Joint ICTP-IAEA Workshop on Advanced Solutions for Field Measurements (SMR 3729), 8-19 Aug 2022, Trieste (Italy)

The potencial source of the environmental radioactivity

S. Tarjan,

Content

- Natural radioactivity
  - Cosmogenic radionuclides
  - Terrestrial radionuclides (briefly)
- Anthropogenic
  - Military application (Atmospheric tests)
  - Nuclear power reactors
  - Satellites

Cosmogenic radionuclides

- **Produced by the high energy cosmic particles (by the neutrons from their interactions)**

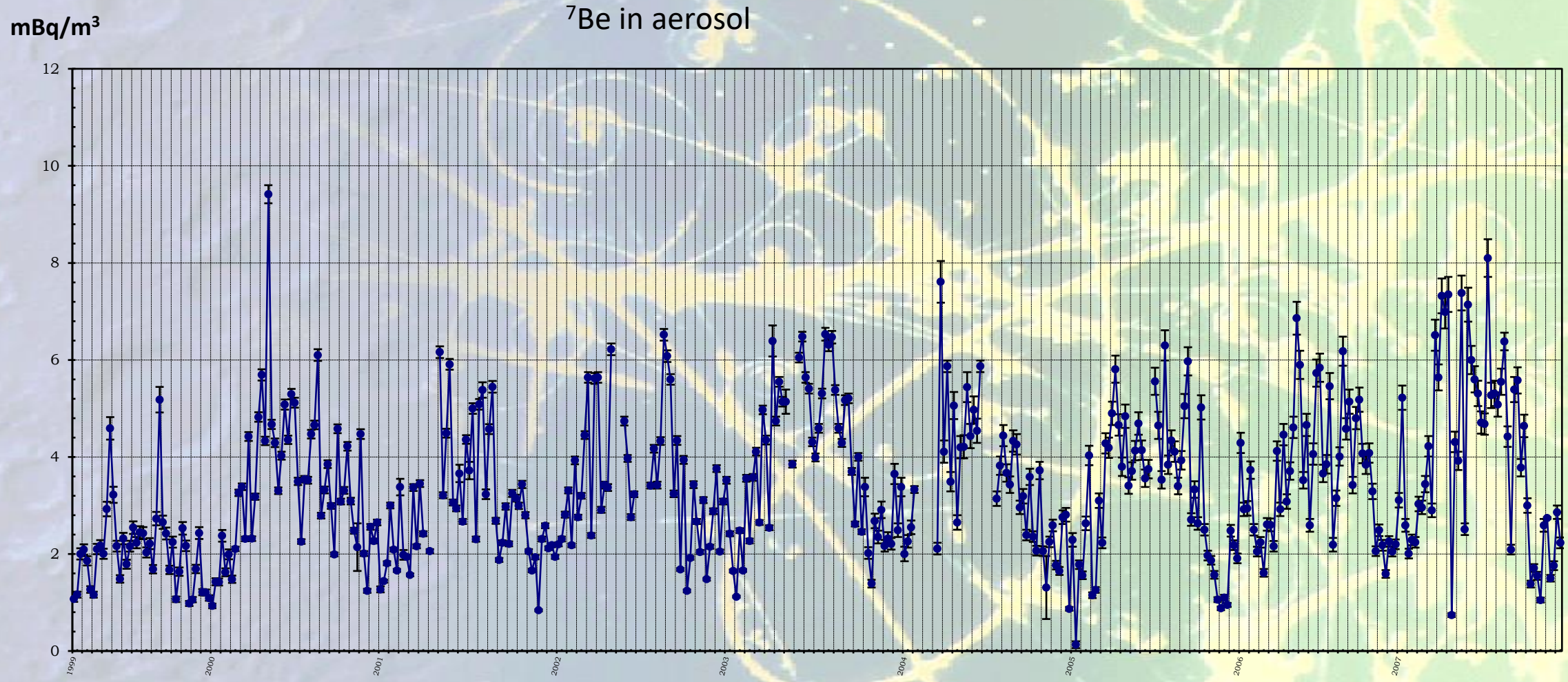
Typical reaction: Spallation (by high energy ≥4MeV neutron)

$$^{14}_{7}N + n \rightarrow {}^{12}_{6}C + {}^{3}_{1}H$$

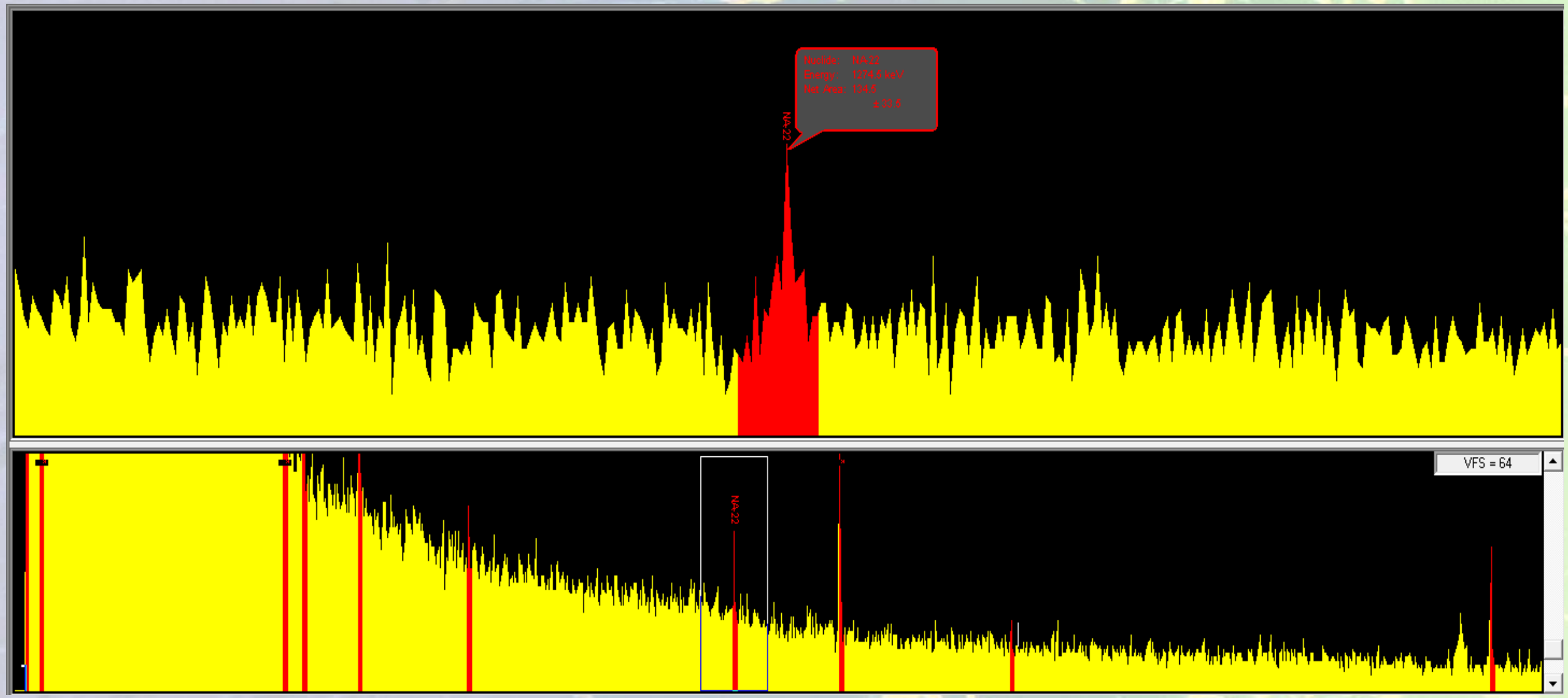
Some other radionuclides:

^{7}Be, ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{80}Kr, ^{14}C, ^{32}Si, ^{39}Ar, ^{22}Na, ^{35}S, ^{37}Ar, ^{33}P, ^{32}P, ^{38}Mg, ^{24}Na, ^{38}S, ^{31}Si, ^{18}F, ^{39}Cl, ^{38}Cl, ^{34m}Cl.

Cosmogenic radionuclides (real measured values at Budapest, Hungary)



^{22}Na *in aerosol* *(sample volume is 40 000 m³)*



Terrestrial radionuclides (primordial)

- Radioactive series:
  - Thorium (^{232}Th, ^{208}Pb)
  - Actinium (^{235}U, ^{207}Pb)
  - Uranium-Radium (^{238}U, ^{226}Ra, ^{206}Pb)
  - Ones upon a time? (^{237}Np, ^{209}Bi $T_{(1/2)}$:1.9×10^{19}y, ^{205}Tl)
- ^{40}K

Others:

- ^{50}V, ^{87}Rb, ^{113}Cd, ^{115}In, ^{123}Te, ^{138}La, ^{142}Ce, ^{144}Nd, ^{147}Sm, ^{152}Gd, ^{174}Hf, ^{176}Lu, ^{187}Re, ^{190}Pt, ^{192}Pt

Anthropogenic radionuclides

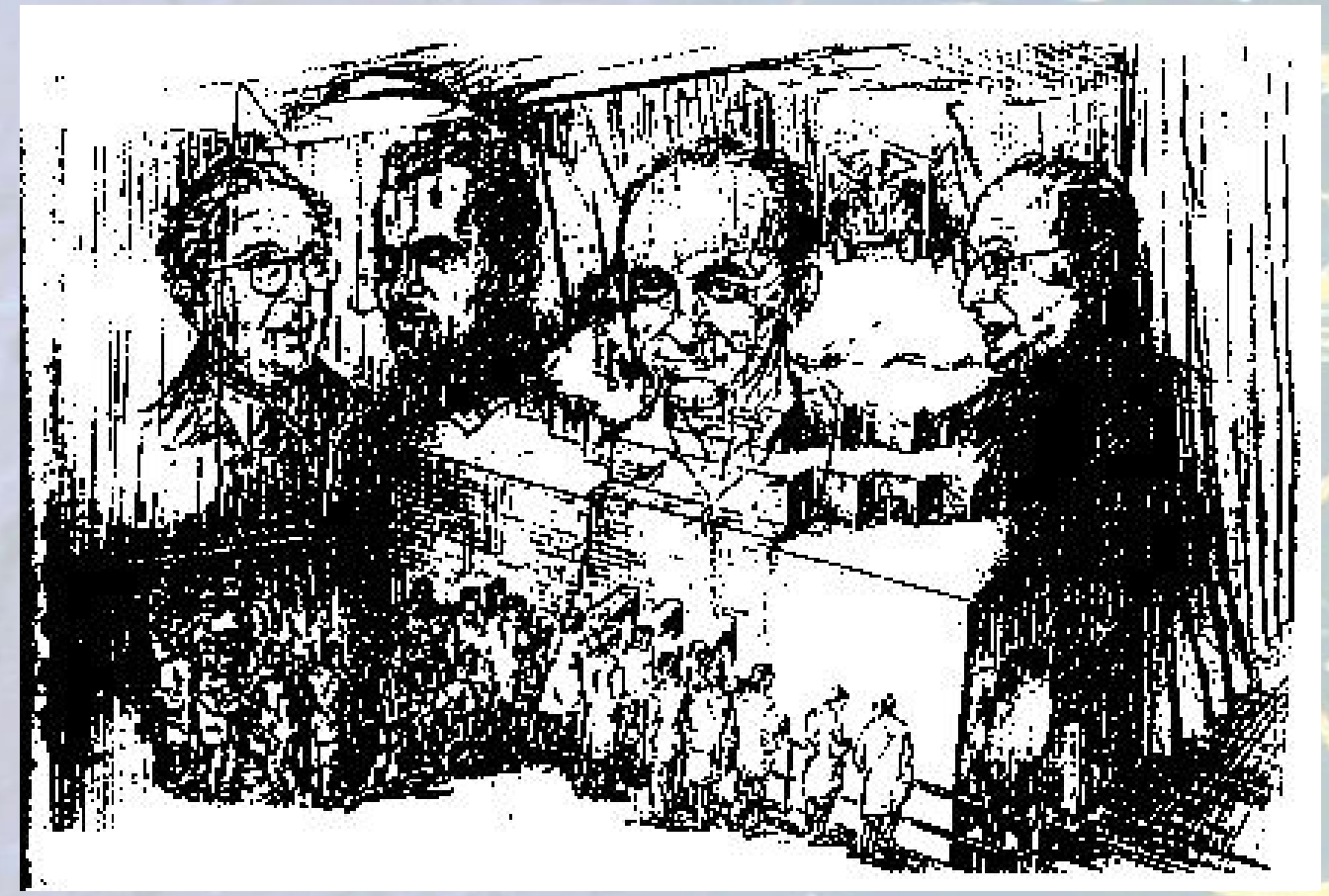
- Nuclear tests
  - Full spectrum of fission and activation product
  - Remaining part of the fission material (^{235}U or Pu-isotopes)

- Nuclear energy production
  - Full spectrum of fission and activation product, including the long half life activation products

- Radiation incident, accident (transport, orphan sources)

The first nuclear reactor

- With leadership of *E. Fermi* 2 December 1942, Chicago



Arthur Holly Compton (US)
Eugen Wigner (Hungary)
Leo Szilard (Hungary)

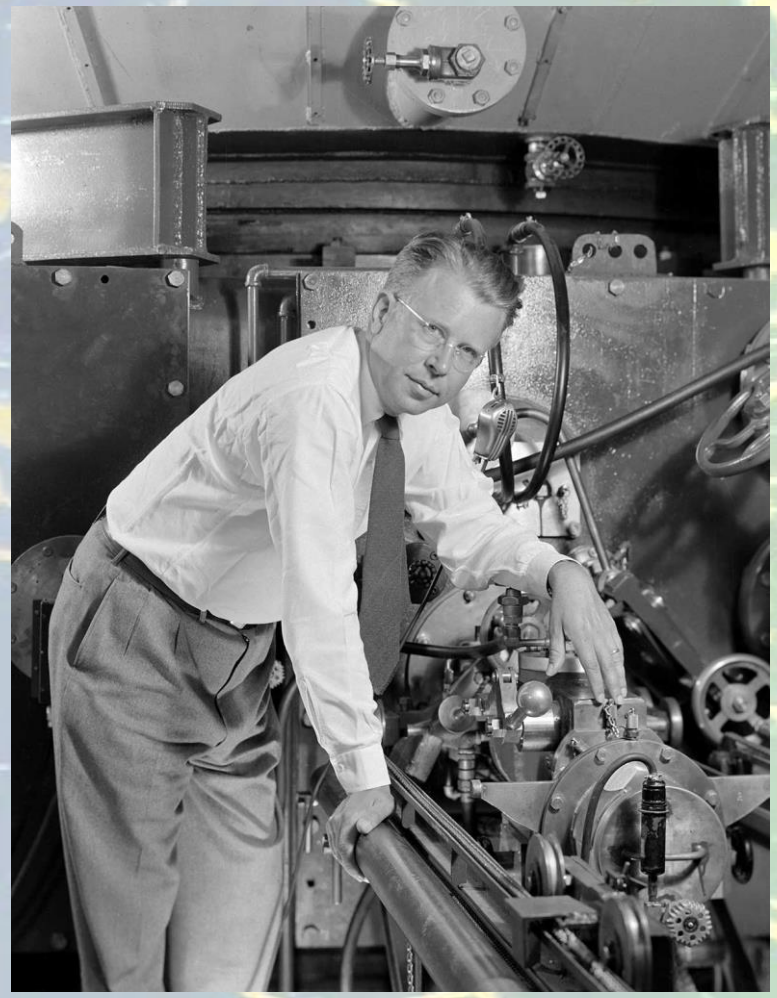
6 t natural U
315 t graphite

Power: 0,5 W
approx. 30 min
operating time

Manhattan Project (US weapon production)

- H-bomb (thermonuclear bomb)
- Neutron bomb

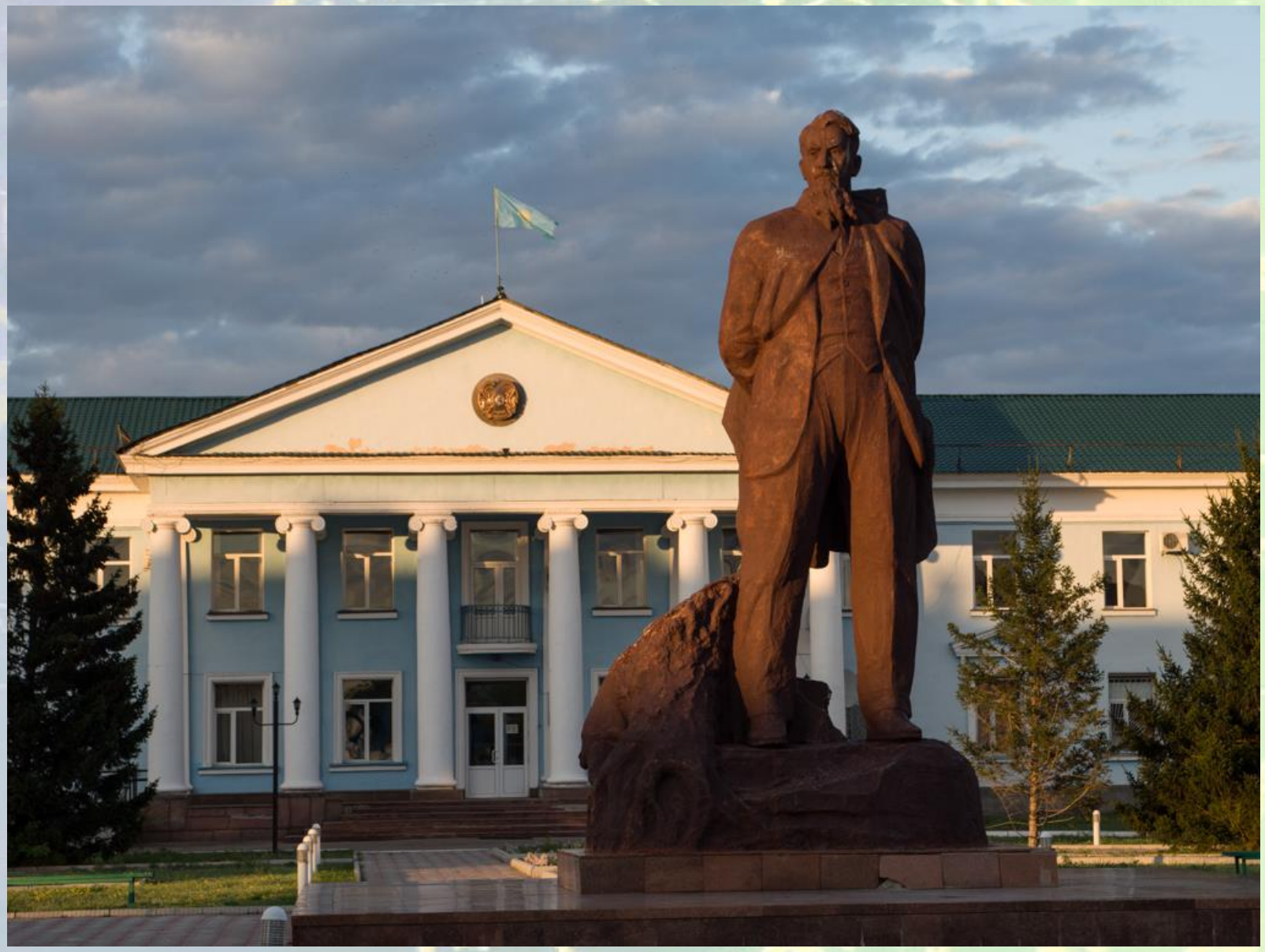
- Edward Teller (Hungarian)
- Ernest Olrlando Lawrence (US)



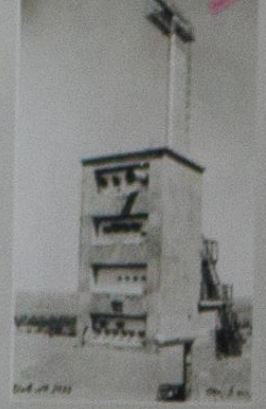
SU weapon production

- Kurchatov

- The first bomb was exploded in 1949

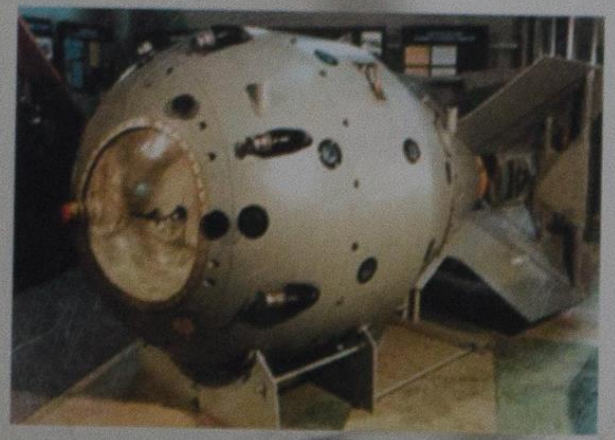


The Russian nuclear bomb cycle



С-1 Приборные башни “Гусаки”

Подготовка гражданских сооружений к исследованию действия ЯВ



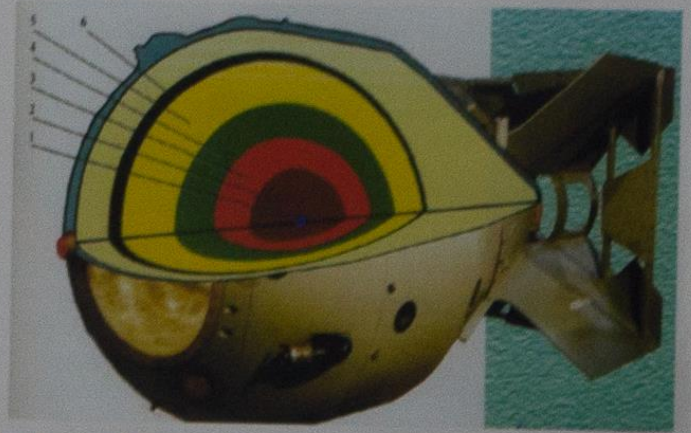


Схема первой советской атомной бомбы (РДС – 1):

Масса – 4

Диаметр

Длина

В кач

мат

исп

1 – нейтронный инициатор;

2 – делящийся материал плутоний;

металлический уран-238;

миний;

атое вещество и

ая система;

ниевый корпус

ТО ЯДЕРНОГО ИСПЫТАНИЯ

произведен взрыв первой в

Control board
(6 digit timing accuracy)

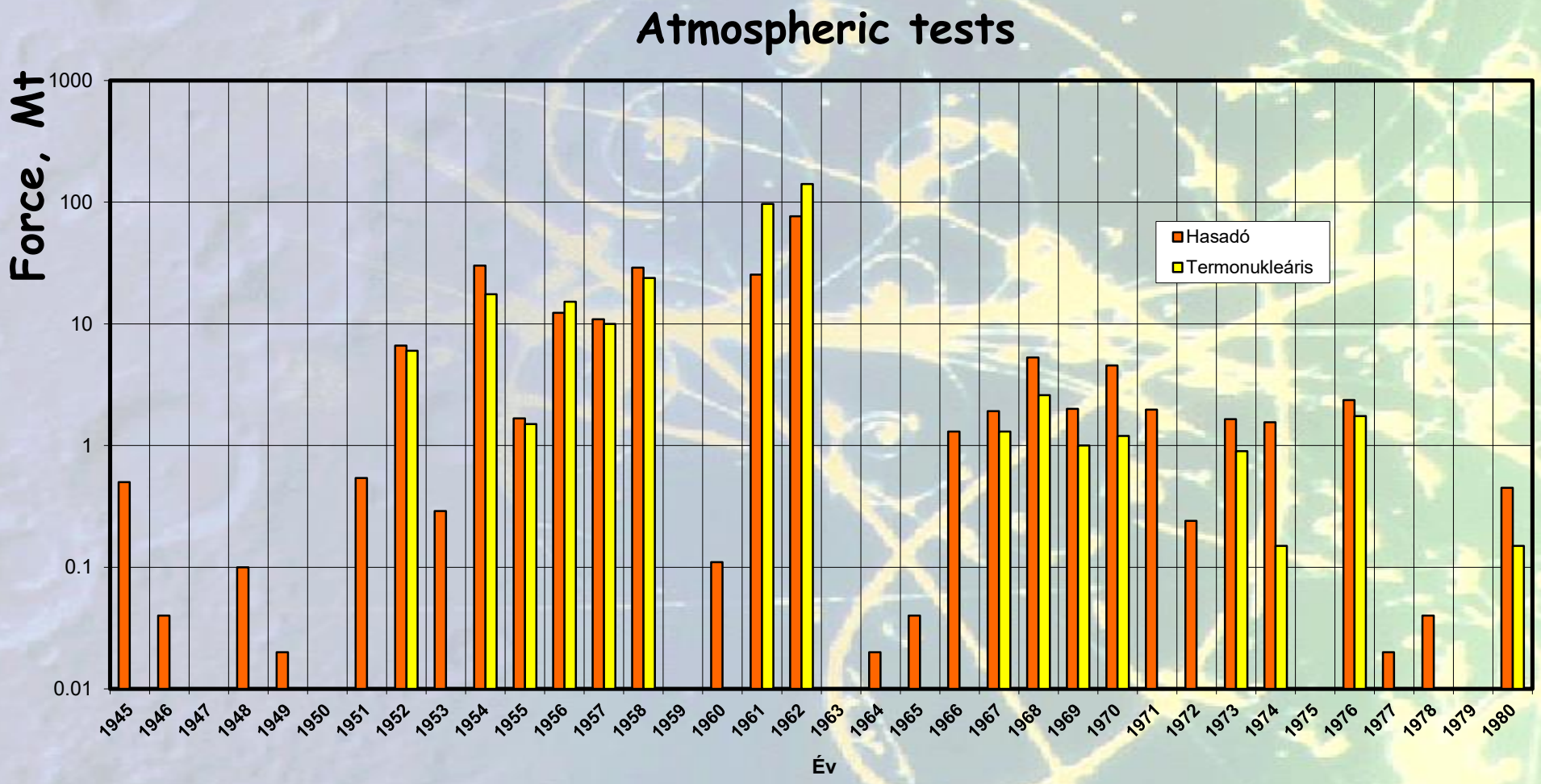
Nuclear bombs in a Museum

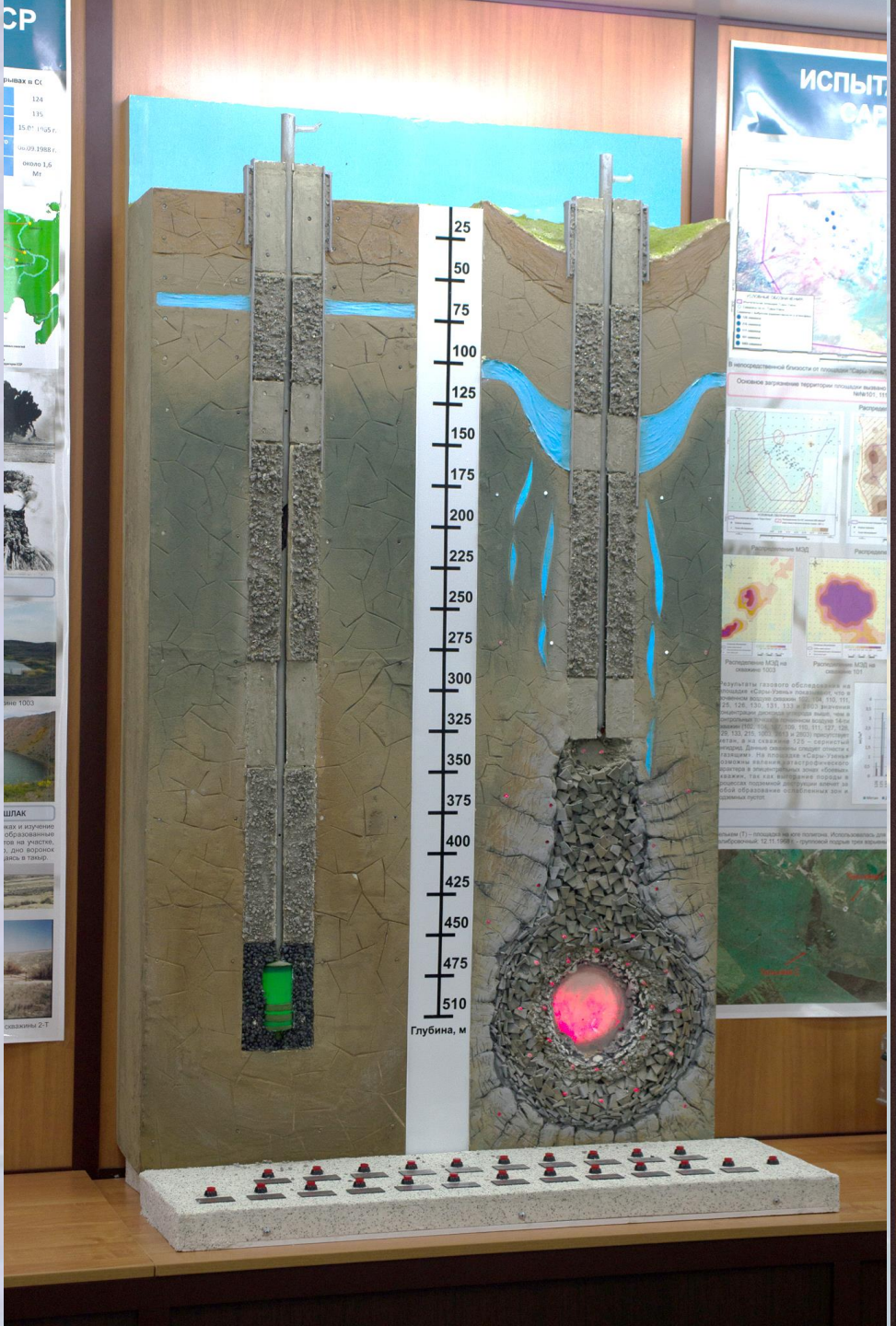
The test site

speed 1/s	1000000	
duration, s	0.01	
frame height, m	0.06	6 cm
length of the film for 1 s in meter	60000	
length of the film for 0.1 s in meter	600	
supposing before and after 0.1 s	1200	
speed of the fim in the camera, m/s	60000	
speed of the sound (at 0 C), m/s	331.5	
factor	181	

High speed camera: 1 000 000 frame/s

Atmospheric tests





Underground experiment and the bore hole „bomb"

Nuclear test programs *(by counties)*

- Total number of tests (1945-2007)
- US: 1029
- SU: 715
- France: 192
- GB: 45
- China: 43
- India: 1
- Pakistan 1
- Korea 1
- Total: 2025

- First experiments:
- US: 1945 - Oppenheimer
- SU: 1949 - Kurchatov
- GB: 1952
- France: 1960
- China: 1964
- India: 1974
- Pakistan: 1998
- Korea: 2007

Accidents of the power reactors

- Chernobil (1986)
- Fukushima (2011)

Nuclide	Half-life	Estimated releases, (Tests) EBq (1993)	Estimated releases – Chernobyl, EBq	Ingestion factor, Sv/Bq
^{3}H	12,33 a	240		$4,2x10^{-11}$
^{14}C	5730 a	0,22		$5,8x10^{-11}$
^{90}Sr	28,5 a	0,6	0,0081	$2,8x10^{-8}$
^{91}Y	58,5 d	116		$2,4x10^{-9}$
^{95}Zr	64,0 d	143	0,16	$9,5x10^{-10}$
^{103}Ru	39,25 a	238	0,14	$7,3x10^{-10}$
^{106}Ru	1,02 a	11,8	0,059	$7,0x10^{-9}$
^{131}I	8,04 d	651	0,67	$2,2x10^{-8}$
^{134}Cs	2,07 a		0,019	$1,9x10^{-8}$
^{137}Cs	30,0 a	0,91	0,037	$1,3x10^{-8}$
^{239}Pu	24110 a	0,00652	0,0008	$2,5x10^{-7}$
^{240}Pu	6540 a	0,00435	0,001	$2,5x10^{-7}$
^{241}Pu	14,4 a	0,142	0,17	$4,8x10^{-9}$
^{241}Am	432 a	0,00054		$2,0x10^{-7}$

Nuclear reactors as power sources of the satellites

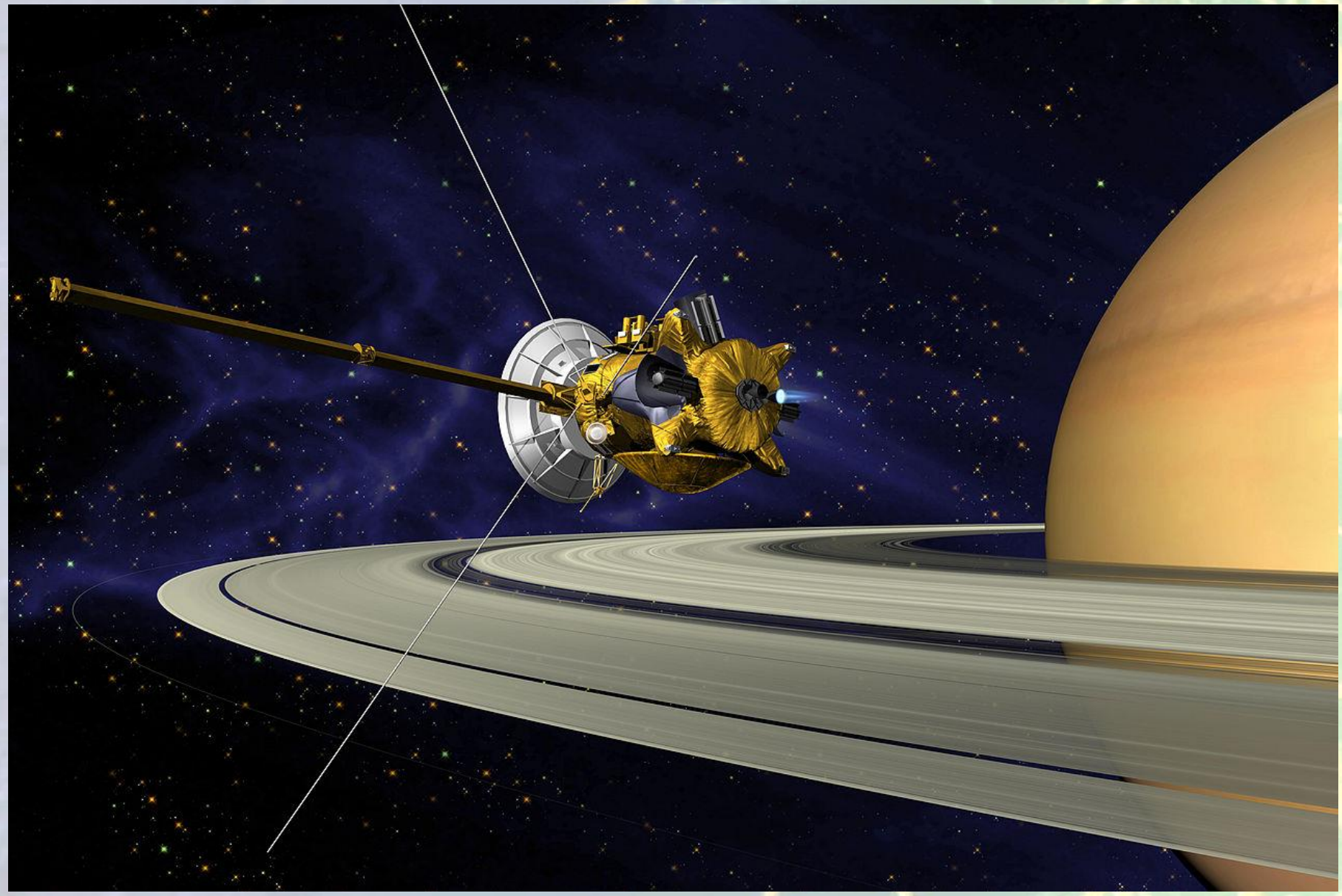
Name and/or model	Fate/Location
Selected examples of nuclear power systems in space[17]	
SNAP-10A	Earth orbit (900+ km altitude)
Cosmos 469 BES-5 Buk	
Cosmos 516	High orbited 1972
Cosmos 626	Earth orbit
Cosmos 954	Earth re-entry 1978 (over Canada)
Cosmos 1176	11788/11971 Earth orbit 870–970 km
Cosmos 1402	Earth re-entry 1983 (South Atlantic)
Cosmos 1607	High orbited 1985
Cosmos 1670	High orbited 1985
Cosmos 1677	High orbited 1985
Cosmos 1682	High orbited 1986
Cosmos 1736	High orbited 1986
Cosmos 1771	High orbited 1986
Cosmos 1818 TEU-5 Topol	Earth orbit[18]
Cosmos 1860	
Cosmos 1867 TEU-5 Topol	
Cosmos 1900	High orbited 1987
Cosmos 1932	Earth orbit 800–900 km

Name and/or model	Launched	Fate/location
MSL/Curiosity rover MMRTG (1)	2011	Mars surface
Apollo 12 SNAP-27 ALSEP	1969	Lunar surface (Ocean of Storms)[49]
Apollo 13 SNAP-27 ALSEP	1970	Earth re-entry (over Pacific near Fiji)
Apollo 14 SNAP-27 ALSEP	1971	Lunar surface (Fra Mauro)
Apollo 15 SNAP-27 ALSEP	1971	Lunar surface (Hadley–Apennine)
Apollo 16 SNAP-27 ALSEP	1972	Lunar surface (Descartes Highlands)
Apollo 17 SNAP-27 ALSEP	1972	Lunar surface (Taurus–Littrow)
Transit-4A SNAP-3B (1)	1961	Earth orbit
Transit 5A3 SNAP-3 (1)	1963	Earth orbit
Transit 5BN-1 SNAP-3 (1)	1963	Earth orbit
Transit 5BN-2 SNAP-9A (1)	1963	Earth orbit
Transit 9	1964	Earth orbit
Transit 5B4	1964	Earth orbit
Transit 5B6	1965	Earth orbit
Transit 5B7	1965	Earth orbit
Transit 5BN-3 SNAP-9A (1)	1964	Failed to reach orbit[52]
Nimbus-B SNAP-19 (2)	1968	Recovered after crash
Nimbus-3 SNAP-19 (2)	1969	Earth re-entry 1972
Pioneer 10 SNAP-19 (4)	1972	Ejected from Solar System
Pioneer 11 SNAP-19 (4)	1973	Ejected from Solar System
Viking 1 lander modified SNAP-19	1976	Mars surface (Chryse Planitia)
Viking 2 lander modified SNAP-19	1976	Mars surface (Utopia Planitia)
Cassini GPHS-RTG (3)	1997	Orbiting Saturn
New Horizons GPHS-RTG (1)	2006	Pluto and beyond
Galileo GPHS-RTG (2),	1989	Jupiter atmospheric entry
Ulysses GPHS-RTG (1)	1990	Heliocentric orbit
LES-8 MHW-RTG	1976	Near geostationary orbit
LES-9 MHW-RTG	1976	Near geostationary orbit
Voyager 1 MHW-RTG(3)	1977	Ejected from Solar System
Voyager 2 MHW-RTG(3)	1977	Ejected from Solar System

Nuclear electric power sources of the satellites

- ^{238}Pu,
- ^{99}Tc
- ^{90}Sr

Cassini Spacecraft 32.7 kg ^{238}Pu

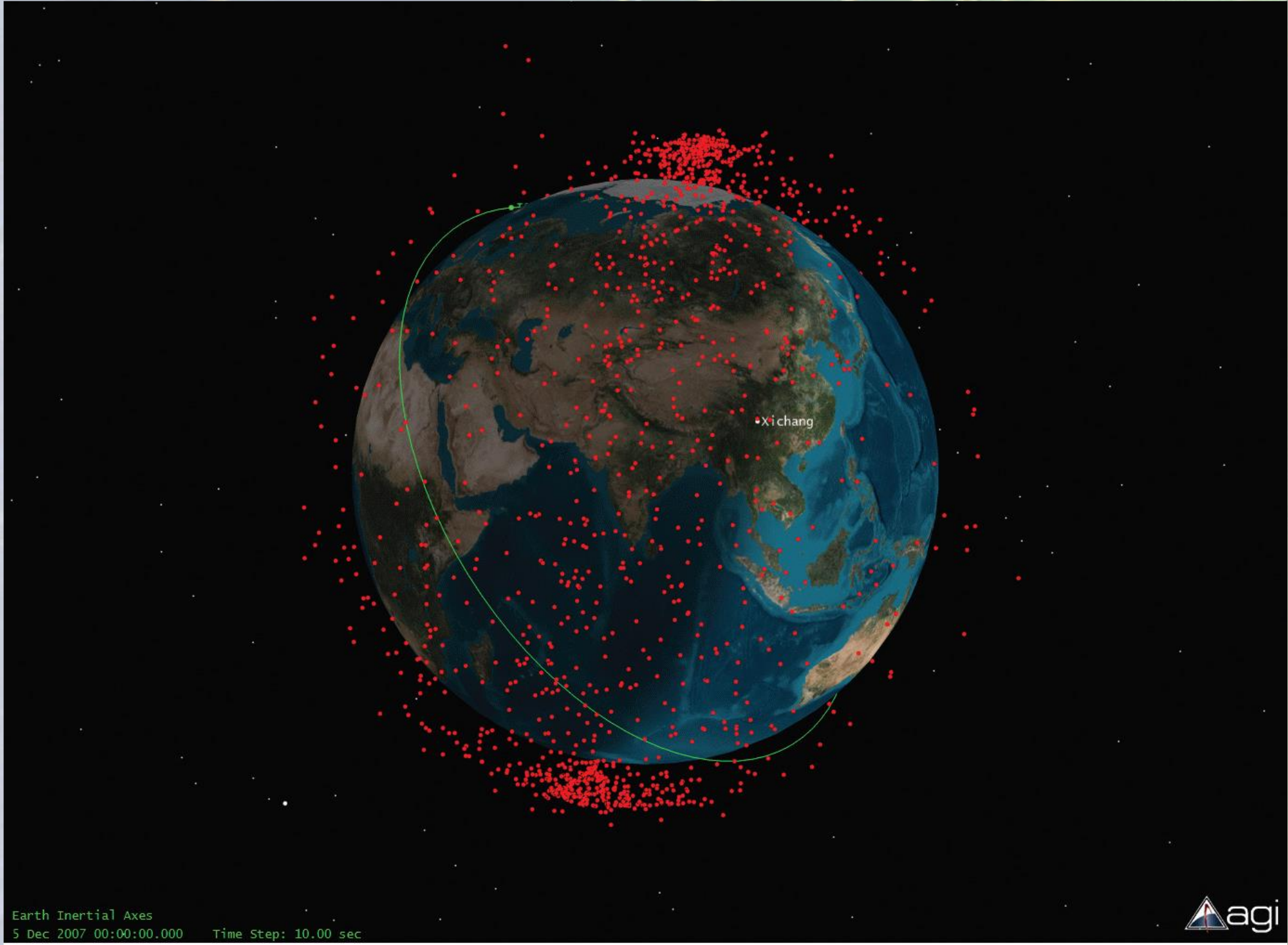


Space junk

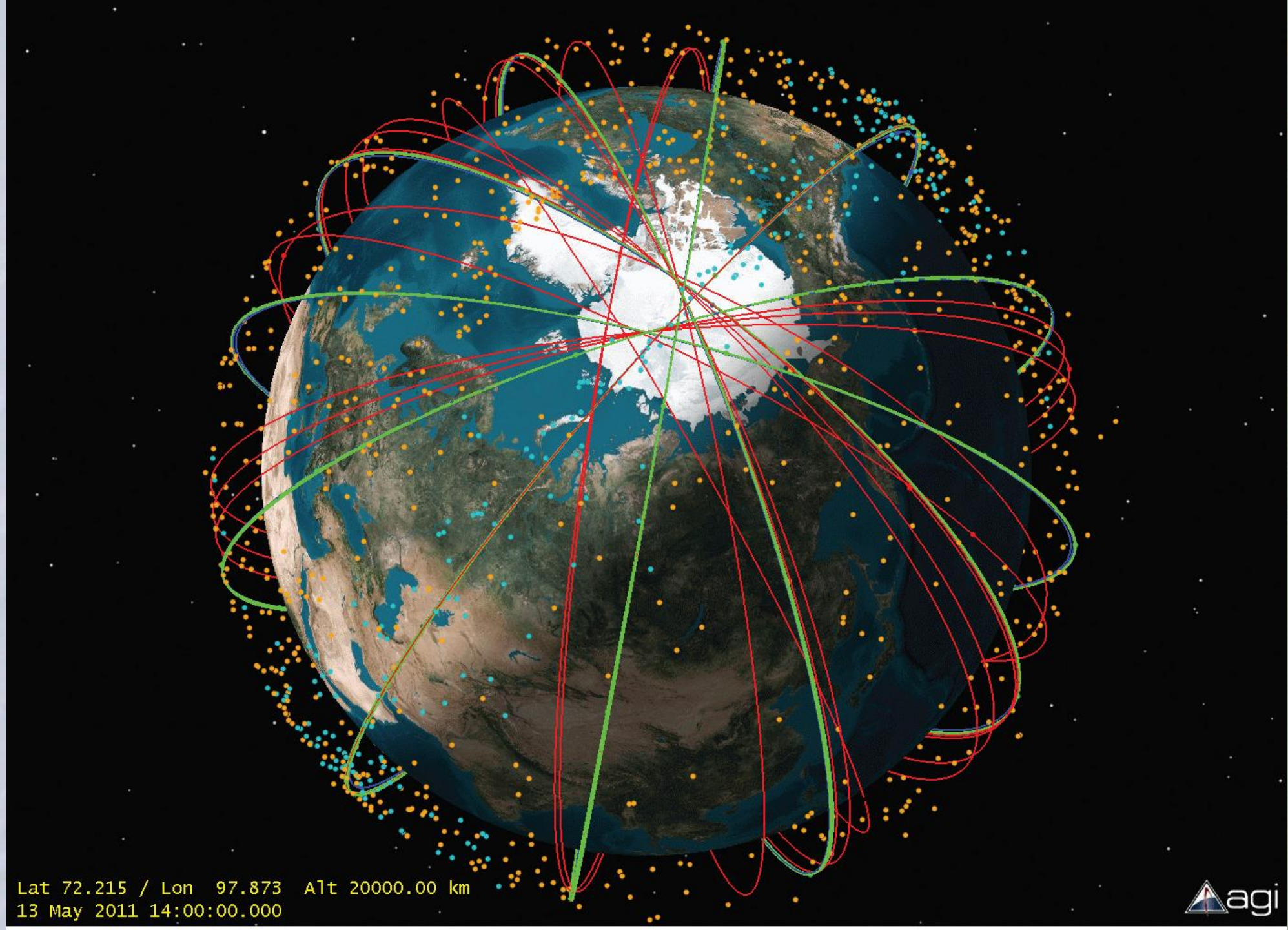
- 22 000 large debris, which are trackable from the surface (including radioactive parts)
  - When any of them reach the surface: 1-5 Sv/h dose rate may expected on the surface

- China anti-satellite experiment against the Fang-Yun 1C (11 Jan 2007)
  - 3000 trackable parts
  - 150 000 larger than 1 cm
  - They speed: 28164 km/h

The result of the China anti-satellite experiment



Overall picture in 2011



Thank you!

Natural reactor at Oklo *(Gabon, Africa)*

1,7-1,8 x 10^9 years before at the place of the natural U enrichment

500 t uranium
40-50% ore
^{238}U 4,5x10^9 év
^{235}U 7,1x10^8 év

^{235}U ratio
3.68%

Estimated power:

100x10^9 kWh

Duration:
200 000 years