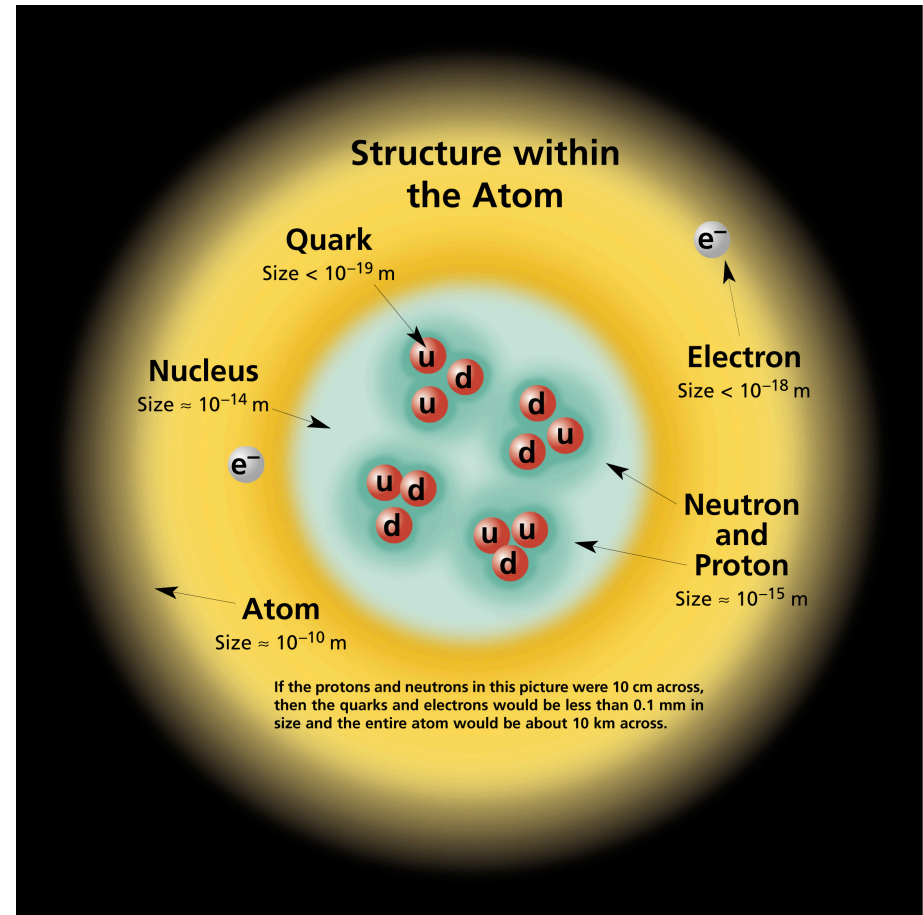


Do que todas as coisas são feitas?

If, in some cataclysm, all scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words?

I believe it is the atomic hypothesis (or atomic fact, or whatever you wish to call it) that all things are made of atoms.

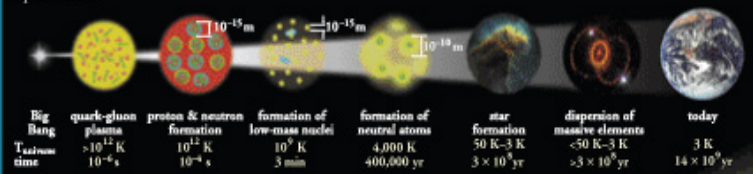
Richard Feynman



Nuclear Science

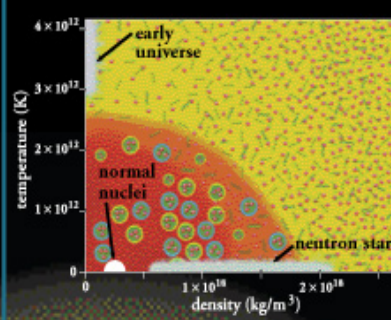
Expansion of the Universe

After the Big Bang, the universe expanded and cooled. At about 10^{-6} second, the universe consisted of a soup of quarks, gluons, electrons, and neutrinos. When the temperature of the Universe, $T_{universe}$, cooled to about 10^{11} K, this soup coalesced into protons, neutrons, and electrons. As time progressed, some of the protons and neutrons formed deuterium, helium, and lithium nuclei. Still later, electrons combined with protons and these low-mass nuclei to form neutral atoms. Due to gravity, clouds of atoms contracted into stars, where hydrogen and helium fused into more massive chemical elements. Exploding stars (supernovae) form the most massive elements and disperse them into space. Our earth was formed from supernova debris.



Nuclear Science is the study of the structure, properties, and interactions of the atomic nuclei. Nuclear scientists calculate and measure the masses, shapes, sizes, and decays of nuclei at rest and in collisions. They ask questions, such as Why do nucleons stay in the nucleus? What combinations of protons and neutrons are possible? What happens when nuclei are compressed or rapidly rotated? What is the origin of the nuclei found on Earth?

Legend	electron (e^-)	quark	A_{mass} number 14
	positron (e^+)	gluon field	Z_{atomic} number 6
	neutrino (ν)	gluon	$N_{neutron}$ number $A - Z$
	antineutrino ($\bar{\nu}$)	photon (γ)	

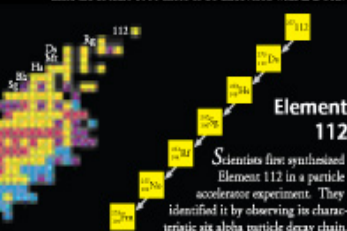


Phases of Nuclear Matter

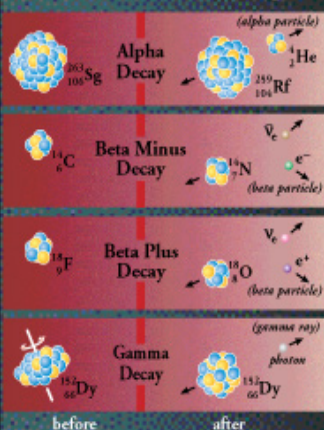
Nuclear matter can exist in several phases. When collisions excite nuclei, individual protons and neutrons may evaporate from the nuclear fluid. At sufficiently high temperature or density, a gas of nucleons (red background) forms. At even more extreme conditions, individual nucleons may cease to have meaningful identities, merging into the quark-gluon plasma (yellow background). Current data provide hints that physicists have glimpsed the quark-gluon plasma.

Unstable Nuclei

Stable nuclides form a narrow white band on the Chart of the Nuclides. Scientists produce unstable nuclides far from this band and study their decays, thereby learning about the extremes of nuclear conditions. In its present form, this chart contains about 2500 different nuclides. Nuclear theory predicts that there are at least 4000 more to be discovered with $Z \leq 112$.

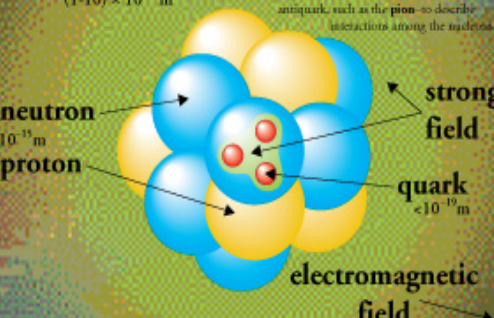


Radioactivity



Radioactive decay transforms a nucleus by emitting different particles. In alpha decay, the nucleus releases a ^4_2He nucleus—an alpha particle. In beta decay, the nucleus either emits an electron and antineutrino (for a positron and neutrino) or captures an atomic electron and emits a neutrino. A positron is the name for the antiparticle of the electron. Antimatter is composed of antiparticles. Both alpha and beta decays change the original nucleus into a nucleus of a different chemical element. In gamma decay, the nucleus lowers its internal energy by emitting a photon—a gamma ray. This decay does not modify the chemical properties of the atom.

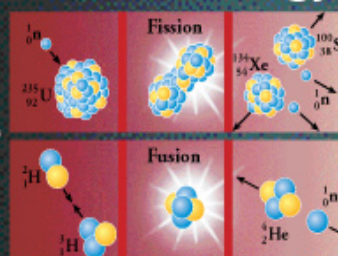
The Nucleus



At the center of the atom is a nucleus formed from nucleons—protons and neutrons. Each nucleon is made from three quarks held together by their strong interactions, which are mediated by gluons. In turn, the nucleus is held together by the strong interaction between the gluon and quark constituents of nucleons. Nuclear physicists often use the exchange of mesons—particles which consist of a quark and an antiquark, such as the pion—to describe interactions among the nucleons.

In an atom, electrons orbit around the nucleus at distances typically up to 10,000 times the nuclear diameter. If the electron cloud were shown to scale, this chart would cover a small room.

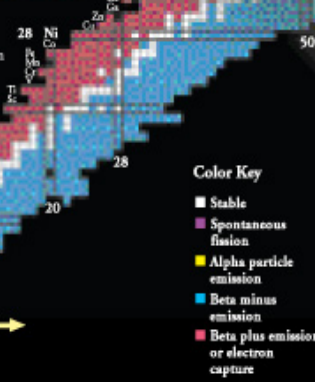
Nuclear Energy



In the early stages of stellar evolution of our sun and other stars, hydrogen fuses to form helium, releasing energy in the form of photons (light) and neutrinos. During the later stages of stellar evolution, more massive nuclei up to and beyond uranium are synthesized by fusion. By measuring the number of neutrinos that come from the Sun, scientists recently have demonstrated that neutrinos must have a mass greater than zero.

Chart of the Nuclides

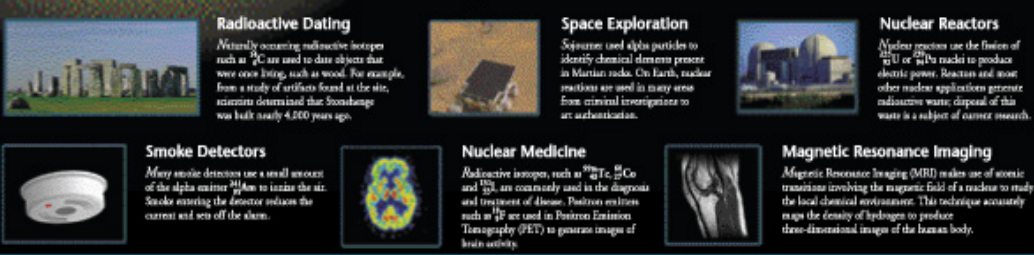
The Chart of the Nuclides presents in graphic form all known nuclei with atomic number, Z , and neutron number, N . Each nuclide is represented by a box colored according to its predominant decay mode. Magic numbers (N or $Z = 2, 8, 20, 28, 50, 82$ and 126) are indicated by a rectangle on the chart. They correspond to major closed shells and show regions of greater nuclear binding energy.



Color Key

- Stable
- Spontaneous fission
- Alpha particle emission
- Beta minus emission
- Beta plus emission or electron capture

Applications



www.CPEPweb.org

Algumas definições importantes

- Z = número atômico = número de prótons no núcleo
- N = número de nêutrons no núcleo
- A = massa atômica = $Z + N$
 - Isótopo = mesmo Z , diferente A
 - Isóbaro = mesmo A , diferente Z
 - Isotono = diferentes A e Z , mesmo N

- Representação de um núcleo

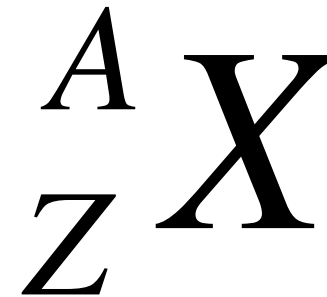
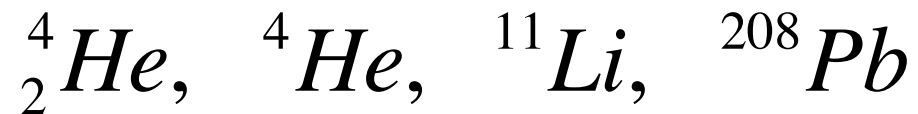


Tabela periódica

1
IA
1A

2
IIA
2A

3
IIIB
3B

4
IVB
4B

5
VB
5B

6
VIB
6B

7
VIIB
7B

8
VIII
8

9
VIII
8

10
VIII
8

11
IB
1B

12
IIB
2B

13
IIIA
3A

14
IVA
4A

15
VA
5A

16
VIA
6A

17
VIIA
7A

18
VIIIA
8A

1
H
Hydrogen
1.008

3
Li
Lithium
6.941

11
Na
Sodium
22.990

19
K
Potassium
39.098

37
Rb
Rubidium
84.468

55
Cs
Cesium
132.905

87
Fr
Francium
223.020

4
Be
Beryllium
9.012

12
Mg
Magnesium
24.305

20
Ca
Calcium
40.078

38
Sr
Strontium
87.62

56
Ba
Barium
137.328

88
Ra
Radium
226.025

5
B
Boron
10.811

13
Al
Aluminum
26.982

21
Sc
Scandium
44.956

29
Cu
Copper
63.546

31
Ga
Gallium
69.723

49
In
Indium
114.818

67
Tl
Thallium
204.383

6
C
Carbon
12.011

14
Si
Silicon
28.086

22
Ti
Titanium
47.867

30
Zn
Zinc
65.38

32
Ge
Germanium
72.631

50
Sn
Tin
118.711

68
Pb
Lead
207.2

7
N
Nitrogen
14.007

15
P
Phosphorus
30.974

23
V
Vanadium
50.942

31
As
Arsenic
74.922

49
Sb
Antimony
121.760

83
Bi
Bismuth
208.980

8
O
Oxygen
15.999

16
S
Sulfur
32.066

24
Cr
Chromium
51.996

32
Se
Selenium
78.971

52
Te
Tellurium
127.6

84
Po
Polonium
[208.982]

9
F
Fluorine
18.998

17
Cl
Chlorine
35.453

25
Mn
Manganese
54.938

33
Br
Bromine
79.904

53
I
Iodine
126.904

85
At
Astatine
209.987

10
Ne
Neon
20.180

18
Ar
Argon
39.948

36
Kr
Krypton
84.798

54
Xe
Xenon
131.294

86
Rn
Radon
222.018

Atomic Number

Symbol

Name

Atomic Mass

2
He
Helium
4.003

10
Ne
Neon
20.180

18
Ar
Argon
39.948

36
Kr
Krypton
84.798

54
Xe
Xenon
131.294

86
Rn
Radon
222.018

118
Uuo
Ununoctium
unknown

117
Uus
Ununseptium
unknown

116
Lv
Livermorium
[298]

115
Uup
Ununpentium
unknown

114
Fl
Flerovium
[289]

113
Uut
Ununtrium
unknown

112
Cn
Copernicium
[277]

111
Rg
Roentgenium
[272]

110
Ds
Darmstadtium
[269]

109
Mt
Meitnerium
[268]

108
Hs
Hassium
[269]

107
Bh
Bohrium
[264]

106
Sg
Seaborgium
[266]

105
Db
Dubnium
[262]

104
Rf
Rutherfordium
[261]

89-103

72
Hf
Hafnium
178.49

73
Ta
Tantalum
180.948

74
W
Tungsten
183.84

75
Re
Rhenium
186.207

76
Os
Osmium
190.23

77
Ir
Iridium
192.217

78
Pt
Platinum
195.085

79
Au
Gold
196.967

80
Hg
Mercury
200.592

81
Tl
Thallium
204.383

82
Pb
Lead
207.2

83
Bi
Bismuth
208.980

84
Po
Polonium
[208.982]

85
At
Astatine
209.987

53
I
Iodine
126.904

52
Te
Tellurium
127.6

51
Sb
Antimony
121.760

50
Sn
Tin
118.711

49
In
Indium
114.818

48
Cd
Cadmium
112.411

47
Ag
Silver
107.868

46
Pd
Palladium
106.42

45
Rh
Rhodium
102.906

44
Ru
Ruthenium
101.07

43
Tc
Technetium
98.907

42
Mo
Molybdenum
95.95

41
Nb
Niobium
92.906

40
Zr
Zirconium
91.224

39
Y
Yttrium
88.906

38
Sr
Strontium
87.62

37
Rb
Rubidium
84.468

29
Cu
Copper
63.546

28
Ni
Nickel
58.693

27
Co
Cobalt
58.933

26
Fe
Iron
55.845

25
Mn
Manganese
54.938

24
Cr
Chromium
51.996

23
V
Vanadium
50.942

22
Ti
Titanium
47.867

21
Sc
Scandium
44.956

20
Ca
Calcium
40.078

19
K
Potassium
39.098

18
Ar
Argon
39.948

17
Cl
Chlorine
35.453

16
S
Sulfur
32.066

15
P
Phosphorus
30.974

14
Si
Silicon
28.086

13
Al
Aluminum
26.982

12
Zn
Zinc
65.38

11
Cu
Copper
63.546

10
Ni
Nickel
58.693

9
Co
Cobalt
58.933

8
Fe
Iron
55.845

7
Mn
Manganese
54.938

6
Cr
Chromium
51.996

5
V
Vanadium
50.942

4
Ti
Titanium
47.867

3
Sc
Scandium
44.956

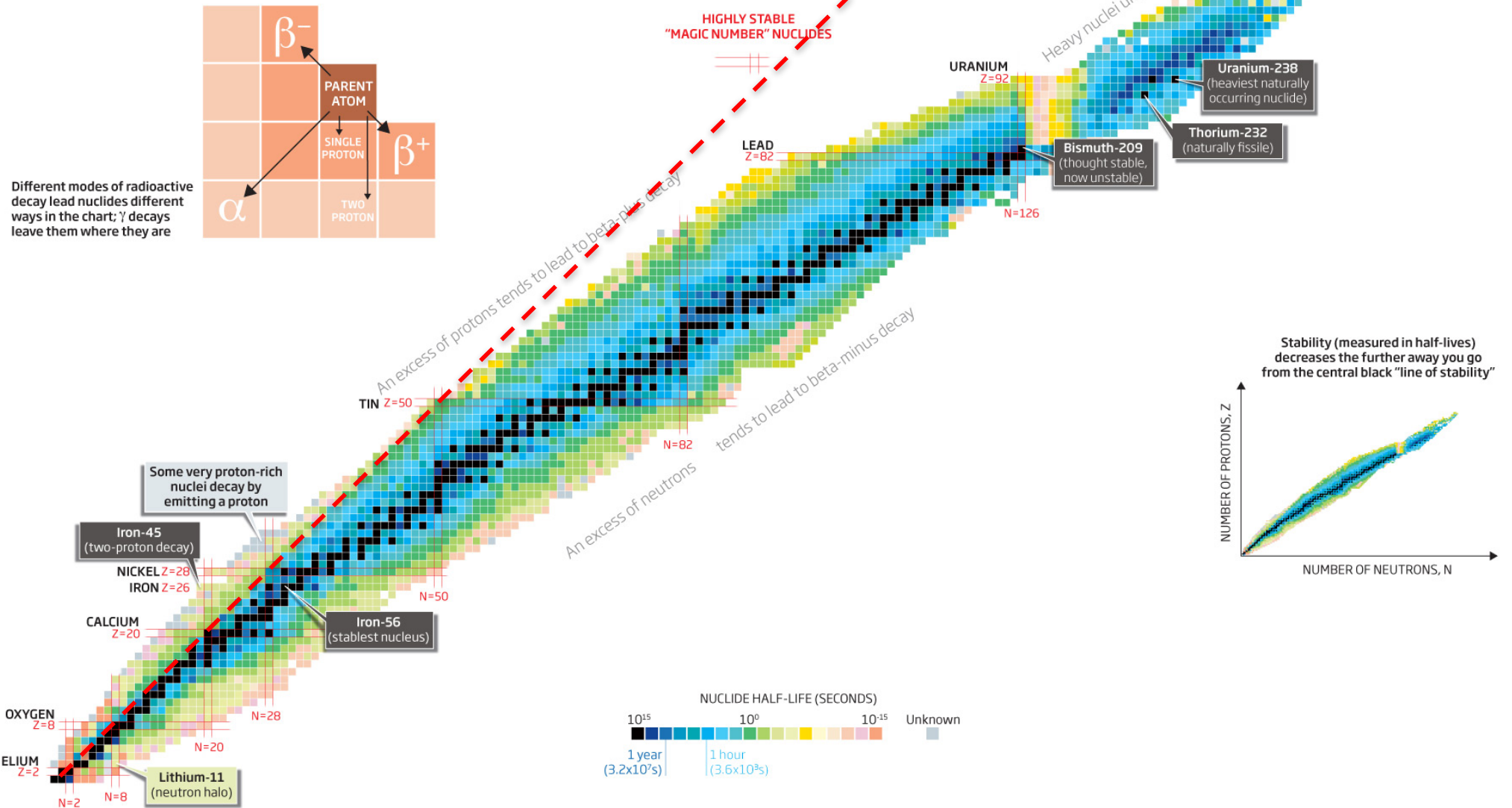
2
He
Helium
4.003

Lanthanide Series	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide
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“Tabela periódica” nuclear

Tábua de nuclídeos



β plus decay
Neutron Deficient Nuclides

13	Al					Al 23	Al 24	Al 25	Al 26	Al 27	Al 28	Al 29	Al 30	Al 31
	26.9814					0.47s	2.07s	7.23s	7.3E5y	100%	2.24m	6.5m	3.6s	0.64s
12	Mg	Mg 20	Mg 21	Mg 22	Mg 23	Mg 24	Mg 25	Mg 26	Mg 27	Mg 28	Mg 29	Mg 30		
	24.305	0.6s	122ms	3.86s	11.3s	78.99%	10.00%	11.01%	9.45m	21.0h	1.4s	~1.2s		
11	Na	Na 19	Na 20	Na 21	Na 22	Na 23	Na 24	Na 25	Na 26	Na 27	Na 28	Na 29		
	22.98977	30ms?	446ms	22.5s	2.601y	100 %	15.02h	60s	1.07s	0.29s	30.5ms	43ms		
10	Ne	Ne 17	Ne 18	Ne 19	Ne 20	Ne 21	Ne 22	Ne 23	Ne 24	Ne 25			17	18
	20.179	109ms	1.67s	17.2s	90.51%	0.27%	9.22%	37.5s	3.38m	0.61s				
9	F		F 16	F 17	F 18	F 19	F 20	F 21	F 22	F 23			15	16
	18.998403		~1E-20s proton	64.5s	109.8m	100%	11.0s	4.33s	4.23s	2.2s				
8	O	O 13	O 14	O 15	O 16	O 17	O 18	O 19	O 20				13	14
	15.9994	8.9ms	70.5s	122ms	99.758%	0.038%	0.204%	26.8s	13.5s					
7	N	N 12	N 13	N 14	N 15	N 16	N 17	N 18	N 19					
	14.0067	11.0ms	9.97m	99.63%	0.37%	7.10s	4.17s	0.63s	0.42s					
6	C	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16				11	12
	12.011	127ms	19.3s	20.3m	98.89%	1.11%	5730y	2.45s	0.75s					
5	B	B 8	B 9	B 10	B 11	B 12	B 13	B 14						
	10.81	770ms	~8E-19s proton	20%	80%	20.4ms	17.3ms	16ms						
4	Be	Be 6	Be 7	Be 8	Be 9	Be 10	Be 11	Be 12					9	10
	9.01218	~5E-21s proton	53.28d	~1E-16s alpha	100%	1.6E6y	13.8s	~11.4ms						
3	Li	Li 5	Li 6	Li 7	Li 8	Li 9								
	6.941	~1E-21s proton	7.5%	92.5%	844ms	177ms								
2	He	He 3	He 4	He 5	He 6	He 8							7	8
	4.00260	0.00014% 99.99986%		~8E-22s neutron	805ms	122ms								
1	H	H 1	H 2	H 3										
	1.0079	99.985%	0.015%	12.33y										
		n 1												
		10.4m												
		0	1	2										

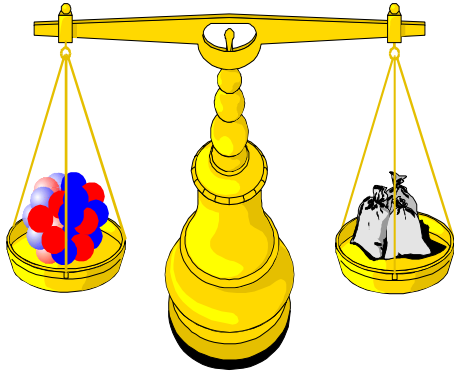
Neutron Excess Nuclides
 β minus decay

Alguns fatos interessantes

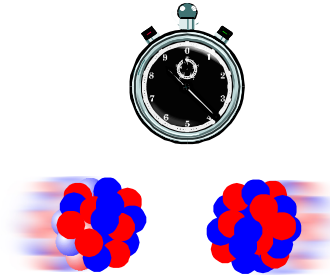
- Cerca de 3000 núclídeos conhecidos
 - Cerca de 300 deles são estáveis
- Outros 4000 ainda previstos pela teoria
- Núclídeo natural mais pesado
 - ^{238}U – vida média 4.5 bilhões de anos
- Núclídeo mais estável na natureza
 - ^{56}Fe

Algumas propriedades gerais

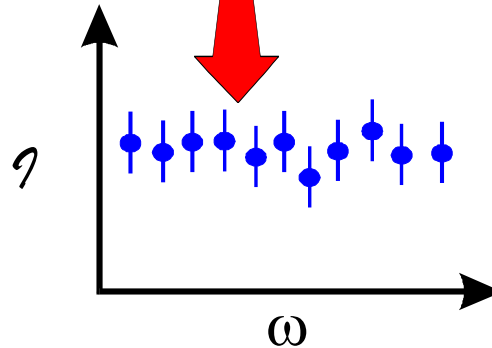
$$\rho \sim 10^{18} \text{ Kg/m}^3$$



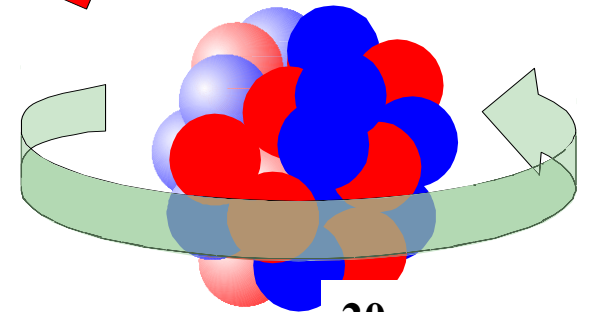
$$\tau = 10^{-16} - 10^{-22} \text{ s}$$



$$T \sim 10^{11} \text{ K}$$

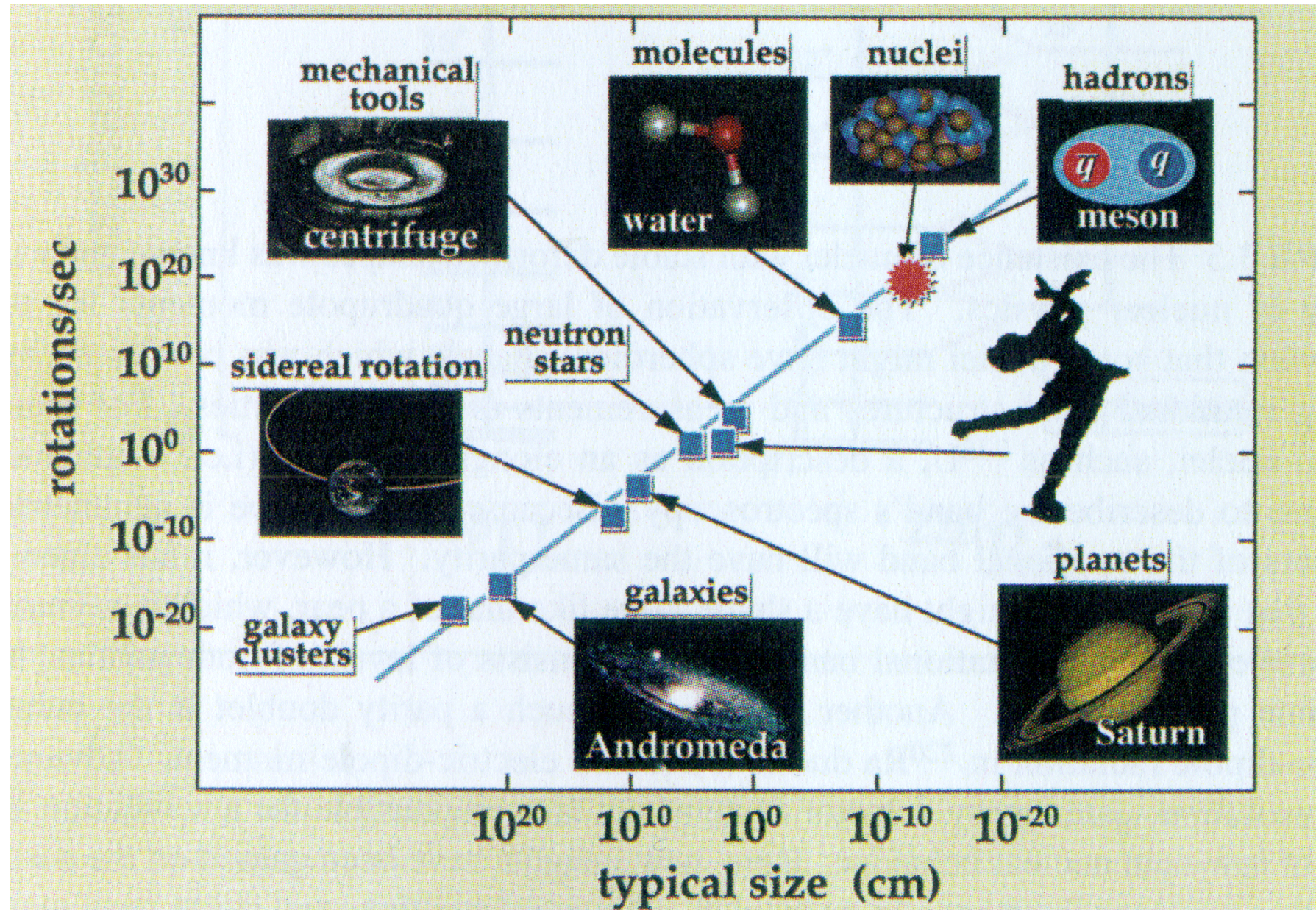


$\eta = \text{constante}$



$$\omega \sim 10^{20} \text{ rpm}$$

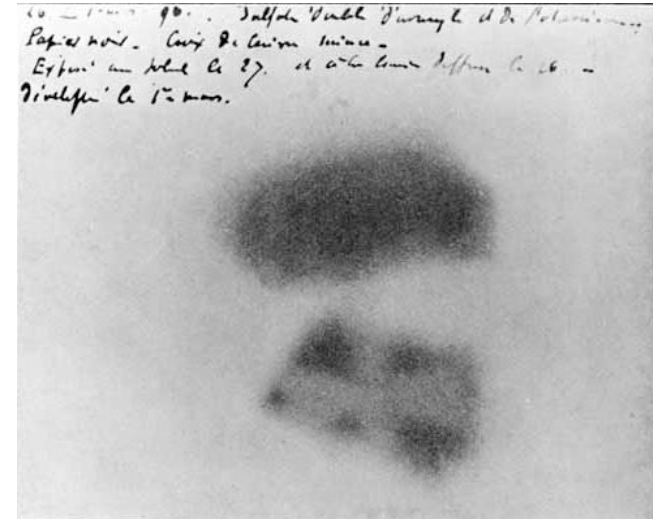
Rotações no Universo





Radioatividade

- 1896 - Henri Becquerel
- Marie e Pierre Curie
- Prêmio Nobel de Física de 1903
- Marie Curie também ganhou o Nobel de Química de 1911 pela descoberta do Rádio.

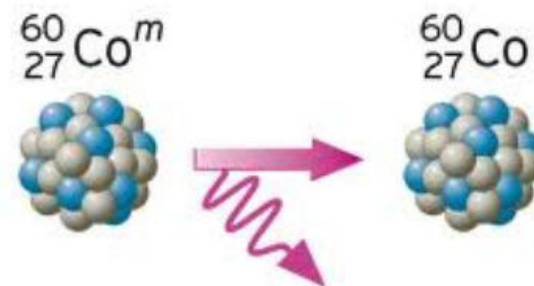
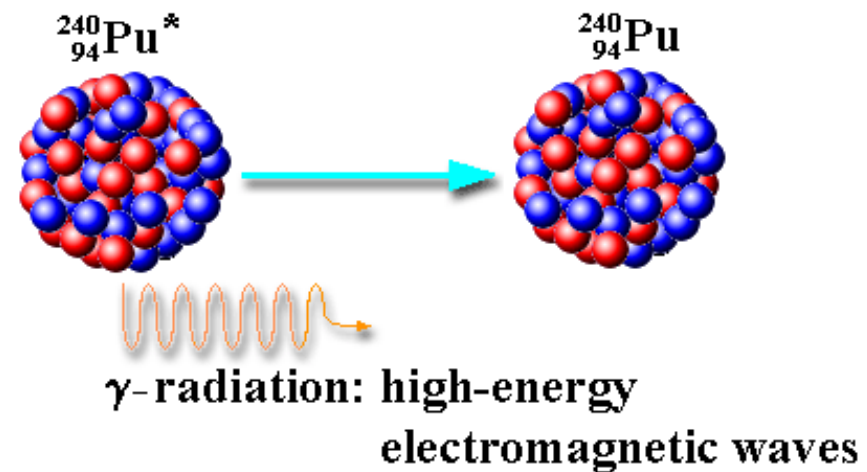
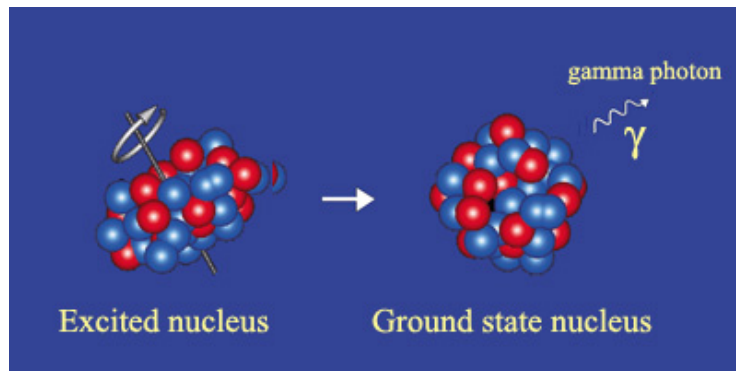
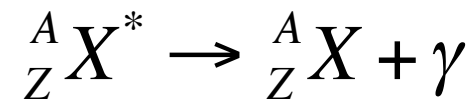


O Que quer dizer radioatividade em física nuclear?

- Um processo no qual um núcleo atômico instável perde energia emitindo radiação na forma de partículas ou de ondas eletromagnética.
- Um núcleo atômico perde energia para tornar-se mais estável

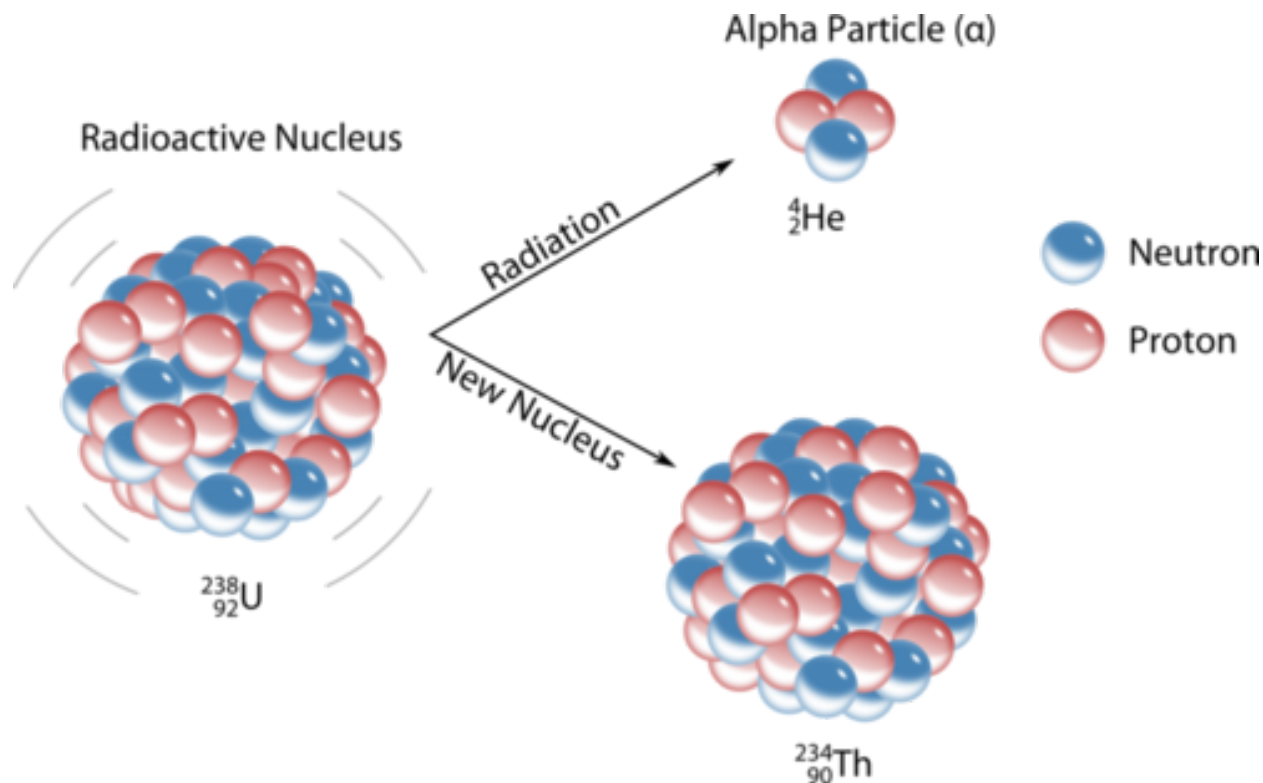
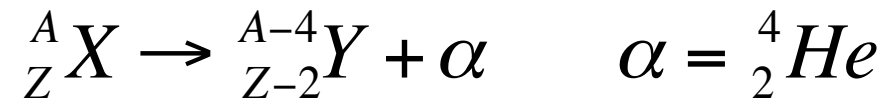
Principais tipos de decaimentos radioativos

- Decaimento gama: radiação eletromagnética



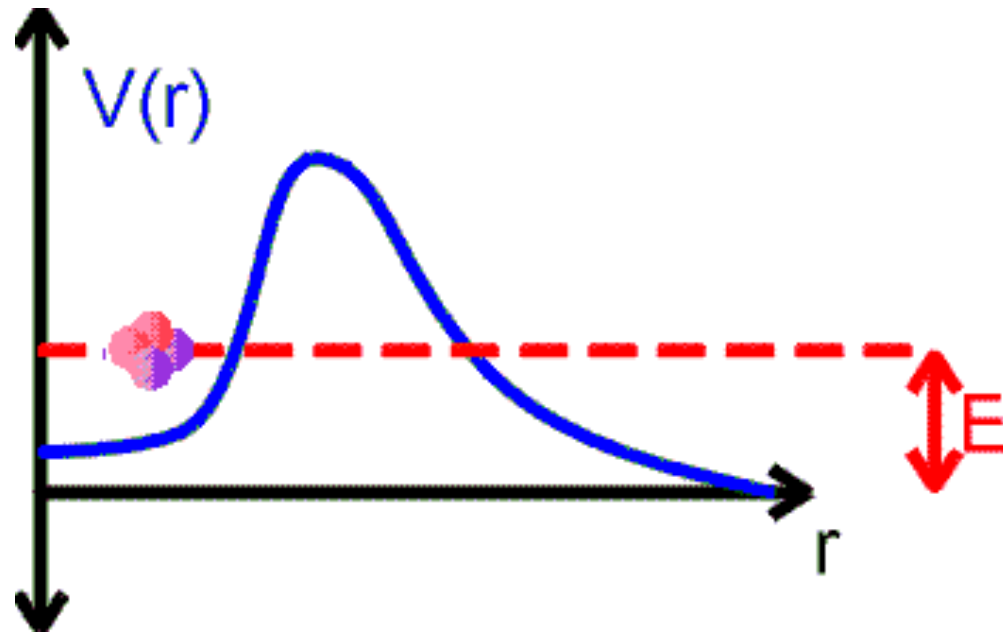
Principais tipos de decaimentos radioativos

- Decaimento alfa



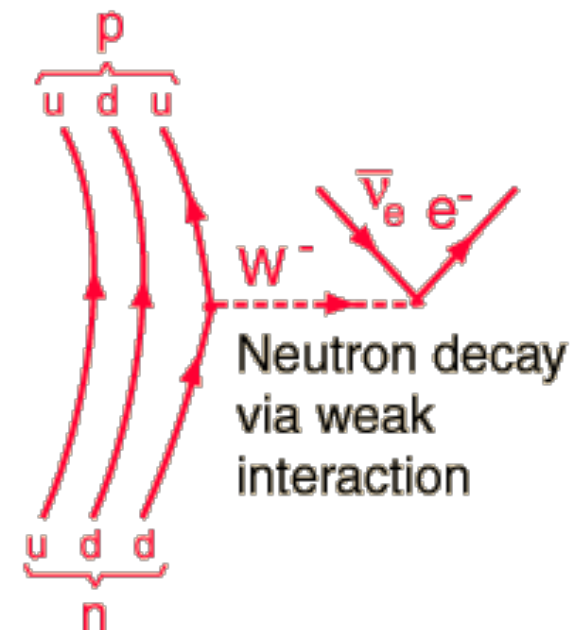
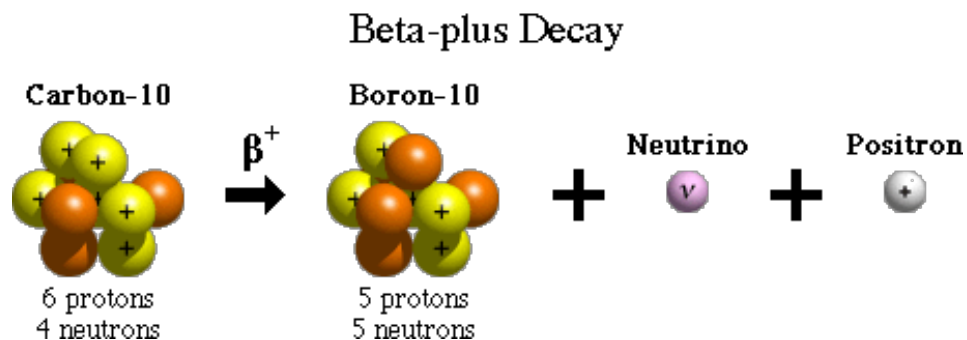
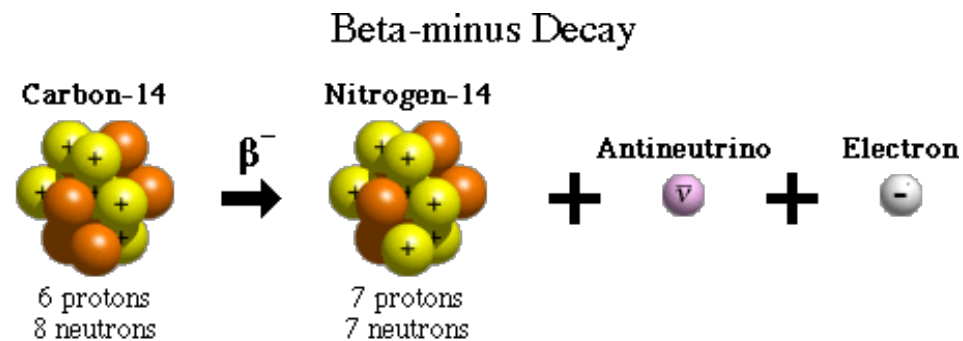
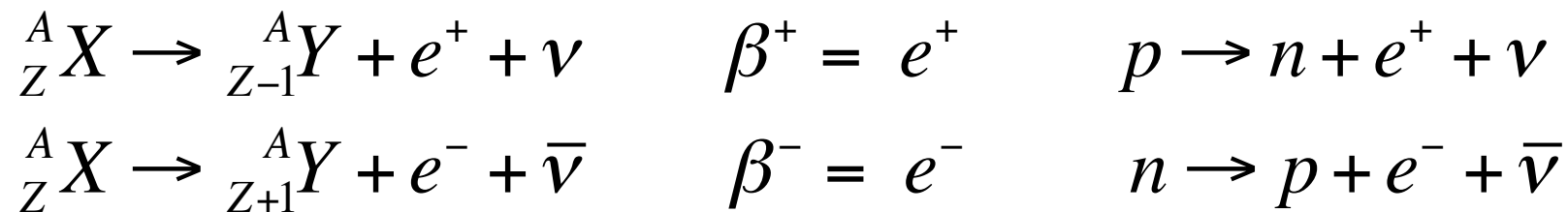
Tunelamento quântico

- No mundo quântico é possível um objeto com energia menor que a altura da barreira de potencial transpor esta barreira



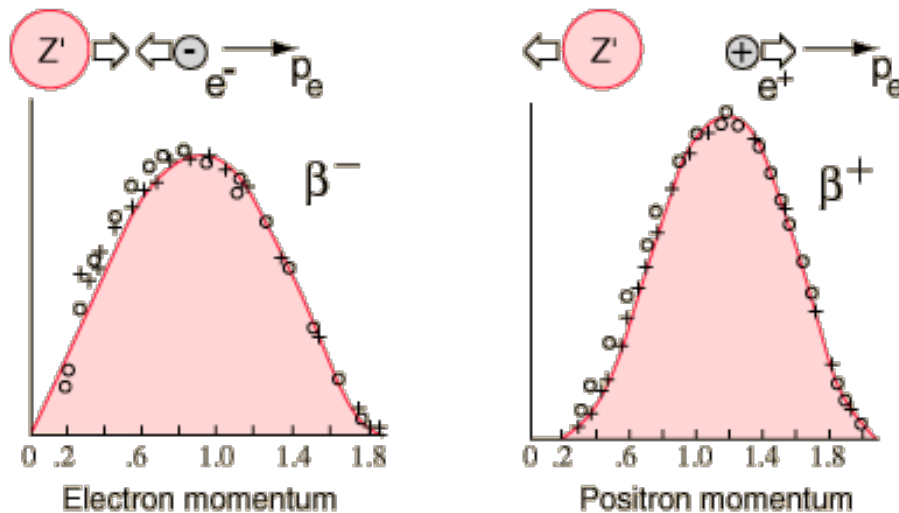
Principais tipos de decaimentos radioativos

- Decaimento beta: dois tipos



O Decaimento beta e o neutrino

16



Momentum spectra from the beta decay of ^{64}Cu

Abschrift/15.12.36

Offener Brief an die Gruppe der Radioaktiven bei der
Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

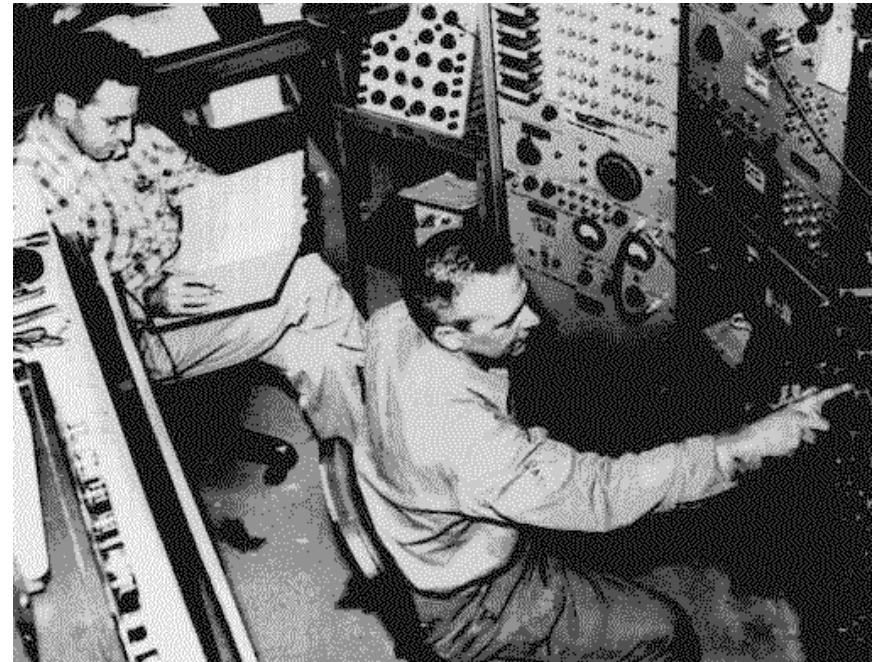
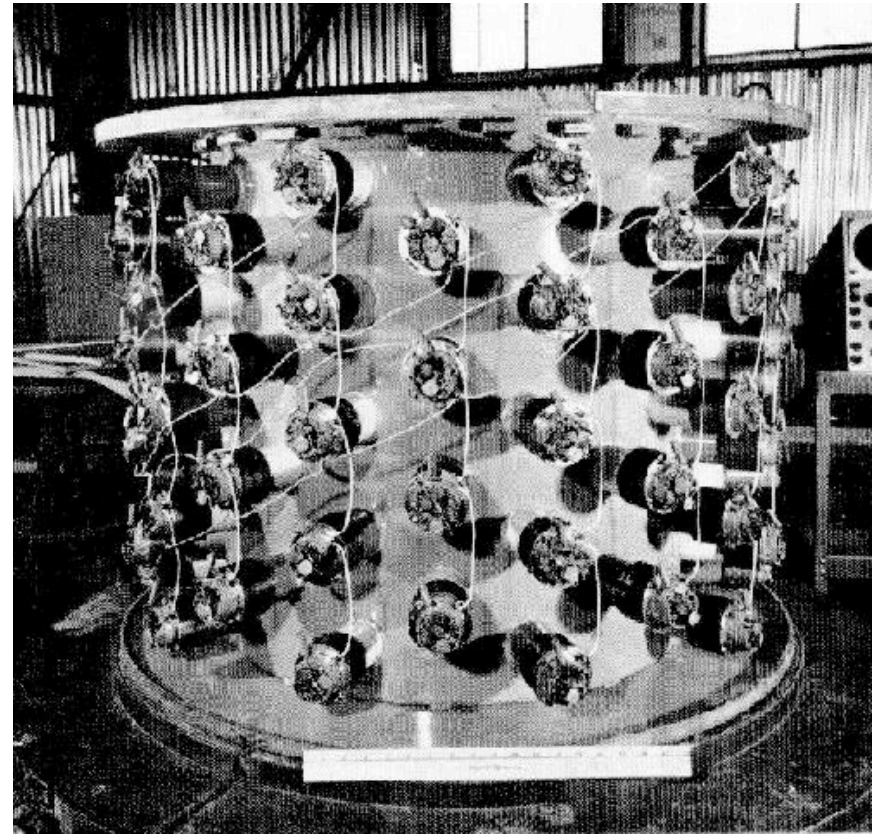
Wie der Ueberbringer dieser Zeilen, den ich baldvollst
anhören bitte, Ihnen das näheren auseinandersetzen wird, bin ich
angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie
des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg
verfallen um den "Wechselstich" (1) der Statistik und den Energiesatz
zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale
Teilchen, die ich Neutronen nennen will, in den Kernen existieren,
welche den Spin 1/2 haben und das Ausschlussprinzip befolgen und
sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie
nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen
müsste von derselben Grössenordnung wie die Elektronenmasse sein und
jedenfalls nicht grösser als 0,01 Protonenmasse. Das kontinuierliche
beta-Spektrum wäre dann verständlich unter der Annahme, dass beim
beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert
wird, derart, dass die Summe der Energien von Neutron und Elektron
konstant ist.

"Prezados senhoras e senhores radioativos. Rogo-lhes escutar com muita boa vontade o portador desta carta. Ele lhes dirá em detalhes que, para sanar a má estatística dos núcleos do N e Li6 e o espectro beta contínuo, descobri um remédio desesperado para salvar as leis de conservação da energia e as estatísticas. Trata-se da possibilidade da existência nos núcleos de partículas neutras de spin 1/2, obedecendo ao principio de exclusão, mas diferentes dos fótons pois elas não se movem à velocidade da luz, e que chamo de nêutrons. A massa dos nêutrons deve ser da mesma ordem de grandeza da dos elétrons e não deve em hipótese nenhuma exceder 0,01 da massa do próton. O espectro beta seria então compreensível se supusermos que durante a desintegração beta, com cada elétron emitido um nêutron seja emitido, de modo que a soma das energias do nêutron e do elétron seja constante."

O neutrino

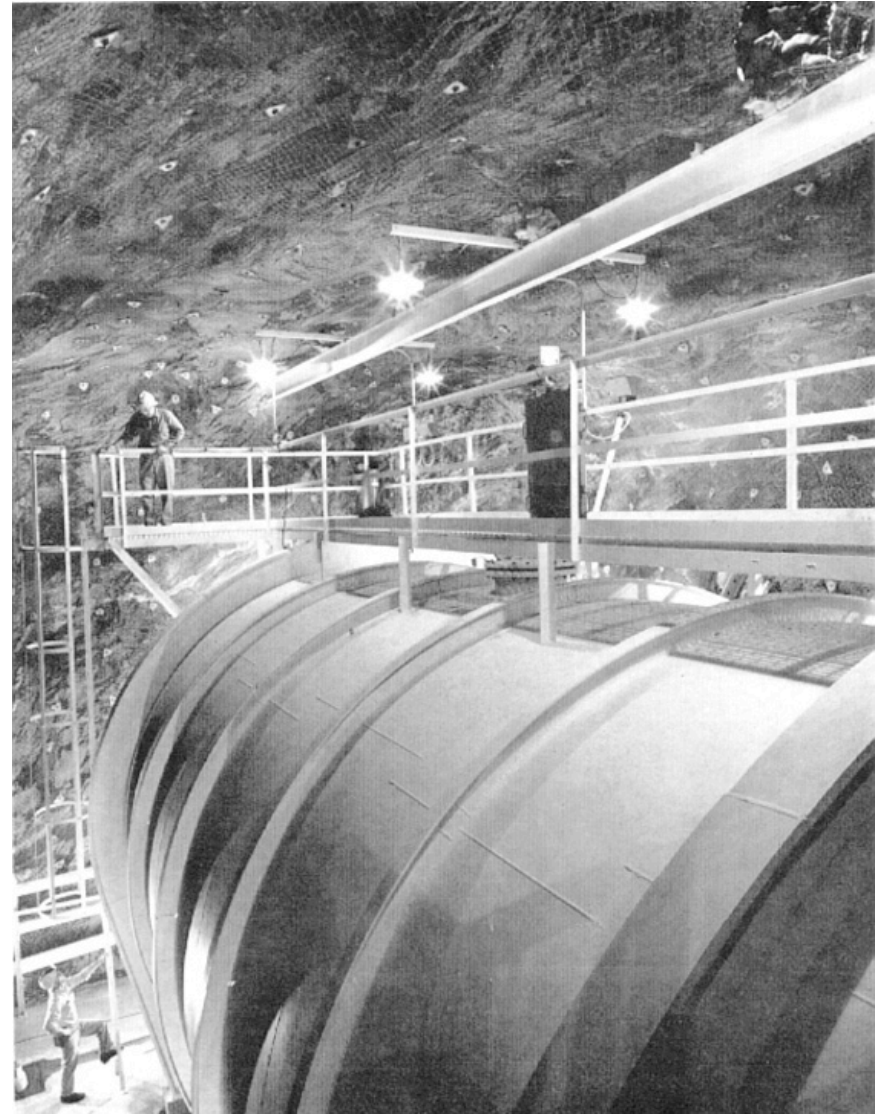
17

- Previsão: Pauli, 1930
 - Primeira medida: Reines e Cowan, 1953.
 - Nobel de 1995
 - Experimento
 - 400 l de água + cloreto de cádmio
- $$\bar{\nu} + p \rightarrow n + e^+$$
- 2 fótons da aniquilação do pósitron + fótons da absorção do neutron 15 μ s depois.



Os neutrinos solares

- Cadeia p-p solar – fusão de hidrogênio em hélio
 - produção de neutrinos
- R. Davis (Nobel de 2002) e J. Bahcall
 - Experimento Homestake
 - Mina de ouro em Dakota do Sul – EUA (~1969-93)
 - Medida de neutrinos solares

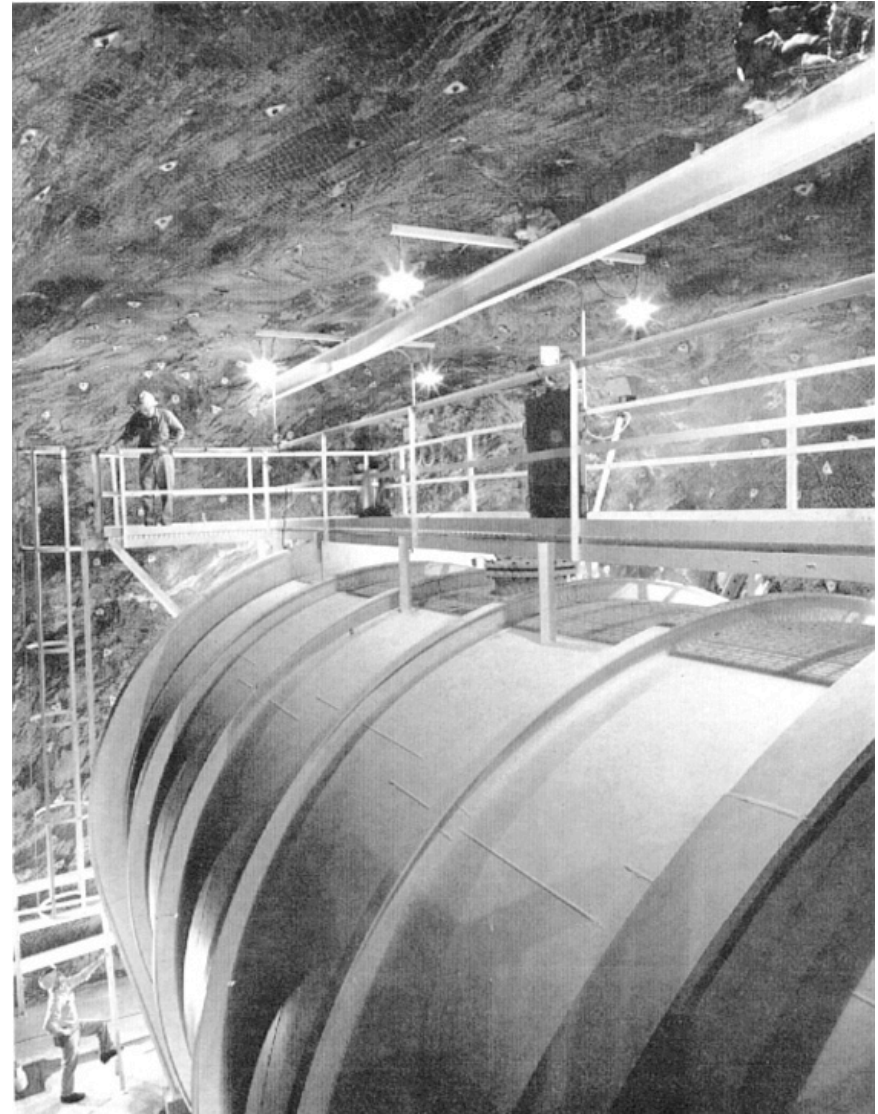


Os neutrinos solares

- 615 toneladas de percloroetileno (prod. Limpeza)



- 1 átomo de Ar a cada 17h
 - A cada 2-3 semanas coletava-se os átomos para medidas



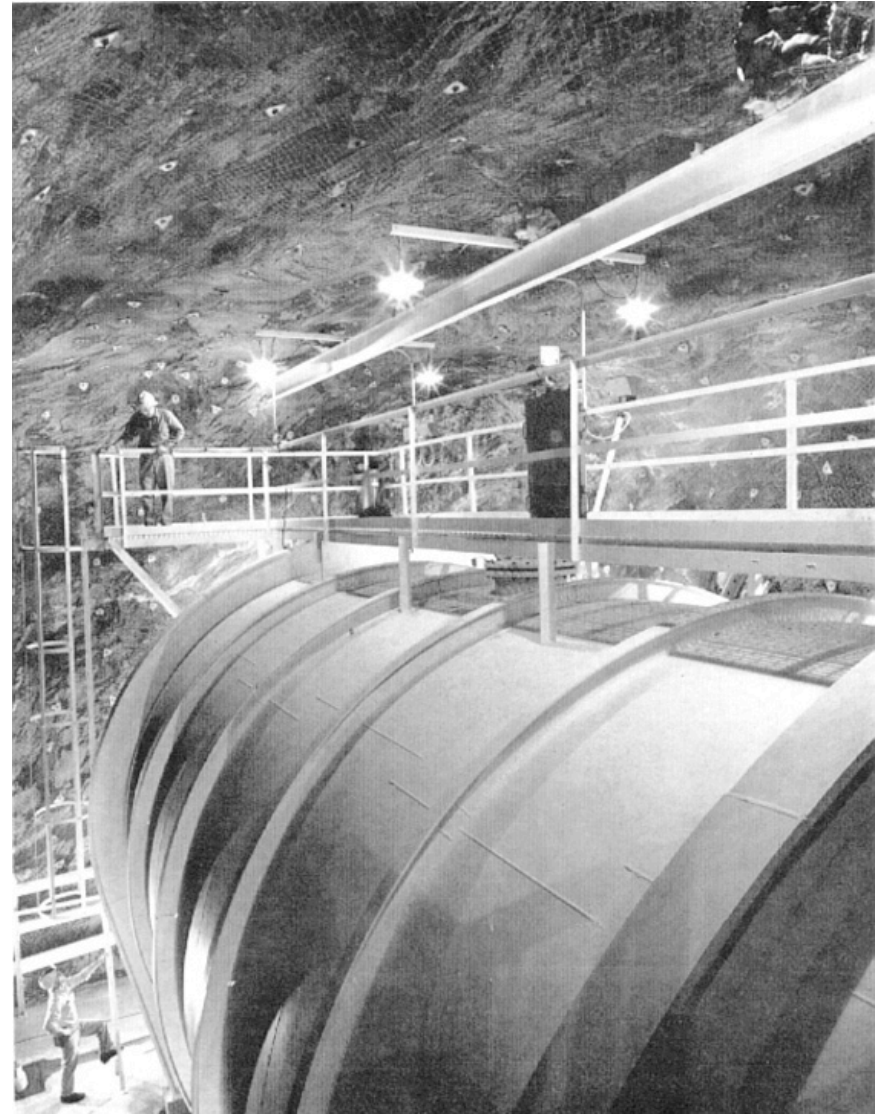
Os neutrinos solares

- Resultados para taxa de interação de neutrinos

$$\sigma = 2.5 \pm 0.2 \text{ SNU}$$

– 1 SNU = 1 int./ 10^{36} átomos

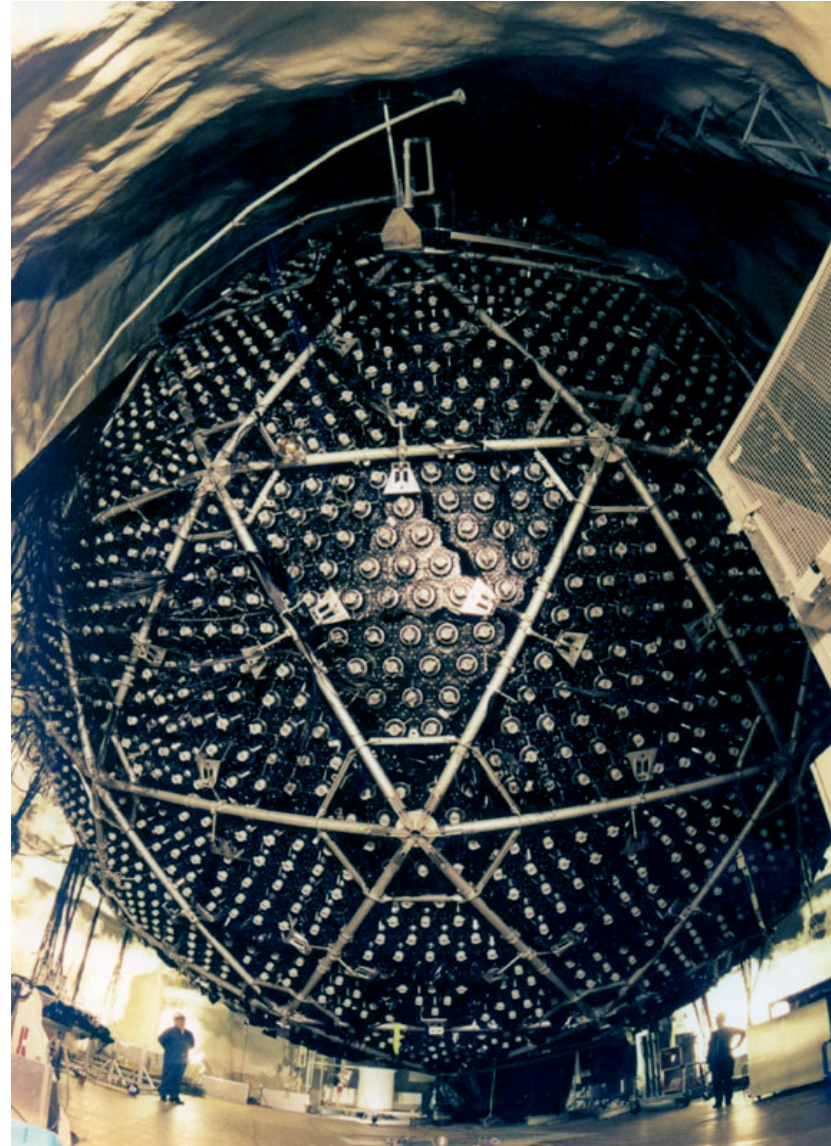
- Esperado: 8 SNU
 - Ou o Sol tinha problemas ou não entendíamos os neutrinos
 - Famoso problema dos neutrinos solares



Neutrinos solares – SNO

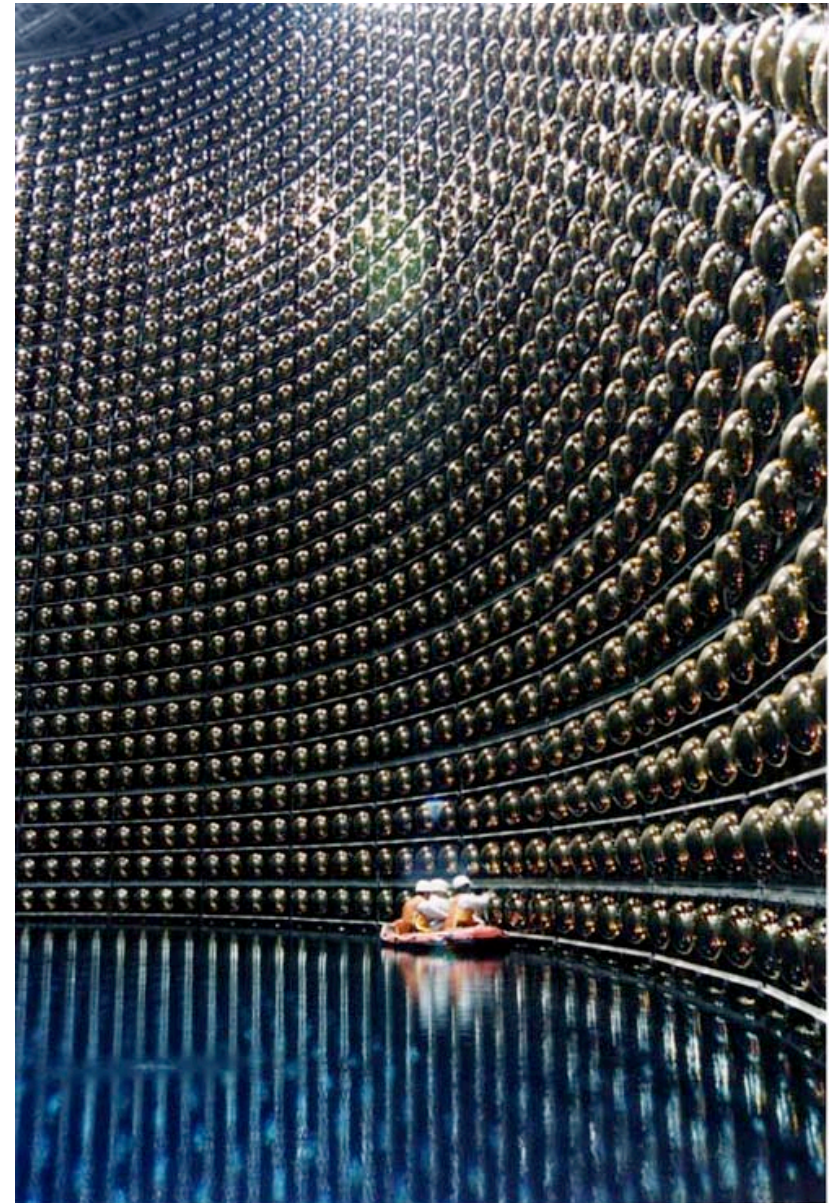
(Sudbury Neutrino Observatory)

- Mina de Creighton, próxima à Sudbury, no Canadá
 - ~2 km sob a superfície
 - Tanque de água pesada
 - Emissão de radiação de Cherenkov
 - Luz coletada por aproximadamente 10 mil fotomultiplicadoras



Super Kamiokande – Super-K

- Mina de Kamioka, Japão
 - ~1 km sob a superfície
 - Tanque de água pesada
 - Emissão de radiação de Cherenkov
 - Luz coletada por aproximadamente 11 mil fotomultiplicadoras

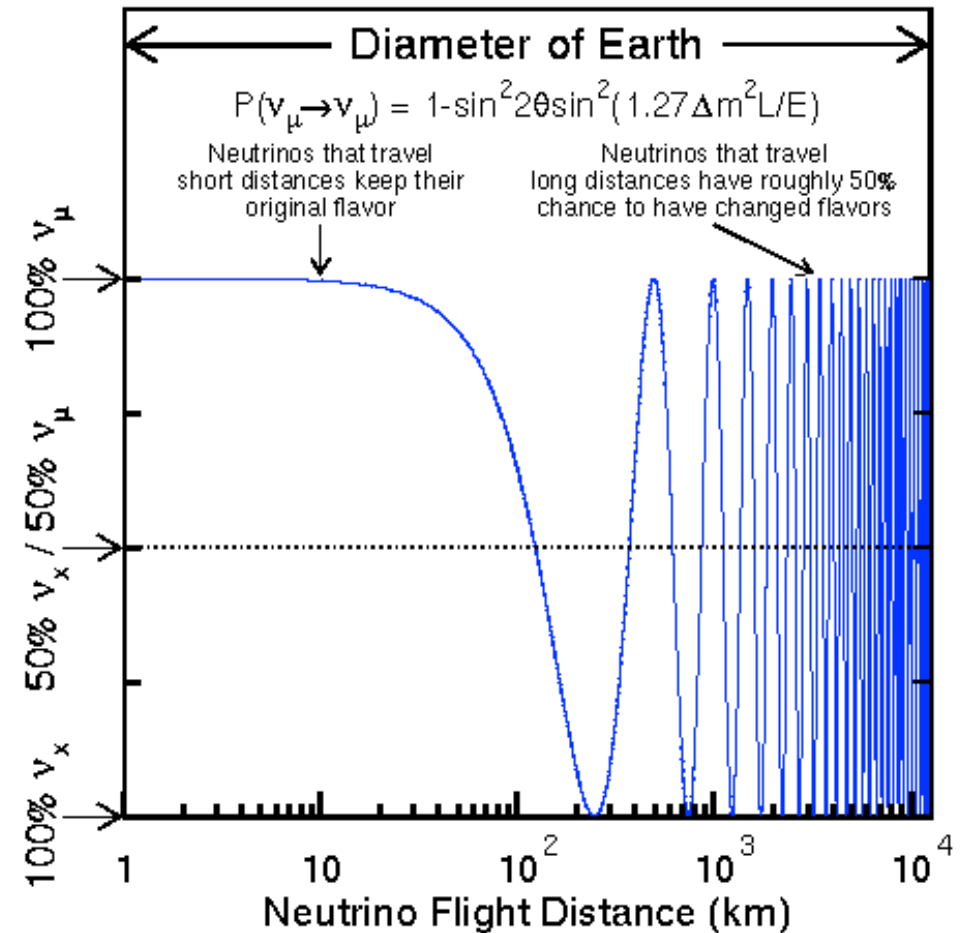


Resolvendo o problema dos neutrinos solares

- Super-K (1998)
 - Neutrinos do múon produzidos na atmosfera
 - Assimetria na taxa de produção se os neutrinos foram produzidos na atmosfera acima do experimento ou no outro lado do planeta
 - O que acontece com neutrinos ao atravessar o planeta?
- SNO (2001)
 - Neutrinos solares
 - Capaz de distinguir neutrinos dos elétrons dos outros tipos
 - Somente $\sim 1/3$ dos neutrinos medidos dão de elétrons
 - Confirma Homestake
 - $\sim 2/3$ dos neutrinos solares são do múon ou tau
 - Total de neutrinos compatível com modelo solar

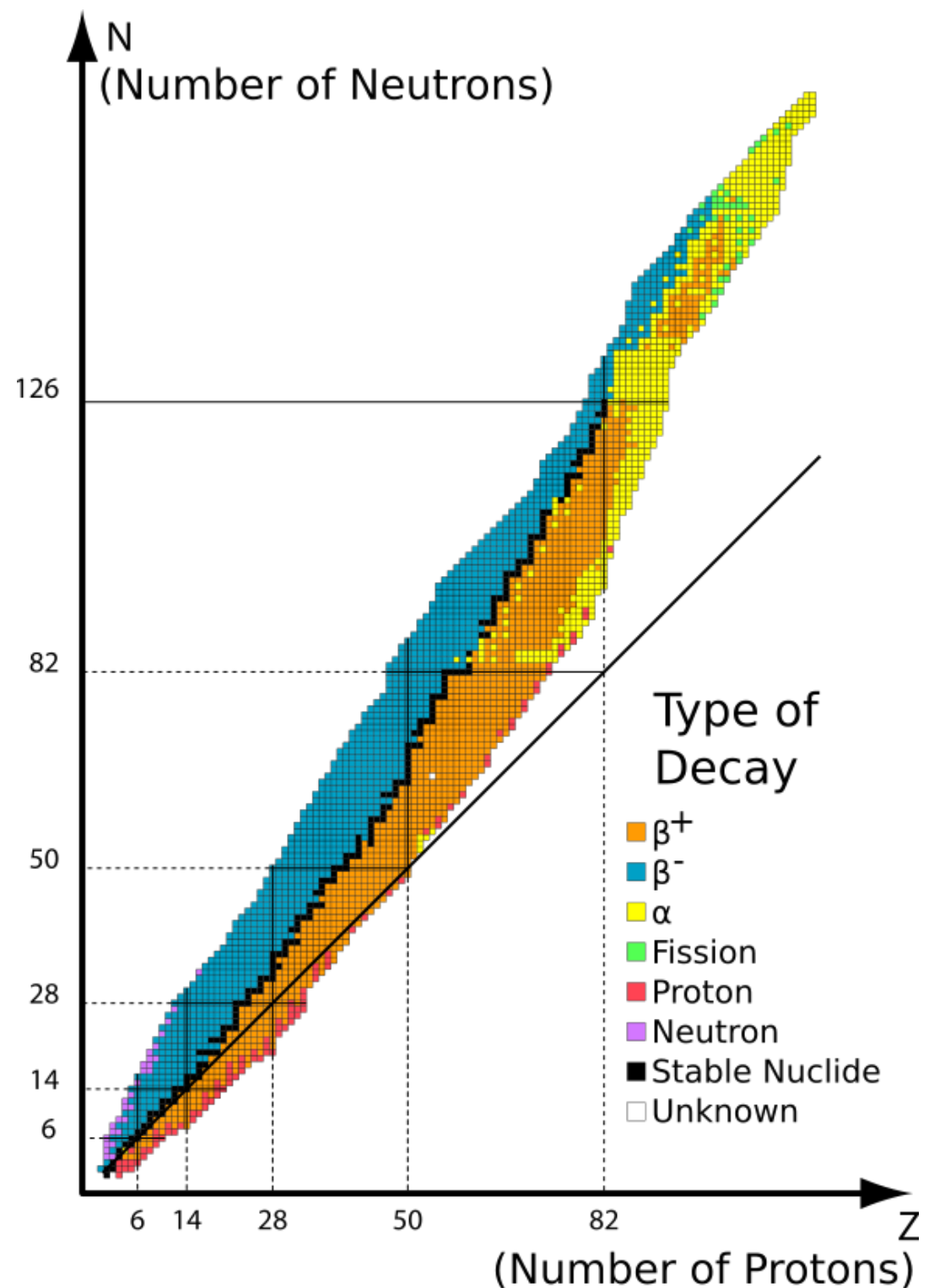
Resolvendo o problema dos neutrinos solares

- Neutrinos oscilam
 - Durante o percurso, neutrinos podem mudar de sabor (elétron, múon, tau)
 - Isso somente é possível se neutrinos possuírem massa



Tipos de decaimento e seus elementos

- Elementos muito pesados tendem a decair por emissão de partículas alfa

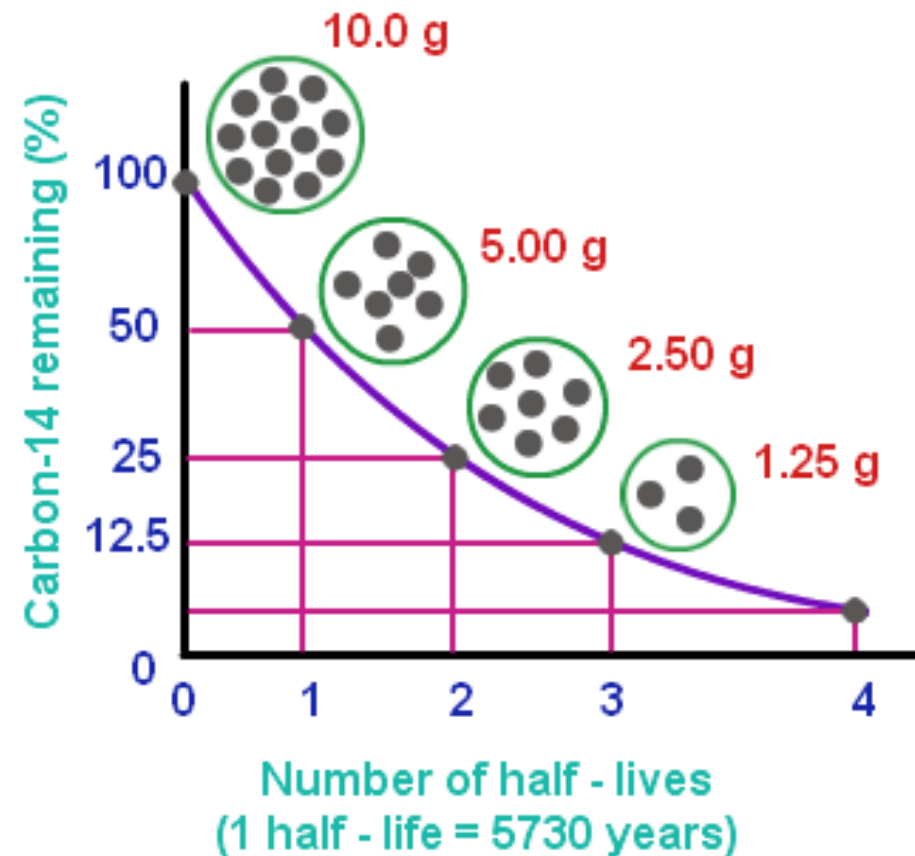


Vida média

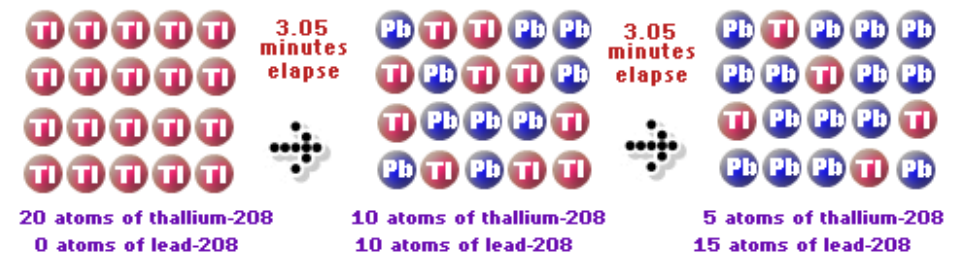
- Emissão de radiação é um evento probabilístico

$$N = N_0 e^{-\lambda t}$$

Decay of Carbon - 14



Thallium -208 decay into lead - 208 with a half of 3.05 minutes



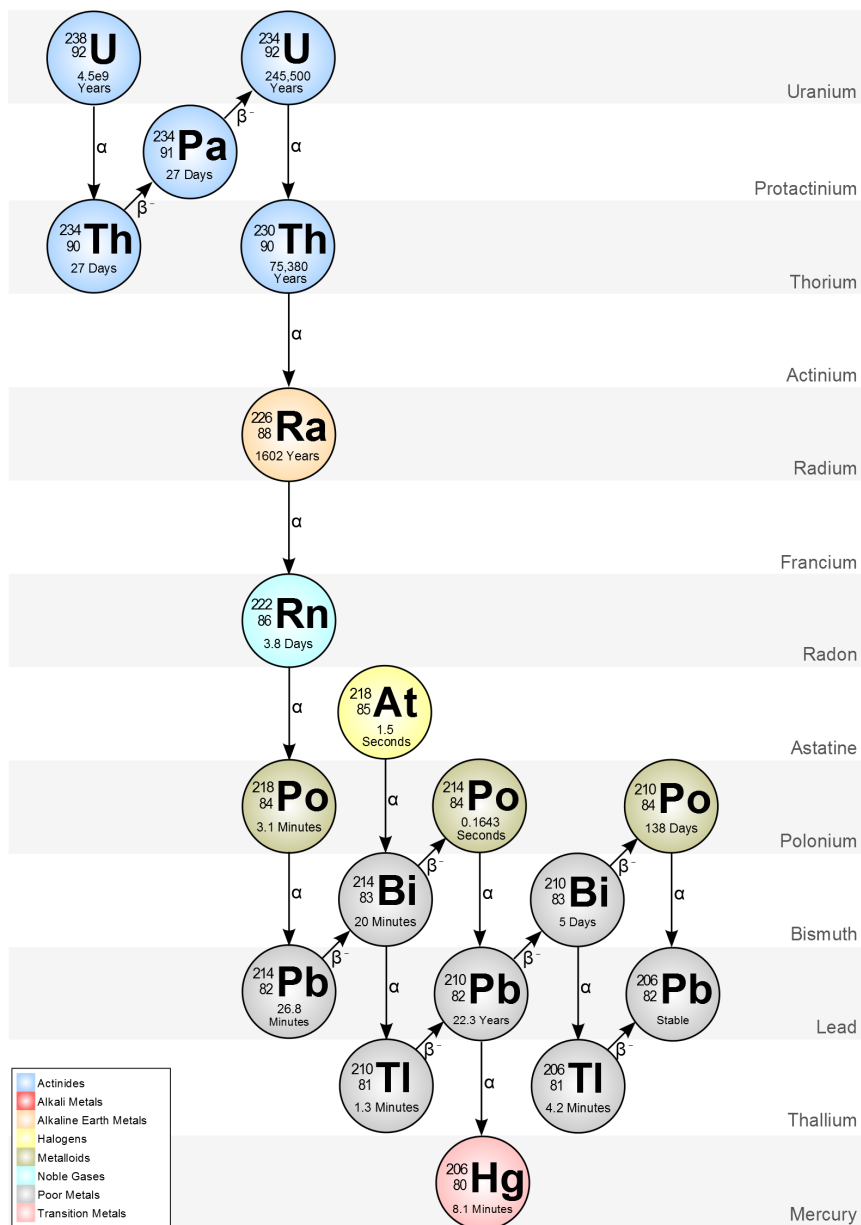
Actinides and fission products by half-life

V·T·E

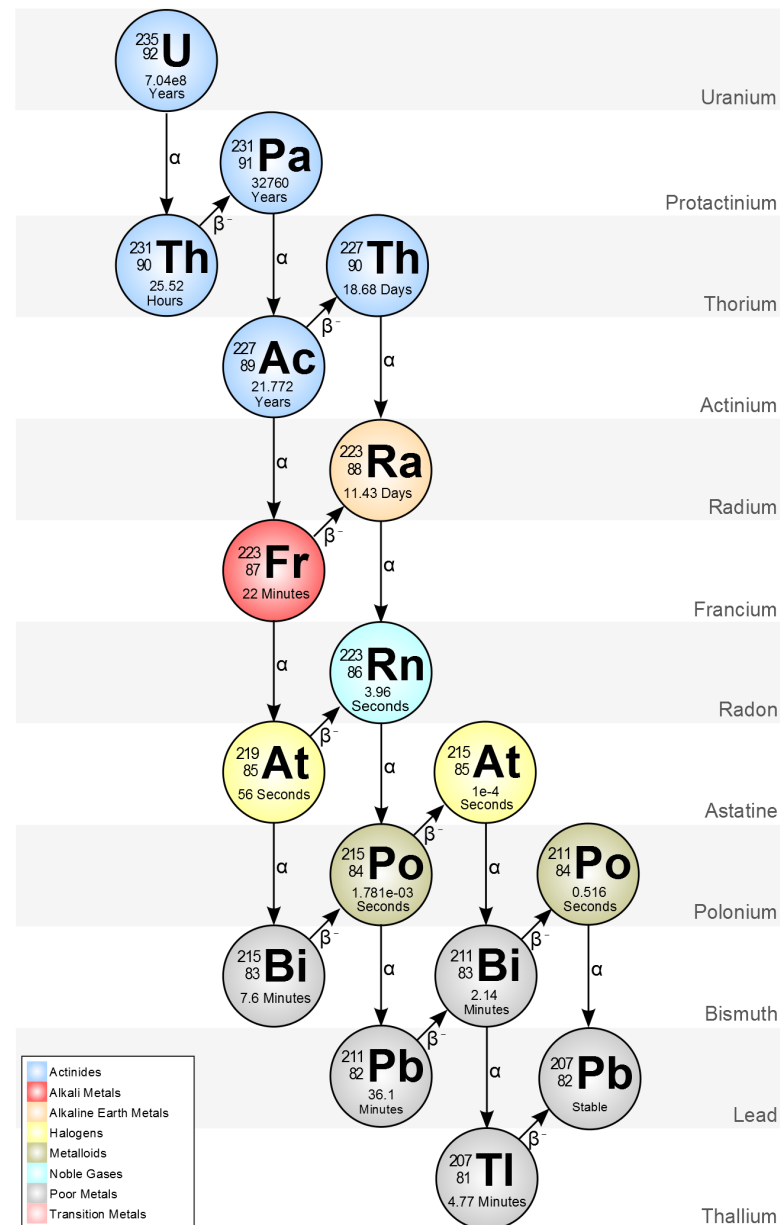
Actinides ^[6] by decay chain				Half-life range (y)	Fission products of ²³⁵ U by yield ^[7]		
4n	4n+1	4n+2	4n+3		4.5–7%	0.04–1.25%	<0.001%
²²⁸ Ra ^{Ne}				4–6	†	¹⁵⁵ Eu ^b	
²⁴⁴ Cm	²⁴¹ Pu ^f	²⁵⁰ Cf	²²⁷ Ac ^{Ne}	10–29	⁹⁰ Sr	⁸⁵ Kr	^{113m} Cd ^b
²³² U ^f		²³⁸ Pu ^{Ne}	²⁴³ Cm ^f	29–97	¹³⁷ Cs	¹⁵¹ Sm ^b	^{121m} Sn
²⁴⁸ Bk ^[8]	²⁴⁹ Cf ^f	^{242m} Am ^f		141–351	No fission products have a half-life in the range of 100–210 k years ...		
	²⁴¹ Am		²⁵¹ Cf ^f ^[9]	430–900			
		²²⁶ Ra ^{Ne}	²⁴⁷ Bk	1.3 k – 1.6 k			
²⁴⁰ Pu	²²⁹ Th ^{Ne}	²⁴⁶ Cm	²⁴³ Am	4.7 k – 7.4 k			
	²⁴⁵ Cm ^f	²⁵⁰ Cm		8.3 k – 8.5 k			
			²³⁹ Pu ^f ^{Ne}	24.1 k			
		²³⁰ Th ^{Ne}	²³¹ Pa ^{Ne}	32 k – 76 k			
²³⁶ Np ^f	²³³ U ^f ^{Ne}	²³⁴ U ^{Ne}		150 k – 250 k	‡	⁹⁹ Tc [℄]	¹²⁶ Sn
²⁴⁸ Cm		²⁴² Pu		327 k – 375 k		⁷⁹ Se [℄]	
				1.53 M	⁹³ Zr		
	²³⁷ Np ^{Ne}			2.1 M – 6.5 M	¹³⁵ Cs [℄]	¹⁰⁷ Pd	
²³⁶ U ^{Ne}			²⁴⁷ Cm ^f	15 M – 24 M		¹²⁹ I [℄]	
²⁴⁴ Pu ^{Ne}				80 M	... nor beyond 15.7 M years ^[10]		
²³² Th ^{Ne}		²³⁸ U ^{Ne}	²³⁵ U ^f ^{Ne}	0.7 G – 14.1 G			

Cadeias radioativas

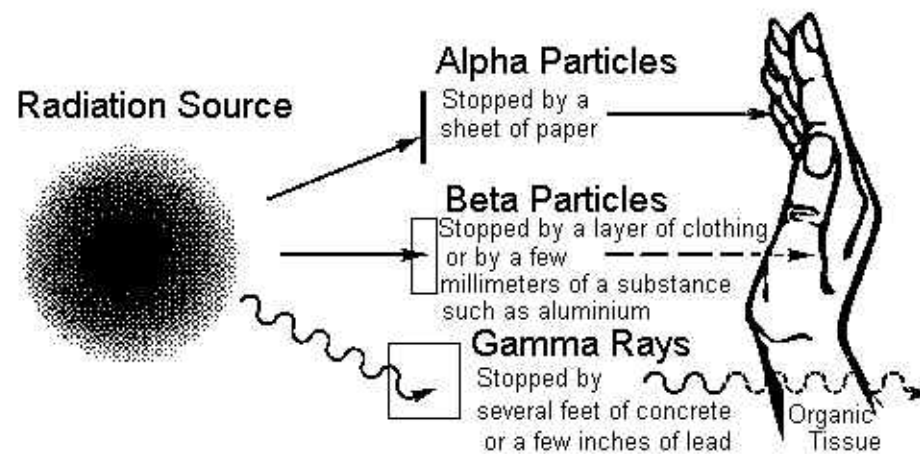
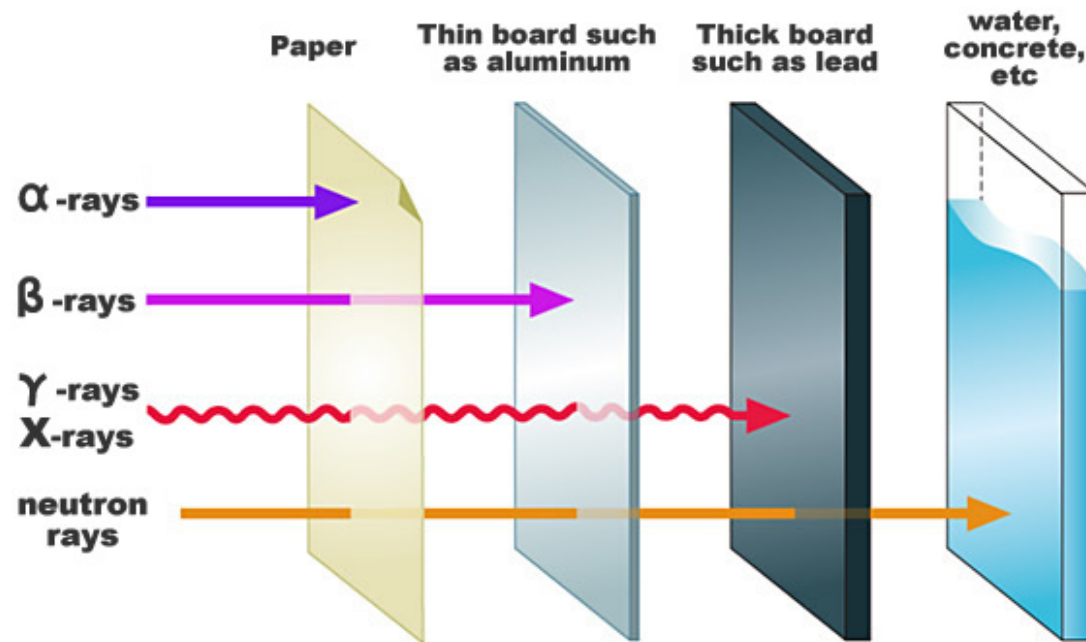
99.27% do urânio natural



0.72% do urânio natural

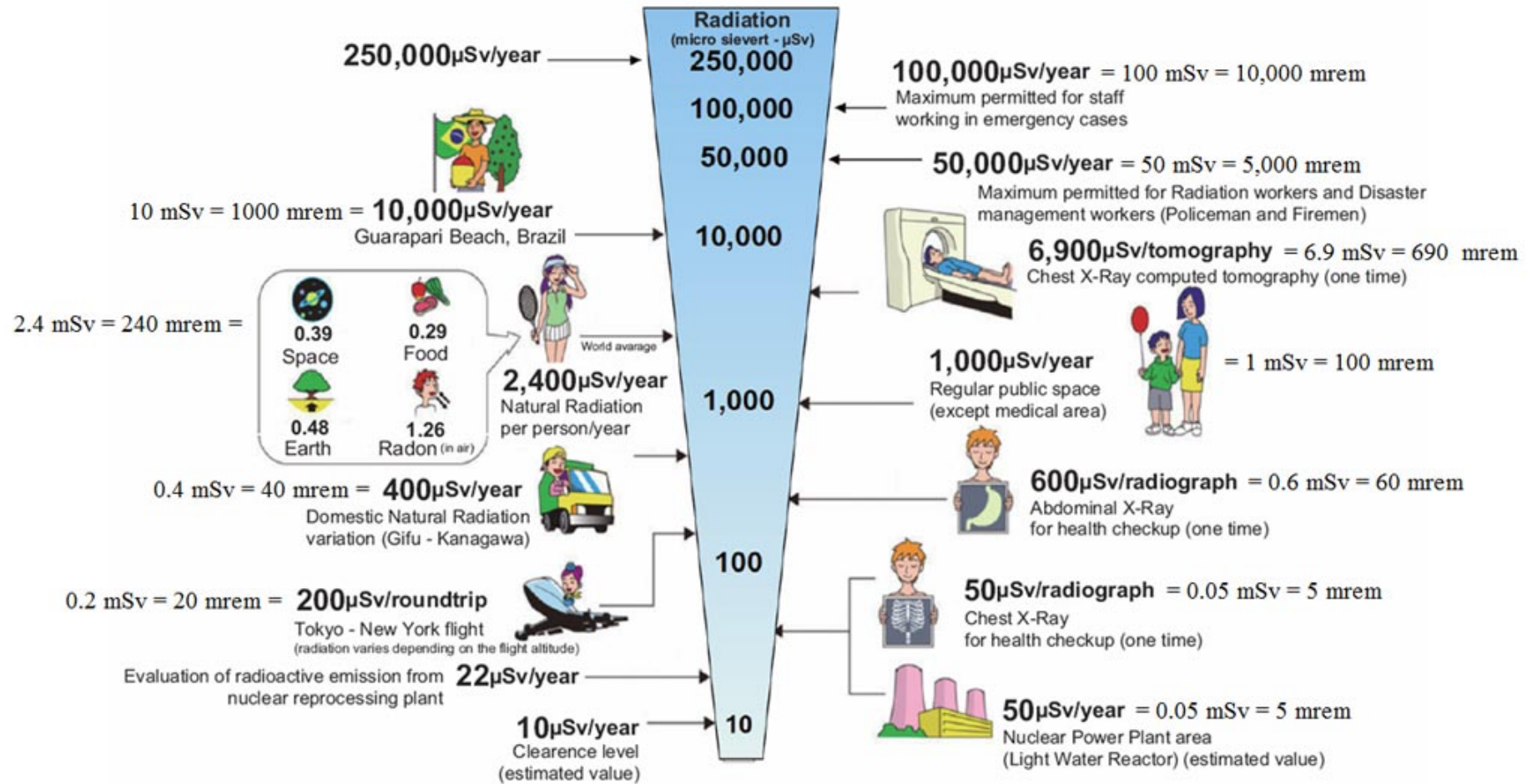


Penetrabilidade



Quanta radiação eu posso suportar?

Radiation Exposure in Daily Life



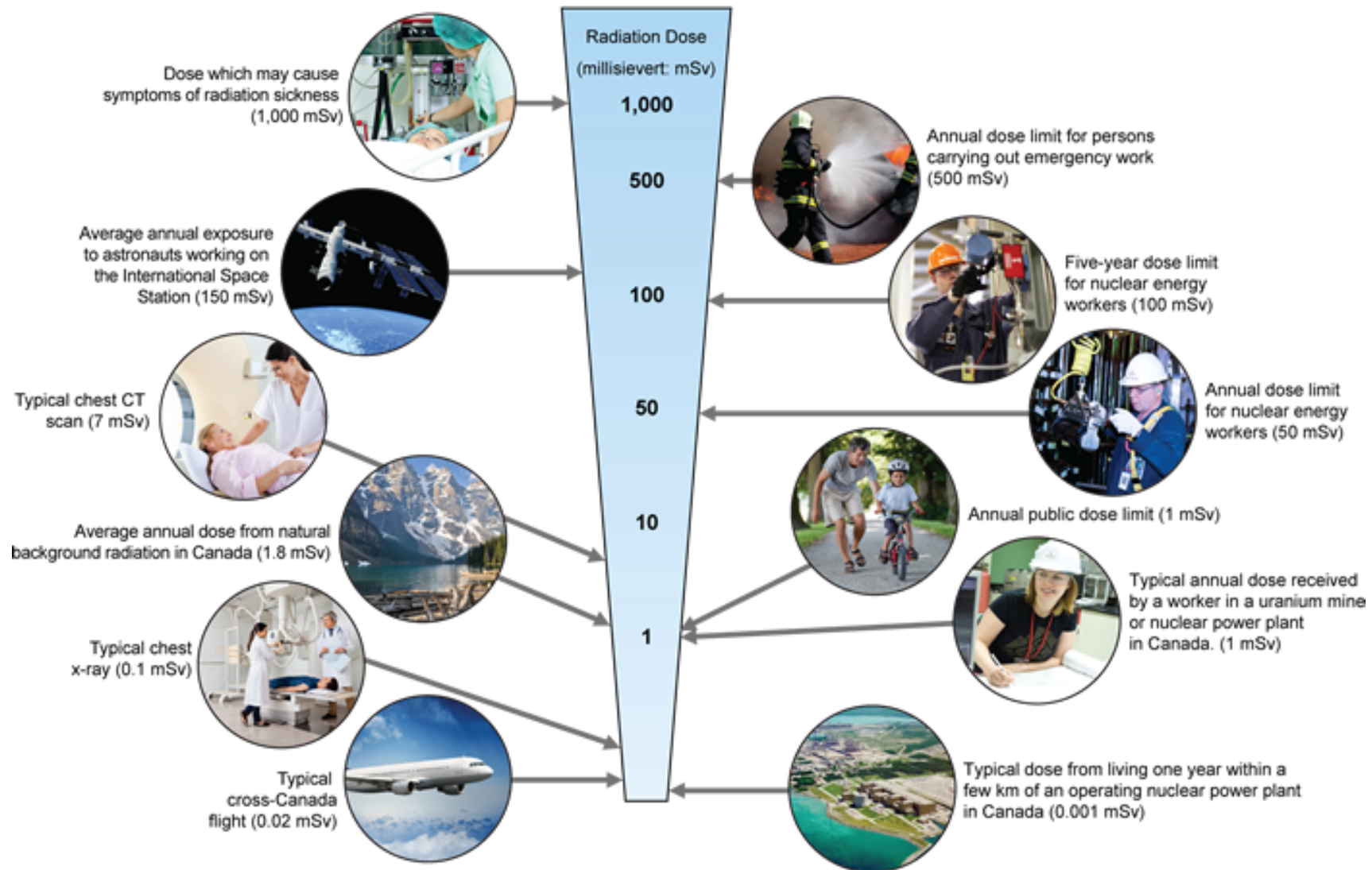
Sv (sievert) = constant of biological effects of radiation* x Gy (Gray)

(*) X-Ray, Y-Ray = 1

Translated by volunteer students of Keio University from material created by the MEXT based in the "Shigenryoku 2002" (Agency for Natural Resources)

Note: Eating 1 banana/day for 1 year results in radiation exposure of 36 μSv = 0.036 mSv = 3.6 mrem

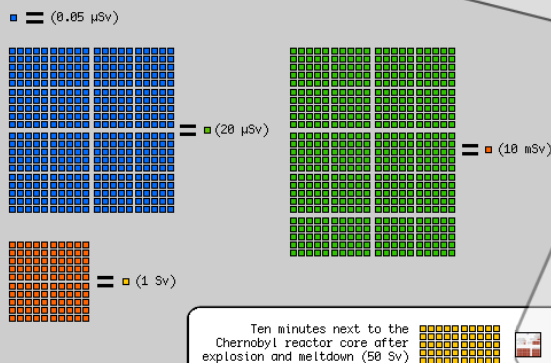
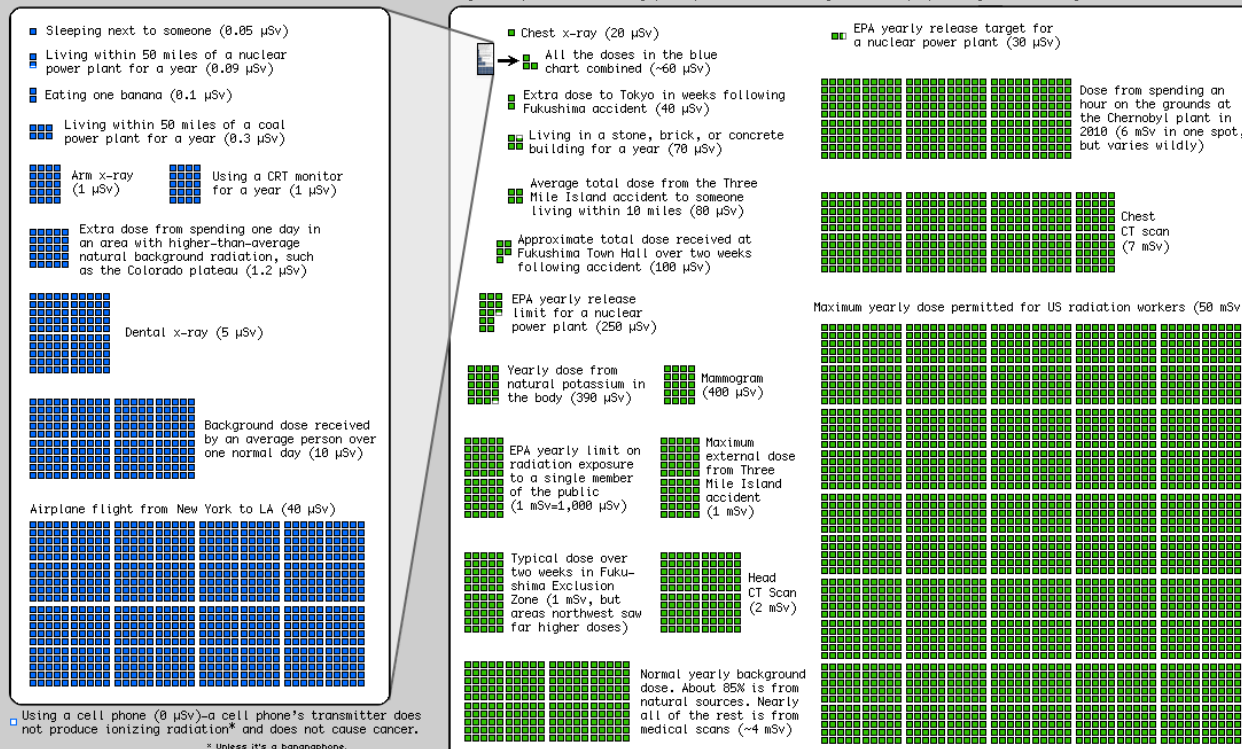
Quanta radiação eu posso suportar?



Quanta
radiação
eu posso
suportar?

Radiation Dose Chart

This is a chart of the ionizing radiation dose a person can absorb from various sources. The unit for absorbed dose is "sievert" (Sv), and measures the effect a dose of radiation will have on the cells of the body. One sievert (all at once) will make you sick, and too many more will kill you, but we safely absorb small amounts of natural radiation daily. Note: The same number of sieverts absorbed in a shorter time will generally cause more damage, but your cumulative long-term dose plays a big role in things like cancer risk.



Sources:

- <http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/>
- <http://www.nema-ne.gov/technological/dose-limits.html>
- http://www.deq.idaho.gov/inl_oversight/radiation/dose_calculator.html
- http://www.deq.idaho.gov/inl_oversight/radiation/radiation_guide.html
- <http://mitse.com/>
- http://www.bnl.gov/bnlweb/DOF/03SER/chapter_8.pdf
- <http://deis-old.nas.edu/deis/rpt/briefs/rev1-final.pdf>
- <http://people.reed.edu/~mmonias/radiation.html>
- <http://en.wikipedia.org/wiki/Sievert>
- <http://blog.ornl.gov/2010/07/16/into-the-zone-chernobyl-pripyat/>
- <http://www.nrc.gov/reading-rm/doc-collections/tzact-sheets/tritium-radiation-fs.html>
- http://www.mst.go.jp/component/a_menu/other/detail/_icsFiles/afile/2011/03/18/1303727_1716.pdf
- <http://radiology.rsna.org/content/248/1/254>

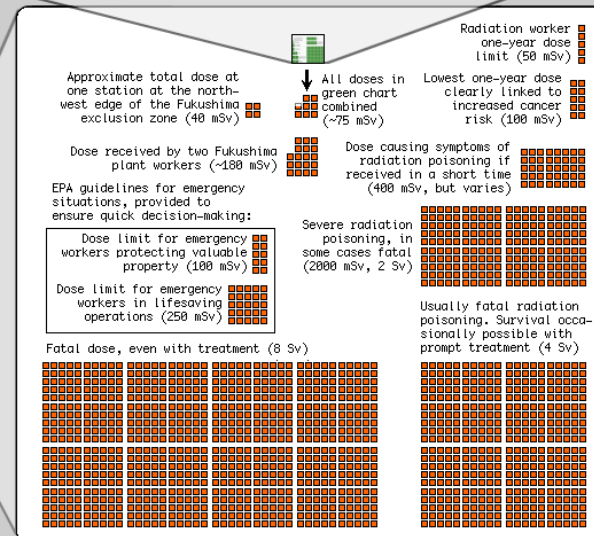


Chart by Randall Munroe, with help from Ellen, Senior Reactor Operator at the Reed Research Reactor, who suggested the idea and provided a lot of the sources. I'm sure I've added in lots of mistakes; it's for general education only. If you're basing radiation safety procedures on an internet PNG image and things go wrong, you have no one to blame but yourself.

Garotas do rádio

- Relógios pintados com rádio nos EUA ~ 1917
 - New Jersey
- Morte por radiação



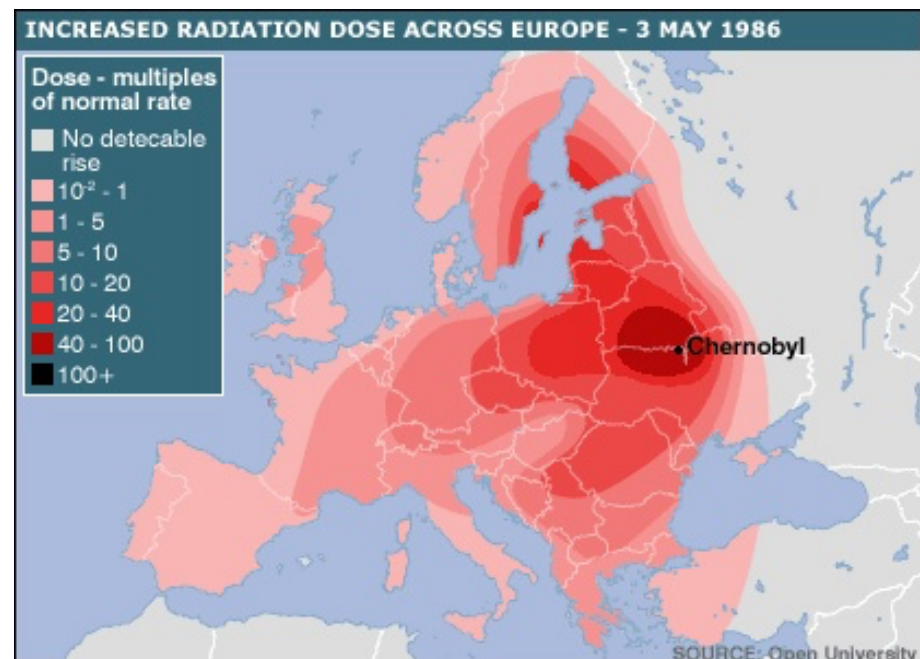
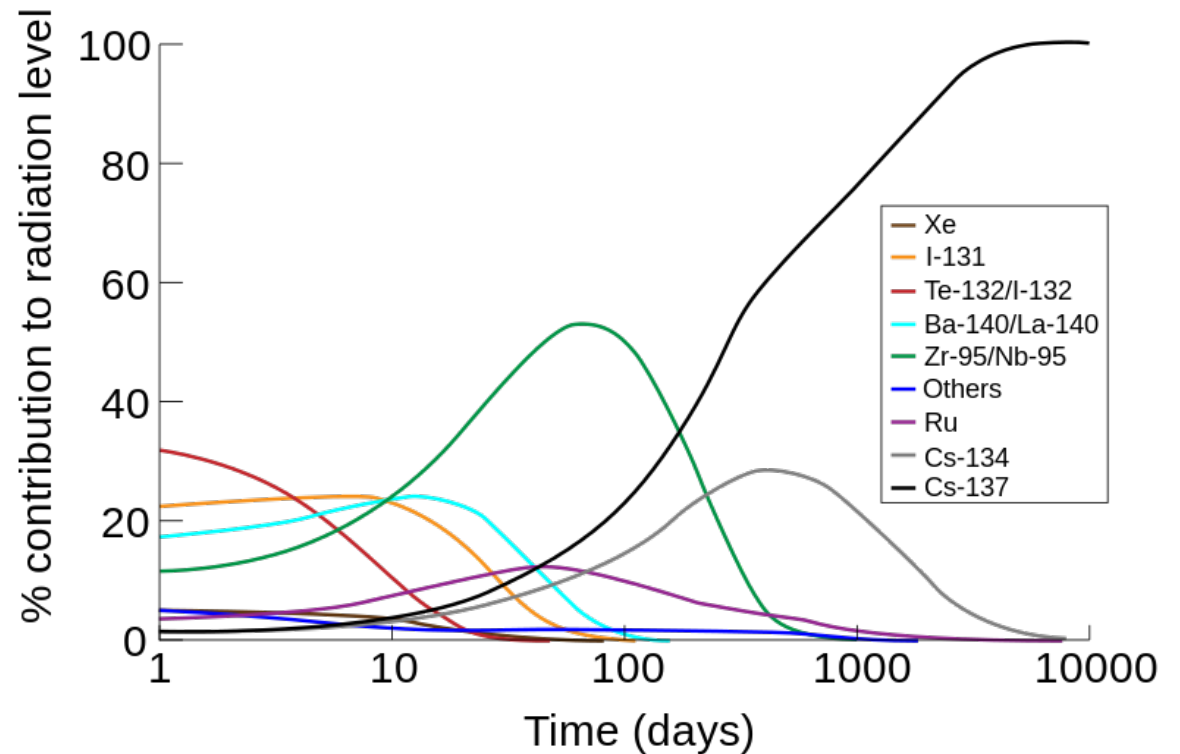
Chernobyl - 1986

- Falhas no design e de operação em um teste do reator 4 resultou no derretimento e explosão do núcleo do reator em abril de 86.
- Inicialmente encoberto pela URSS
- Usina desligada somente em 15 de dezembro de 2000



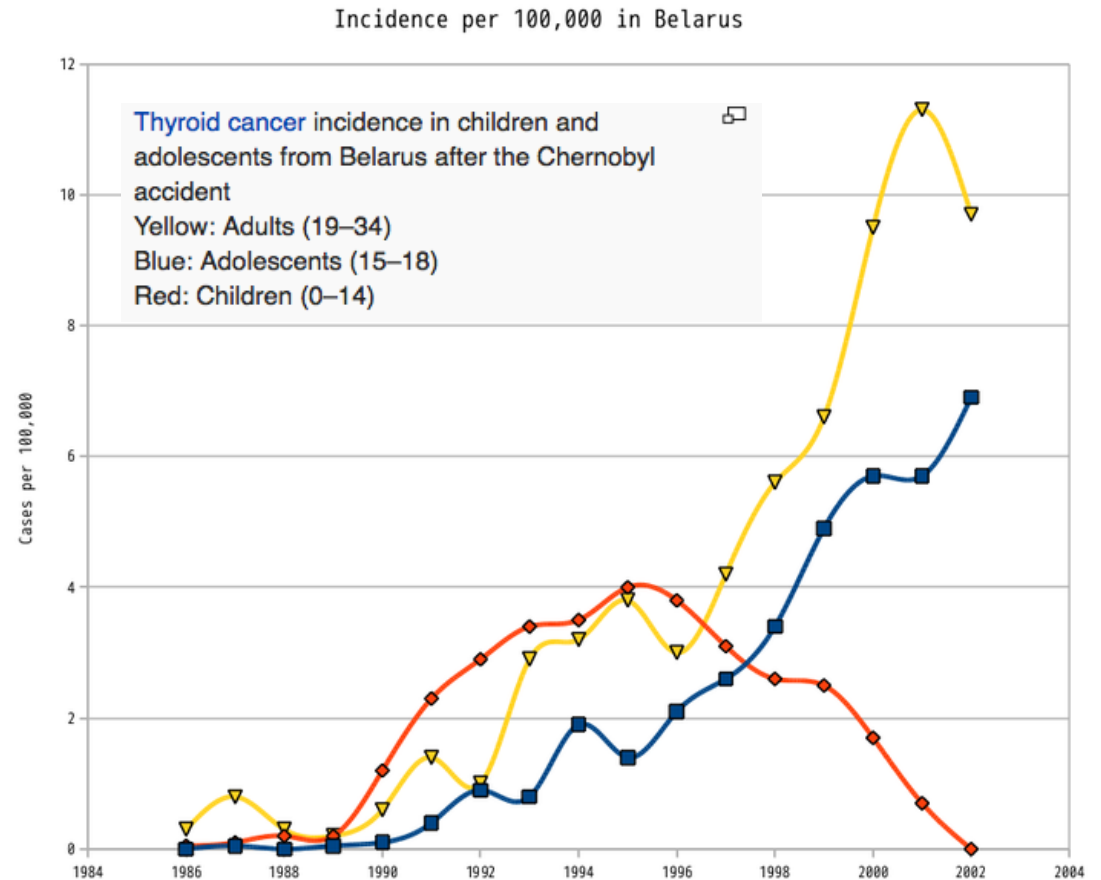
Chernobyl

- Reator somente com contenção parcial – vapores radioativos foram despejados na atmosfera
- “Nuvem” radioativa atingiu toda Europa
- Evacuação em massa de Pripjat
- Zona de exclusão com raio de ~ 30 km
 - Algumas regiões não poderão ser habitadas por aproximadamente 20 mil anos!



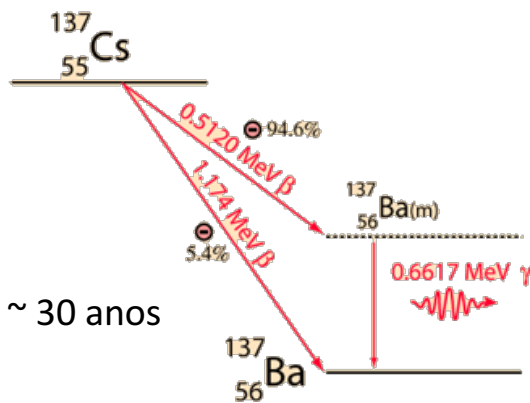
Chernobyl

- Segundo a ONU houve 64 mortes até 2008.
 - Estima-se que o número total possa atingir ~ 4000 com o tempo



Goiania – 1987 césio-137

- 19,3 g de cloreto de césio
 - 4 mortes diretas
 - Alguns dias até poucas semanas
 - 2 mortes posteriores
 - Milhares de contaminados



Meia-vida ~ 30 anos



Goiania – 1987 césio-137

- Cerca de 13 toneladas de lixo atômico
 - Barris em capsulas de concreto e chumbo, enterradas
- Abadia, Go
 - Quente por ~ 180 anos

