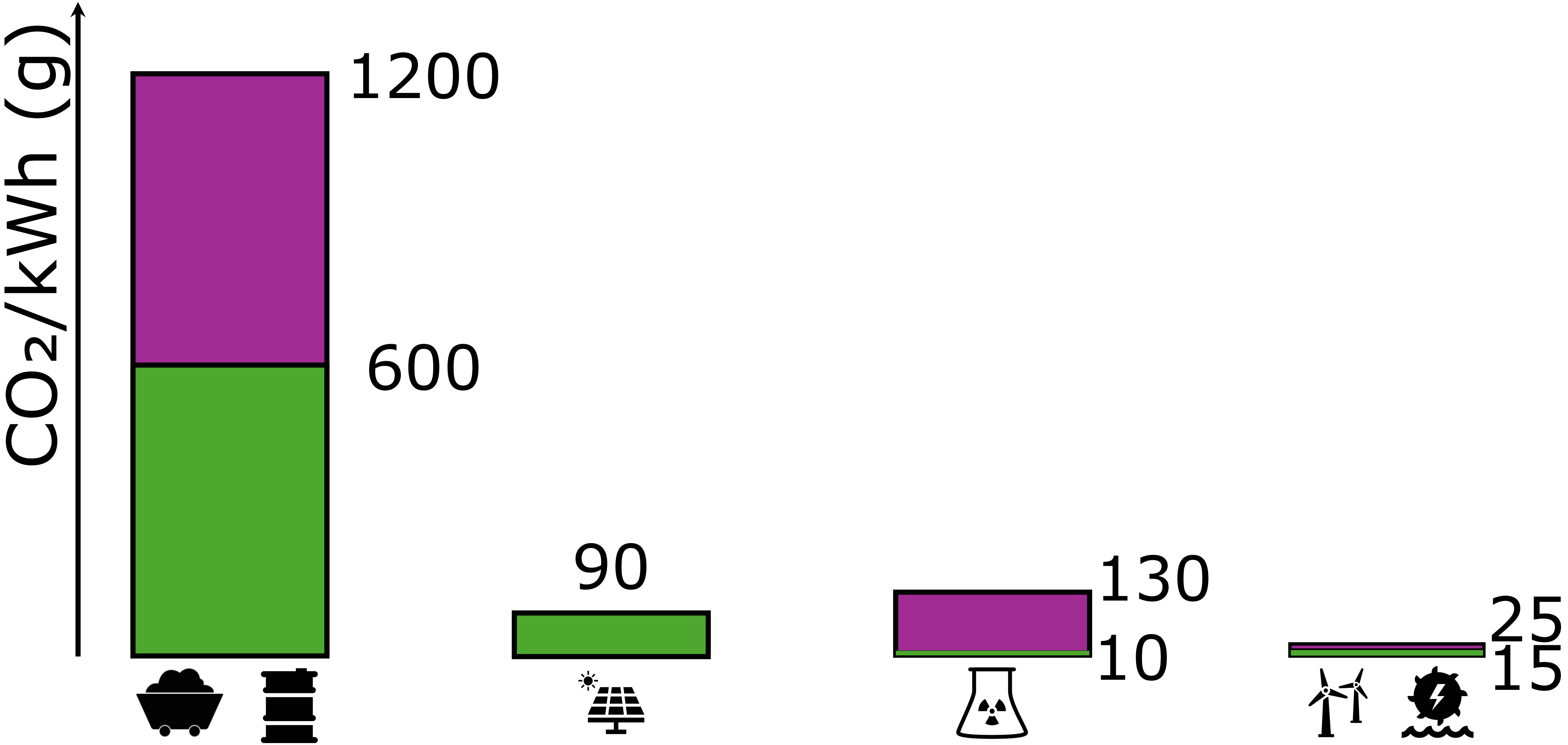
Life cycle energy and greenhouse gas emissions of nuclear energy: A review, 2008

Sydney University

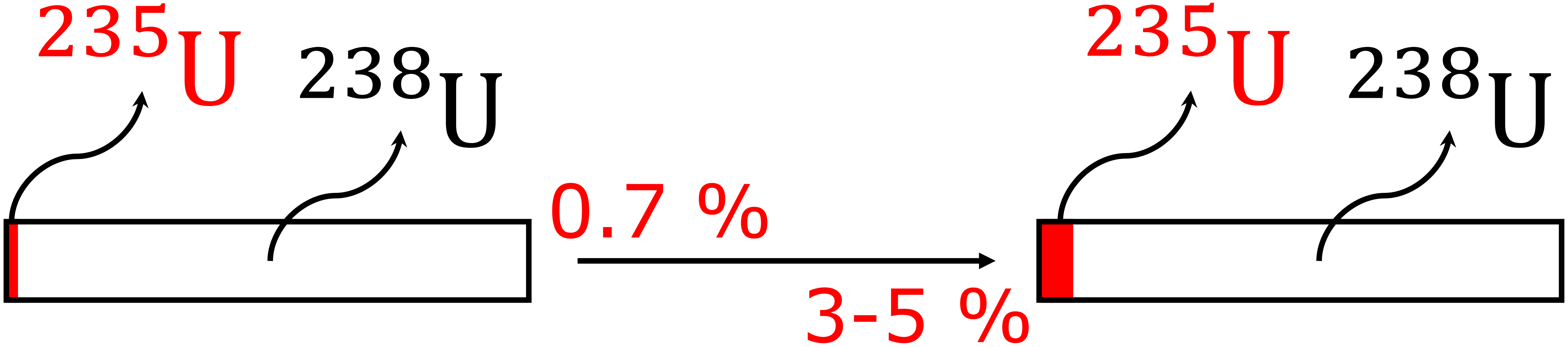
Manfred Lenzen



EMISSIONI DI CO_2 PER kWh



Manfred Lenzen, *Life cycle energy and greenhouse gas emissions of nuclear energy: A review*, 2008



Focus, *Energia nucleare e CO2: quanto è verde l'atomo?*, 2010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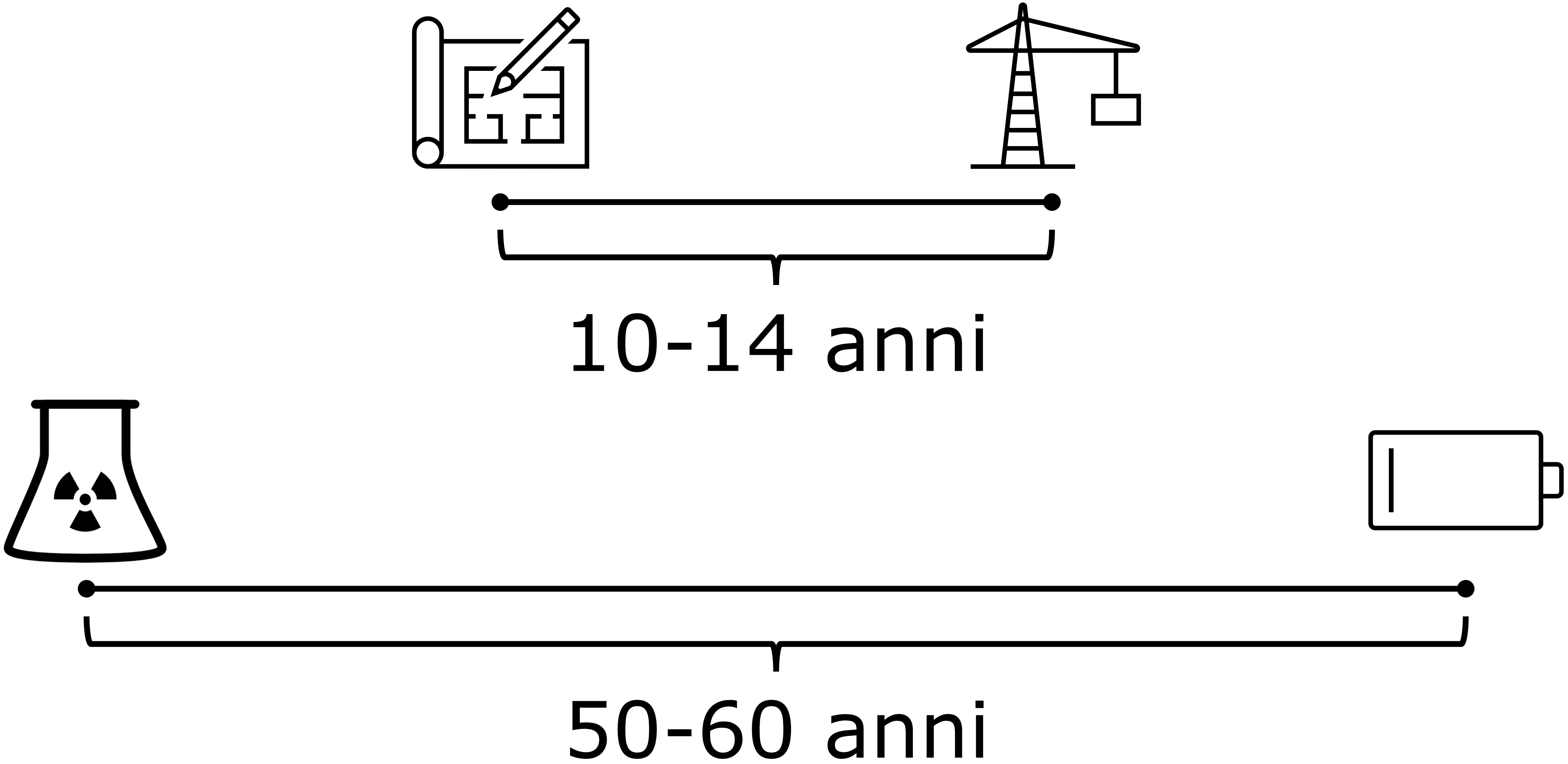
10-14 anni
50-60 anni


Sicurezza e affidabilità
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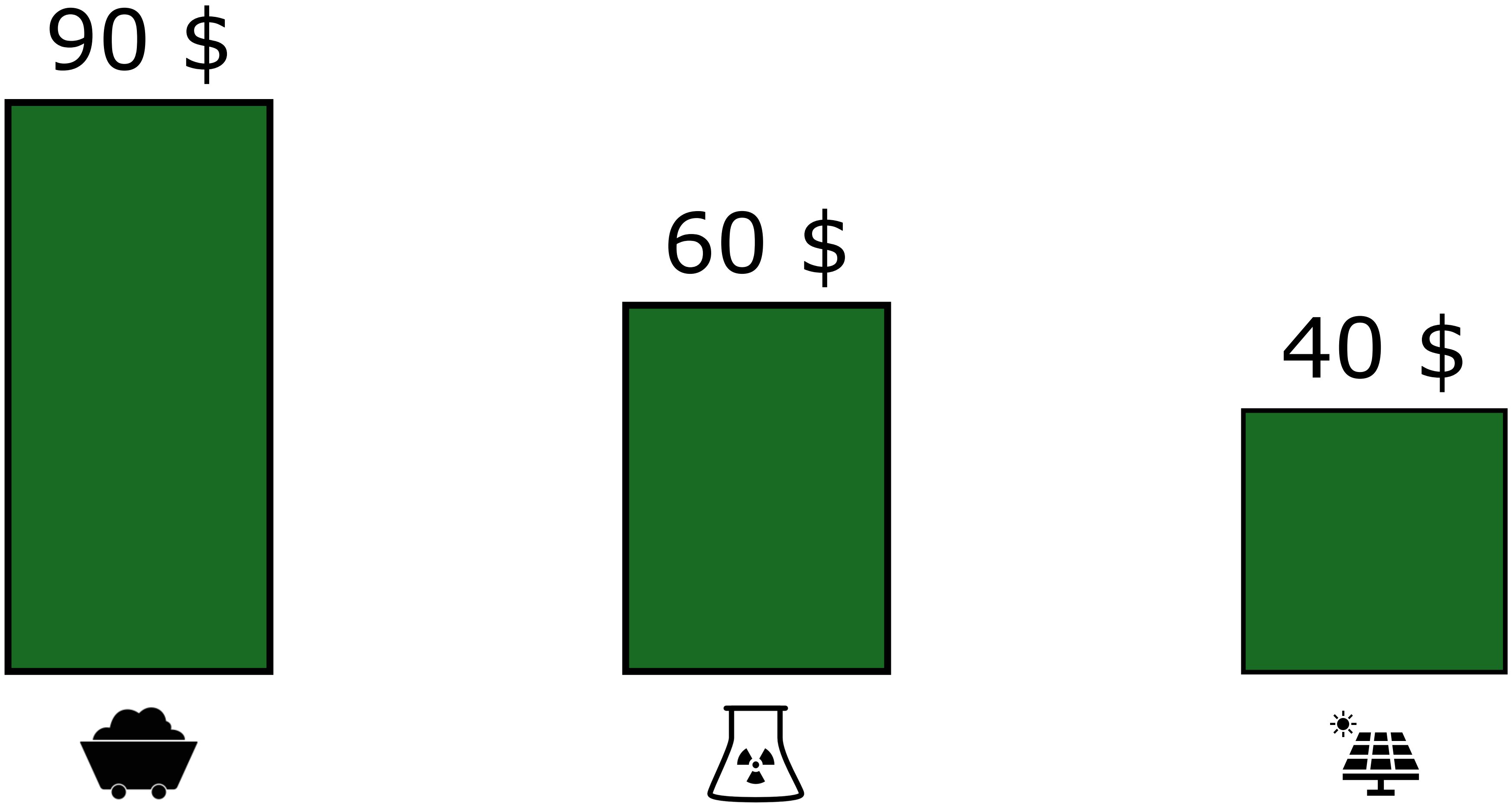
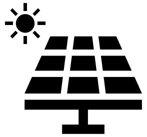
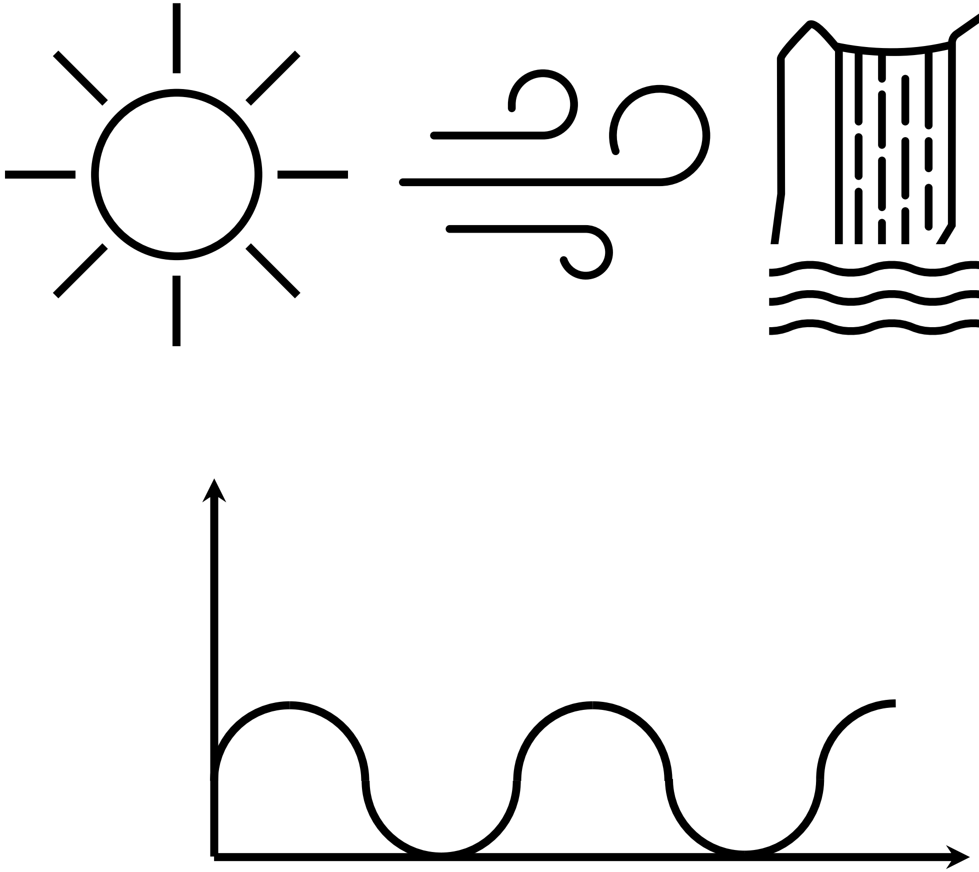
COSTI PER kWh

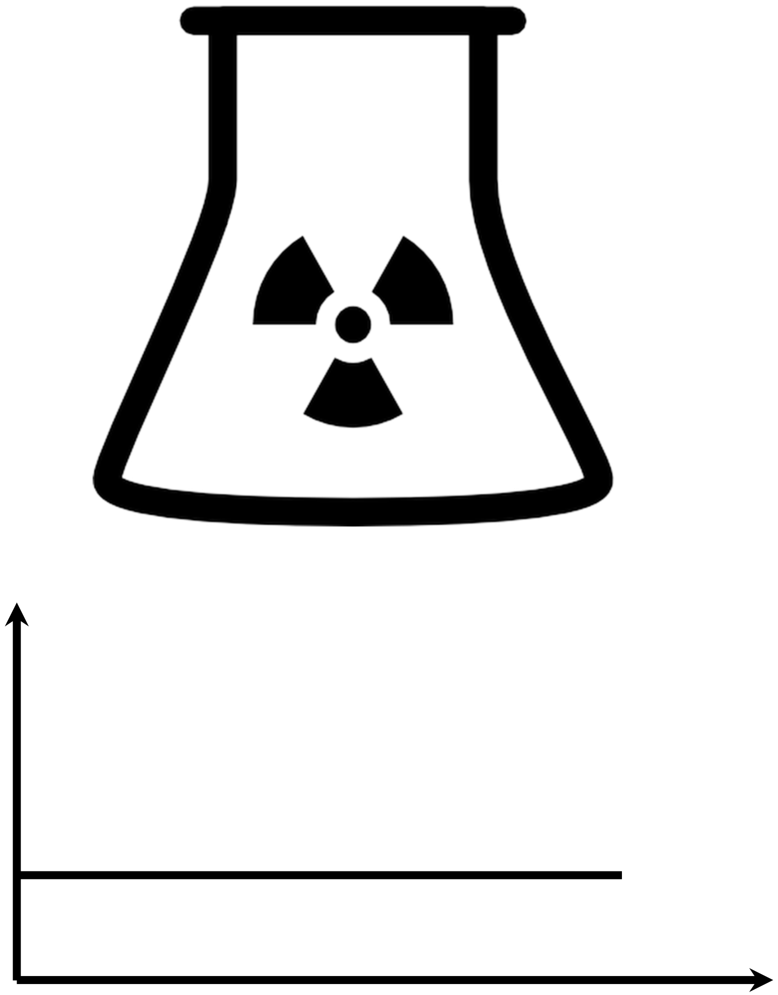


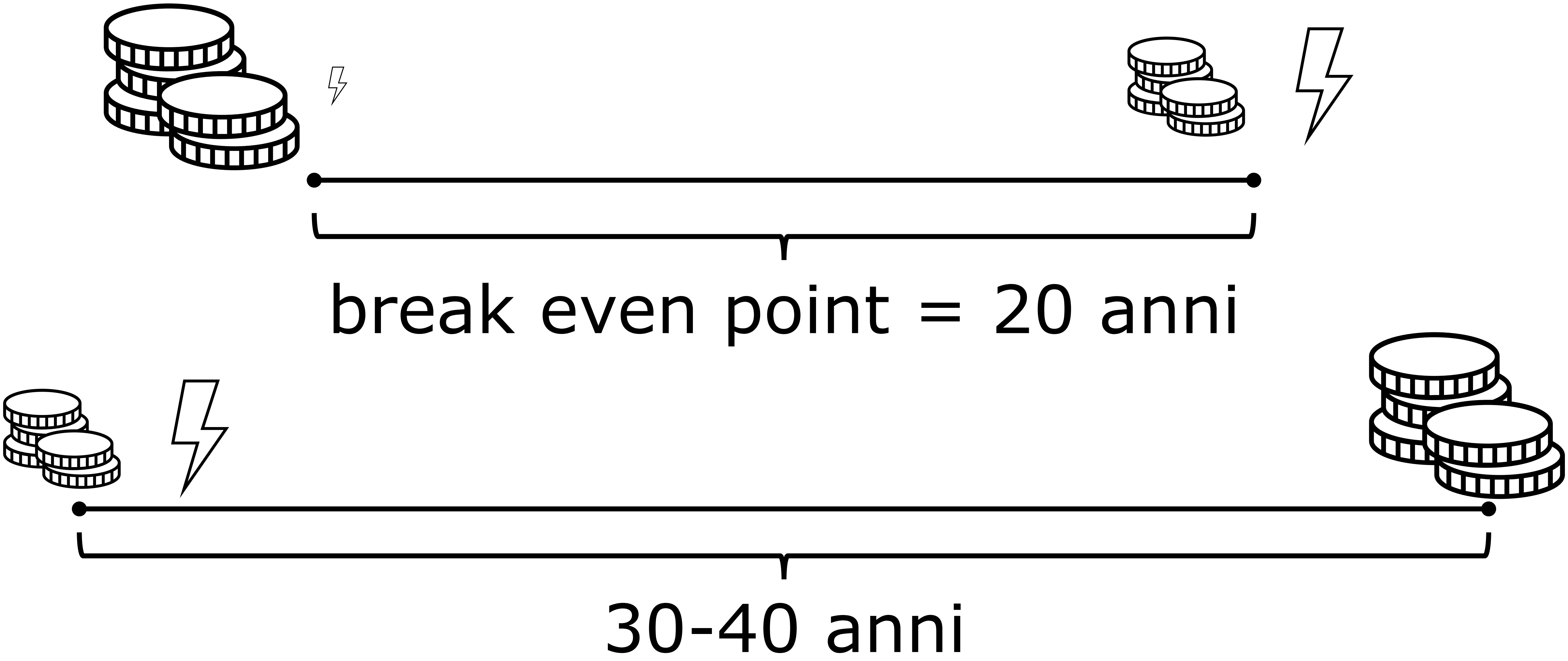
ENEA, 2022

1 kg di ^{235}U = 18.7 milioni di kWh

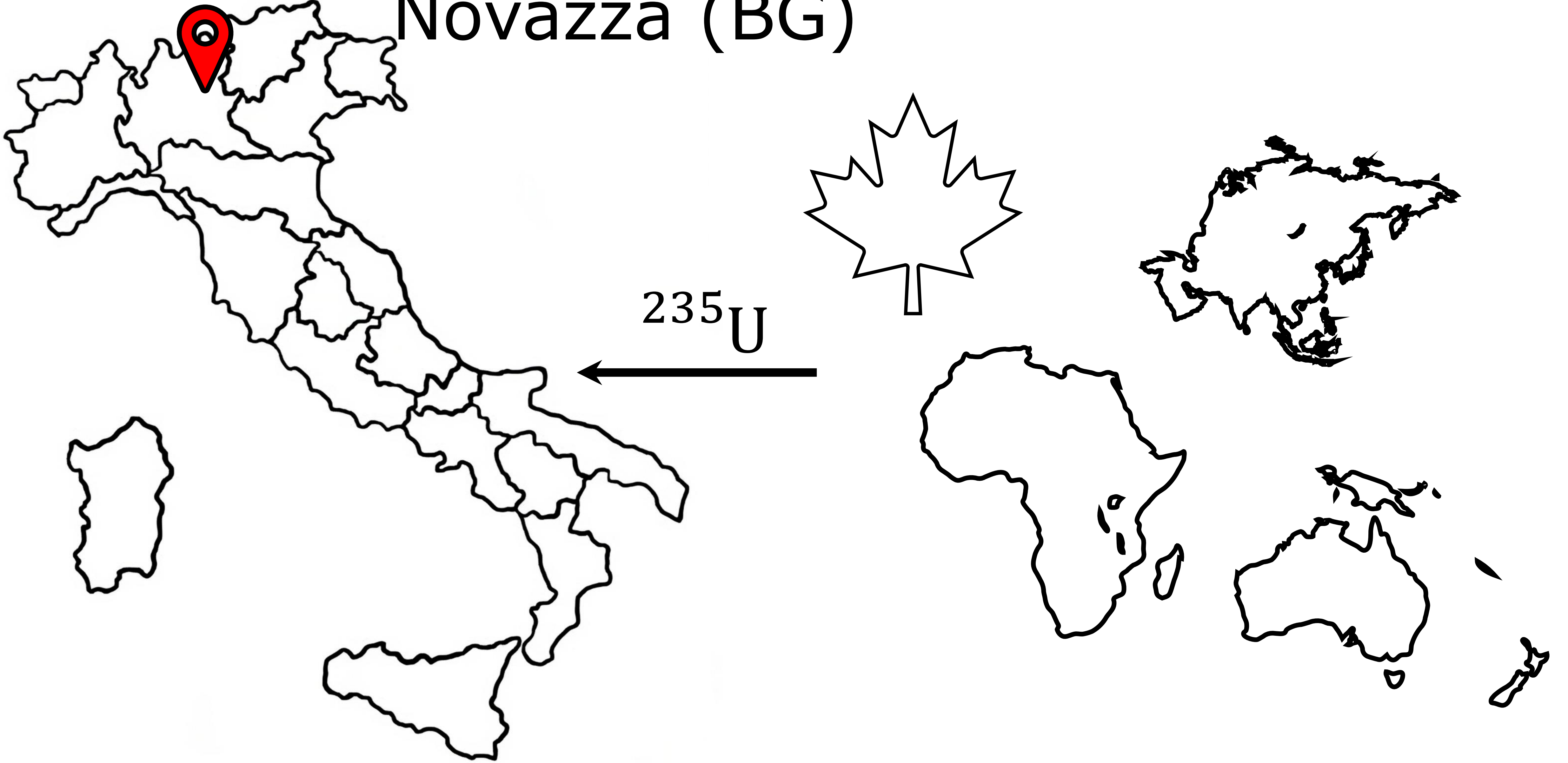
60 milioni di  da 1.7 m² al 100%



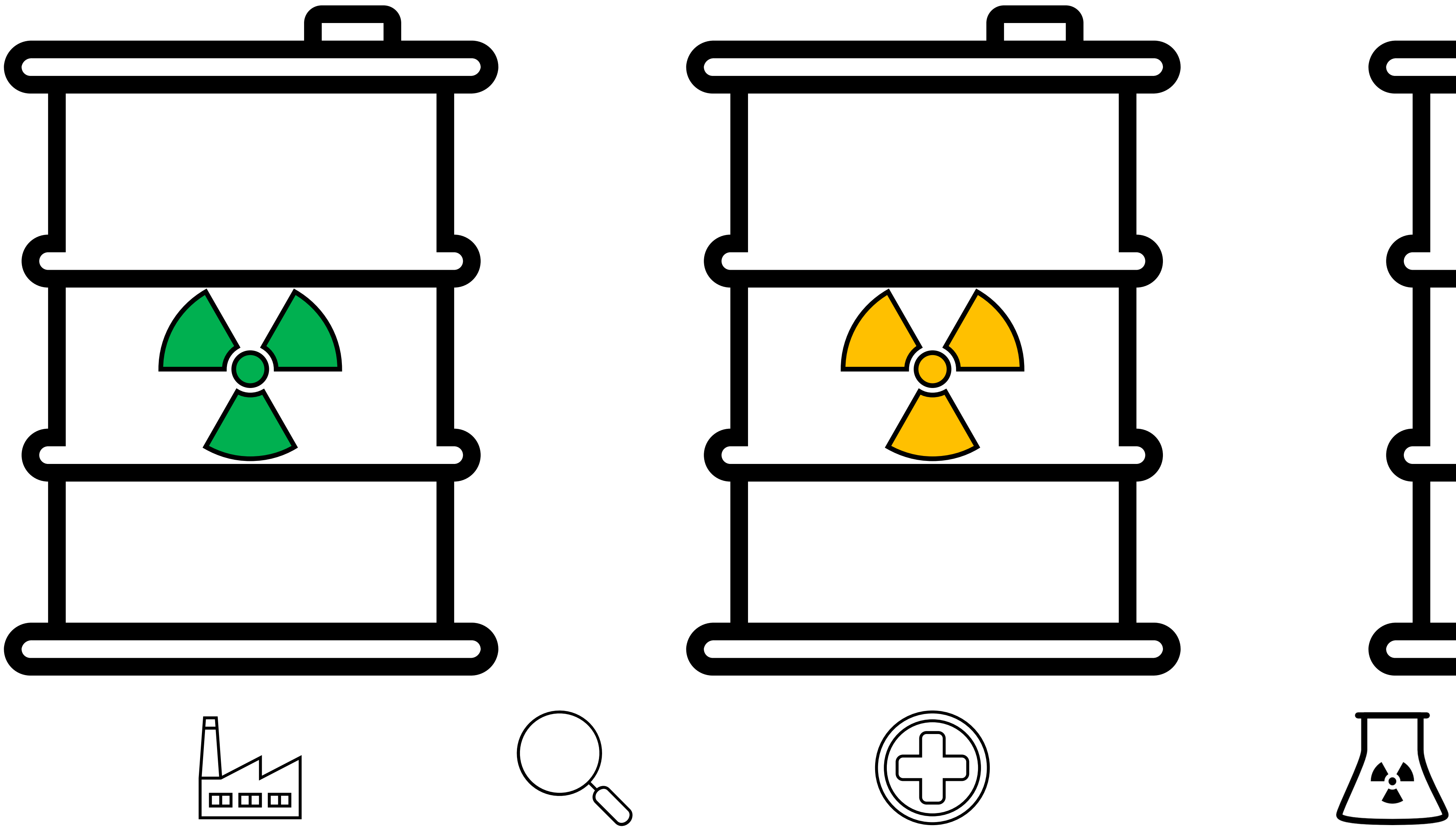



break even point = 20 anni
30-40 anni

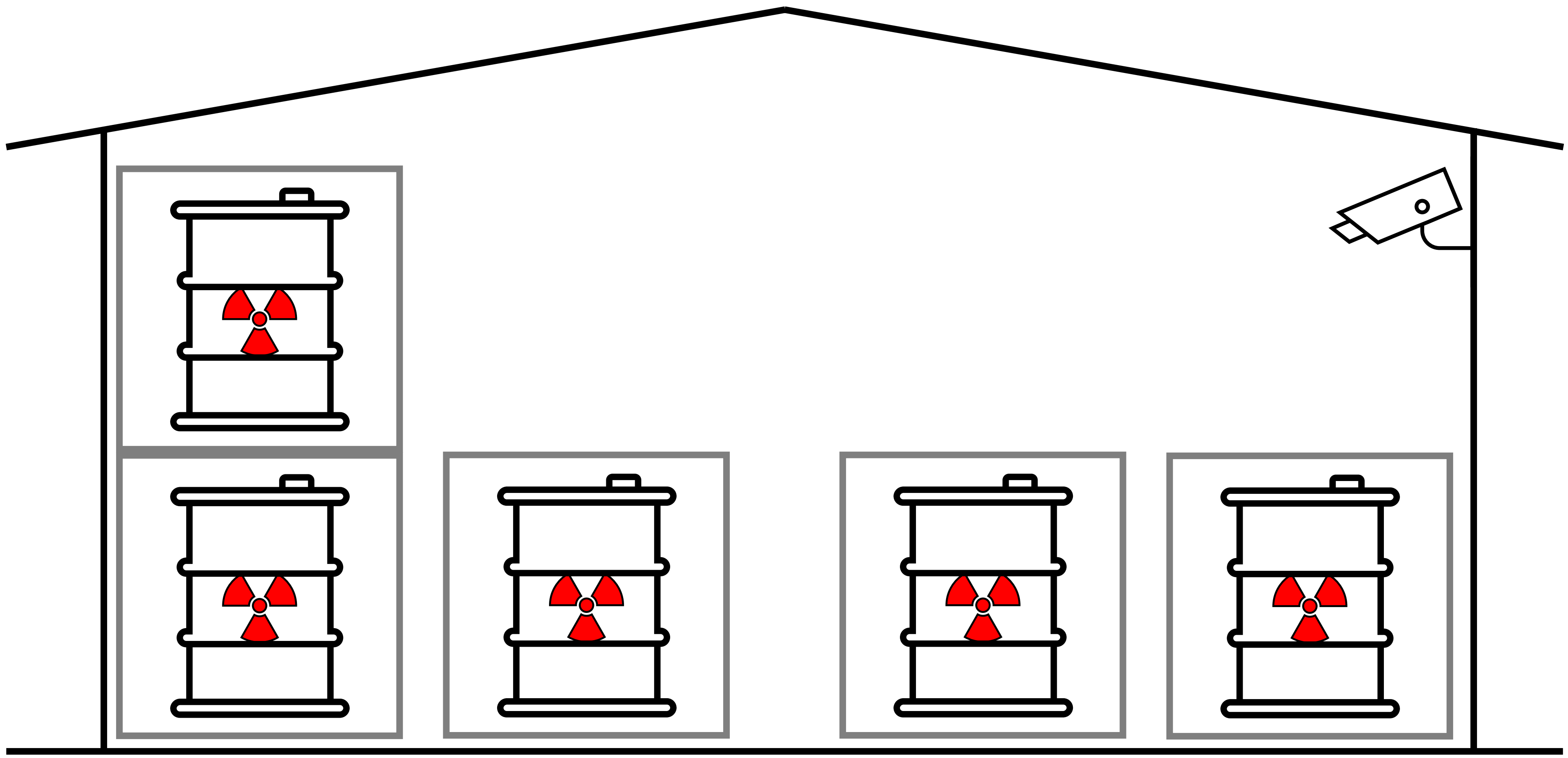
Novazza (BG)

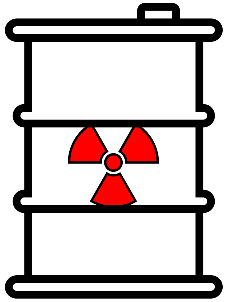
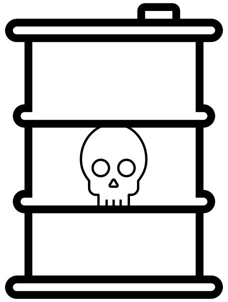
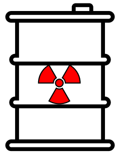
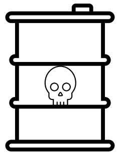



Sicurezza e affidabilità
Rischio
Basso impatto ambientale
Tempi lunghi
Costi
Scorie

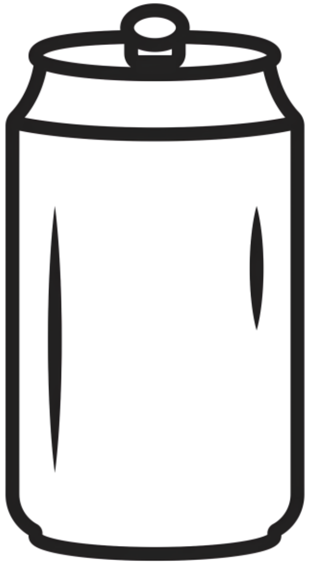


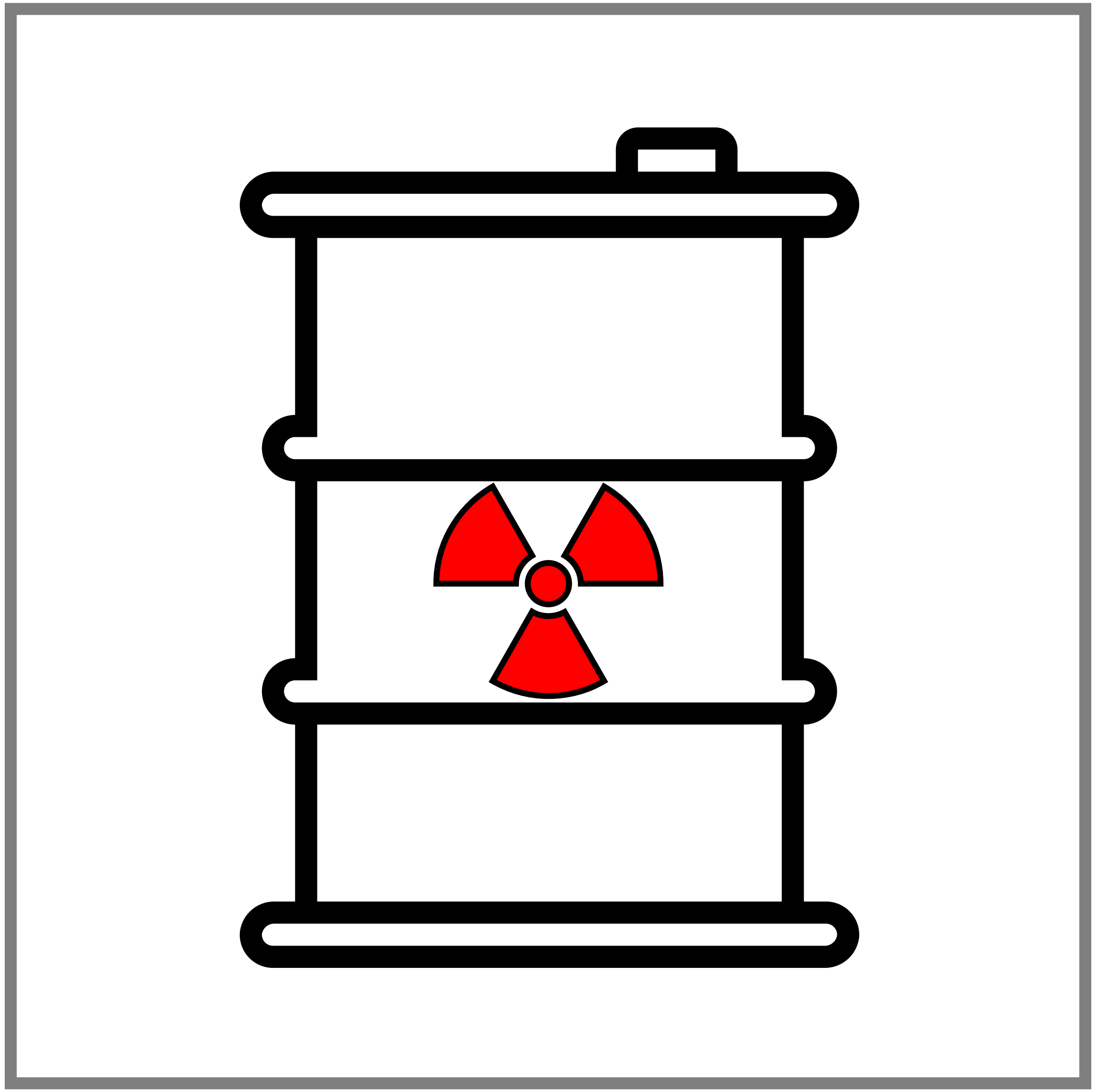
3 m^3/anno

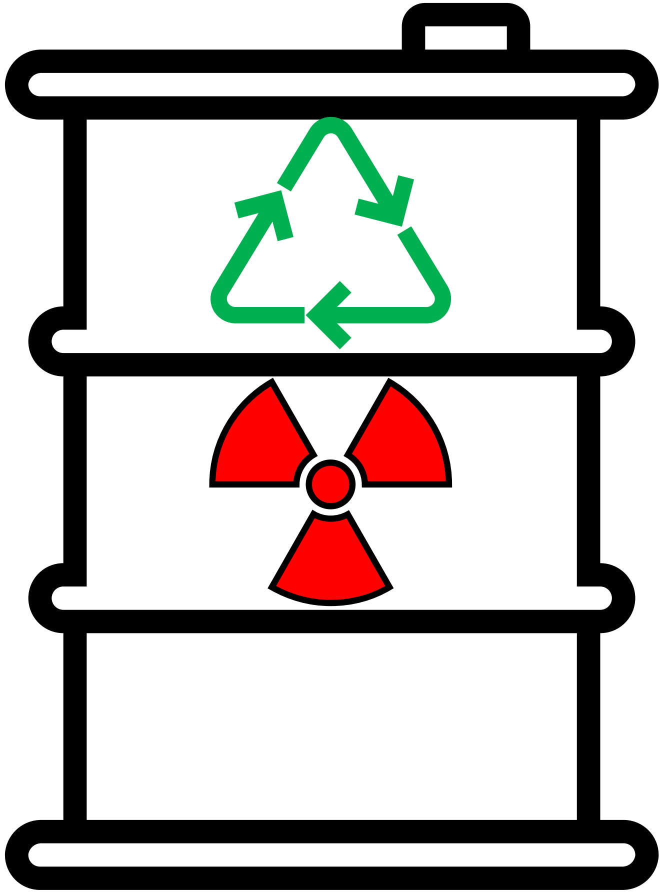


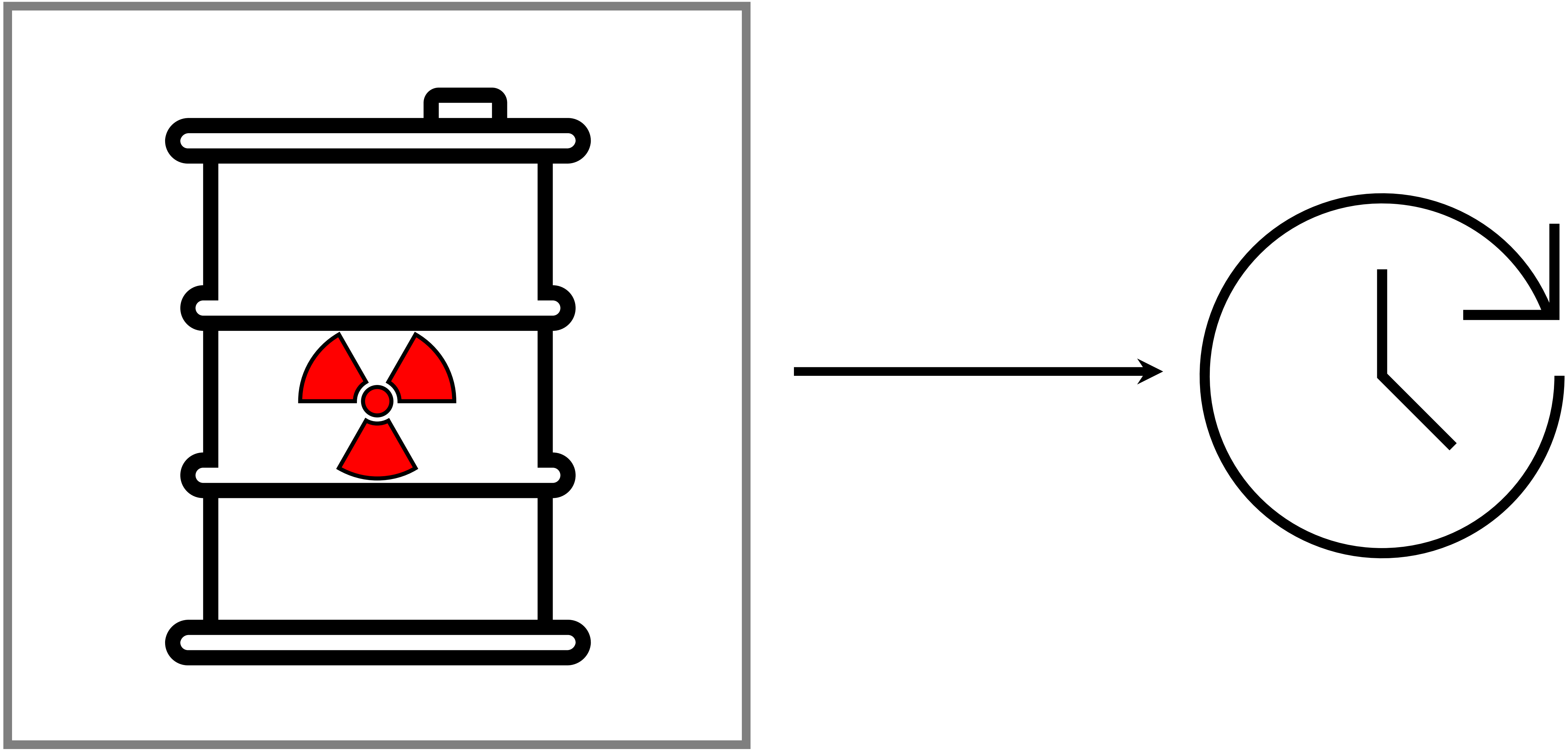
	radioattivi 	 chimici
durata	10/100 k anni	∞
riciclo	sì	no
volume/energia		 x 10^3

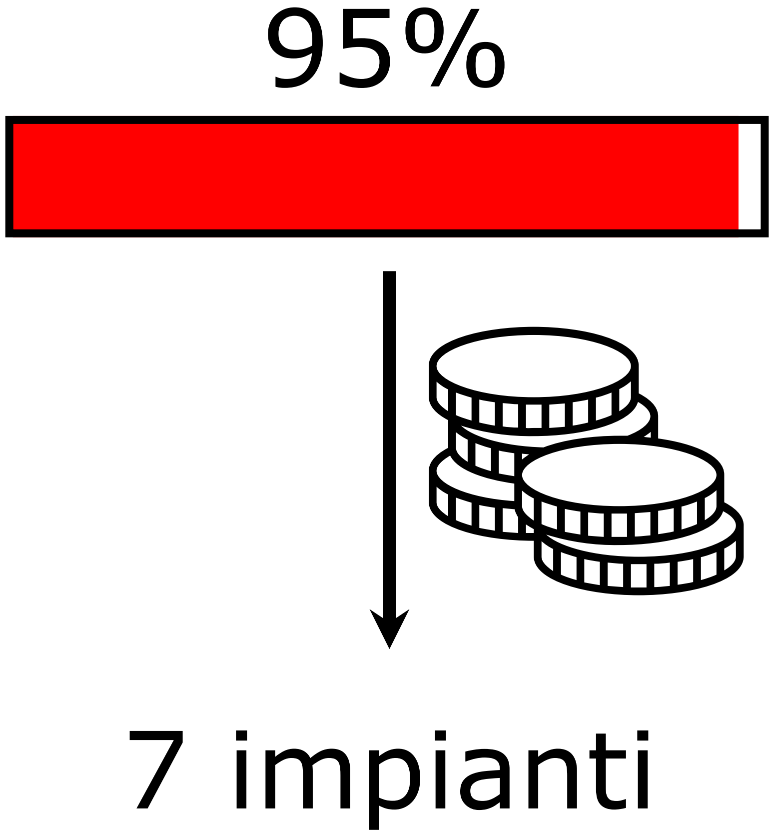
Se l'intero mix energetico mondiale contasse solo sul nucleare, quali sarebbero le dimensioni delle scorie prodotte per persona?

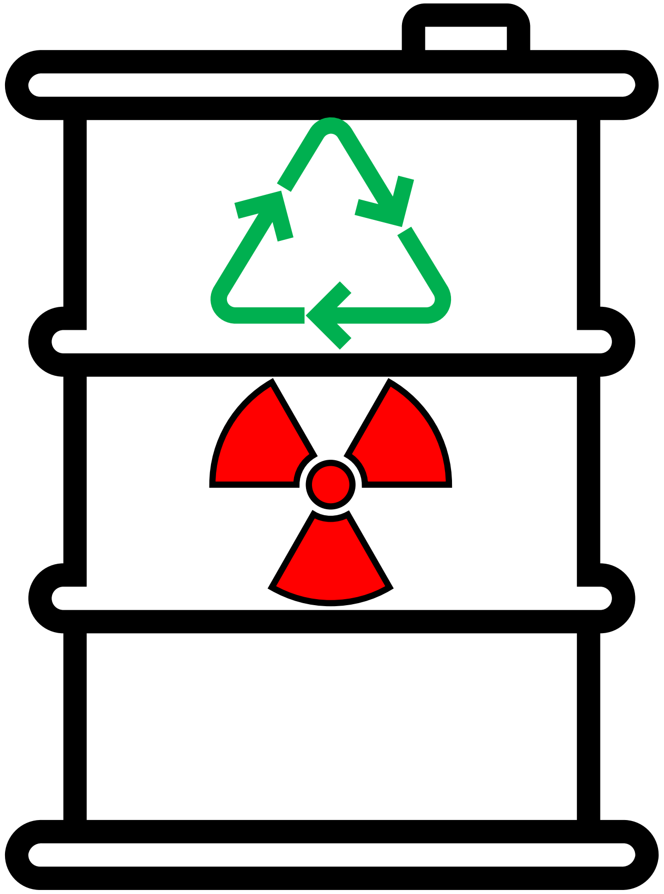


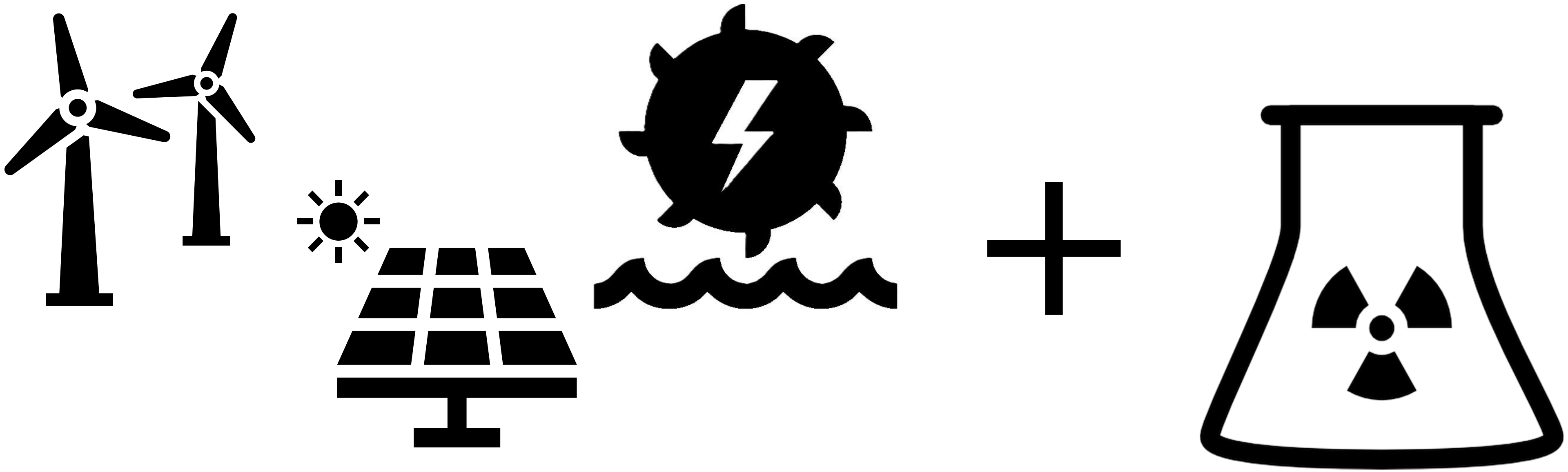


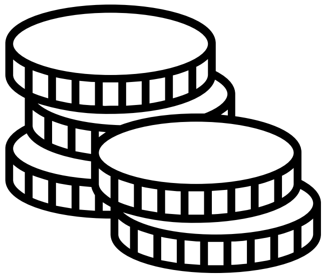





95%
7 impianti







25-35%
in meno