Peaceful usage of nuclear energy

Konstantin German

II Letnia Szkoła Energetyki i Chemii Jądrowej

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II Summer school of Energetic and Nuclear Chemistry

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Peaceful usage of nuclear energy

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&

Medical institute REAVIZ

Discovery of radioactivity and estimation of its importance

Becquerel

- In 1896 found out that Uranium ore is emitting some new kind of rays.

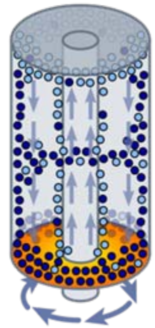
Curie and Sklodowska

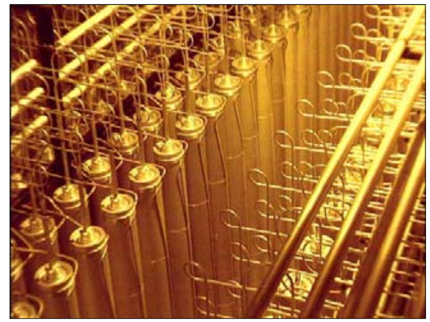
- Pierre Curie (a **famous French** physicist) and his **young Pole assistant** (radio)**chemist** Maria Sklodowska in 1898 were the first to separate a new element, Ra. They found out that Radium samples are **more hot compared** to the environments as long as for many months.
- They concluded that radioactivity is new and very important source of energy and ***proposed its usage*** for medical, pharmaceutical, …, …, purposes. Some other applications – drugs and creams… were considered important.
- Vernadsky in Russia in 1920 predicted that Ra and allied matter could be a very important key for new energetic in the World scale.

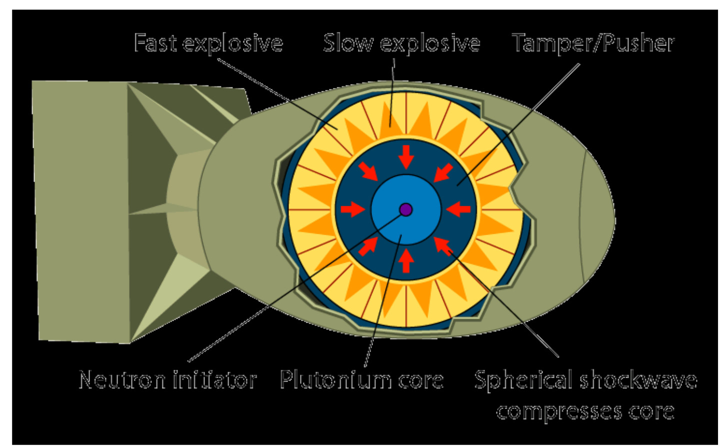
MARIE SKŁODOWSKA-CURIE
BY GRZEGORZ ZAJĄC

In 1945, two explosions in Japan have demonstrated the power of atom with absolute evidence

Duality of Nuclear Technology

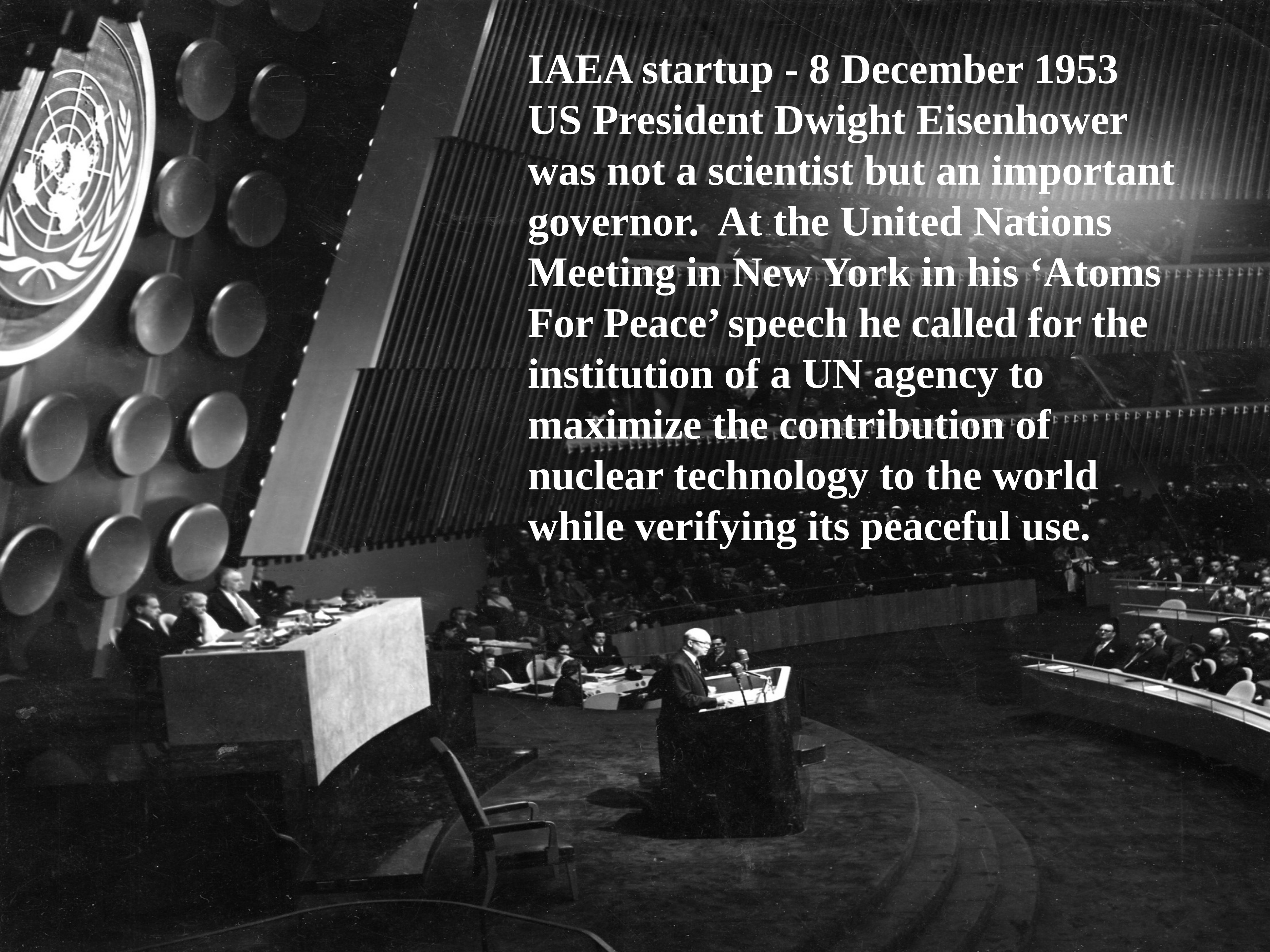






Obninsk, Russia, 1954

Hiroshima and Nagasaki, Japan, 1945



IAEA startup - 8 December 1953

US President Dwight Eisenhower was not a scientist but an important governor. At the United Nations Meeting in New York in his ‘Atoms For Peace’ speech he called for the institution of a UN agency to maximize the contribution of nuclear technology to the world while verifying its peaceful use.

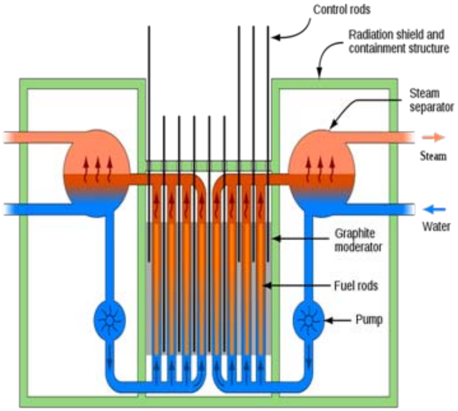
Peaceful uses of atomic energy

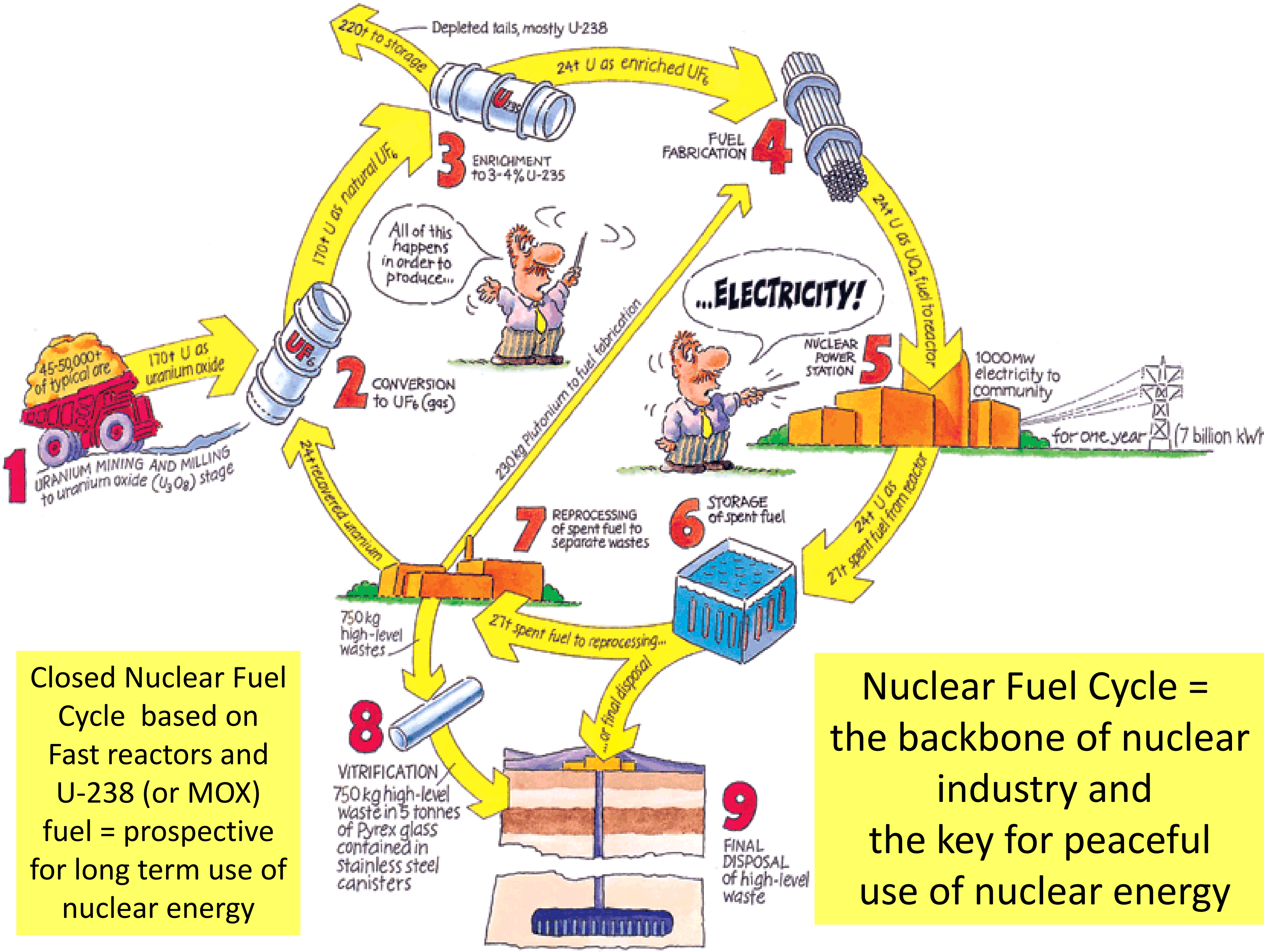
- Supervised by IAEA : that seeks to promote the peaceful use of nuclear energy, and to inhibit its use for any military purpose, including nuclear weapons
- Missions
- 3.1 Peaceful uses
- 3.2 Safeguards
- 3.3 Nuclear safety
- 3.4 Criticism

- Nuclear power plants (electricity production, thermal source, water distillation stations)
- Nuclear reactor propulsion (icebreakers, special plants)
- Radioisotope sources (closed – RITEGs etc., open)
- Nuclear medicine (radiation use, radioisotope use – radiodiagnostics and radiotherapy)
- Nuclear explosions - peaceful uses (historical and prospective)

First NPP

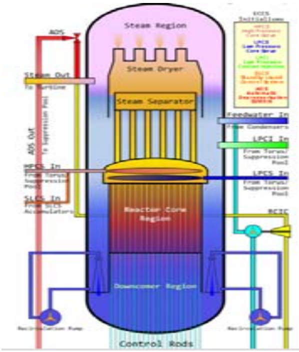
- At the time of Dwight Eisenhower speech on Dec. 1953 the first NPP was 85% constructed in Obninsk, Russia , the start-up done in 1954
- Construction started on January 1, 1951, startup was on June 1, 1954, and the first grid connection was made on June 26, 1954 providing the city of Obninsk with electrisity. For around 4 years, till opening of Siberian Nuclear Power Station, Obninsk remained the only nuclear power reactor in the USSR; the power plant remained active until April 29, 2002 when it was finally shut down.
- The single reactor unit at the plant, *AM-1* (*Atom Mirny*, or "peaceful atom"), had a total electrical capacity of 6 MW and a net capacity of around 5 MWe. Thermal output was 30 MW.
- It was a prototype design using a graphite moderator and water coolant. This reactor was a forerunner of the RBMK reactors.





Closed Nuclear Fuel Cycle based on Fast reactors and U-238 (or MOX) fuel = prospective for long term use of nuclear energy

Nuclear Fuel Cycle = the backbone of nuclear industry and the key for peaceful use of nuclear energy



Nuclear reactor is a device to initiate and control a sustained nuclear chain reaction. Nuclear reactors are used at :

- **Nuclear power plants (NPP)   for generation electricity**
- **In propulsion of ships.**
- Heat from nuclear fission is passed to a working fluid (water or gas), which runs through turbines. These either drive a ship's propellers or turn electrical generators. Nuclear generated steam in principle can be used for industrial process heat, for district heating or for water distillation.

- Some reactors are used to produce isotopes for medical and industrial use, or for production of plutonium for weapons.
- Some are run only for research.

NPPs are different in the nature of Nuclear Reactor Type:

Thermal neutrons reactors

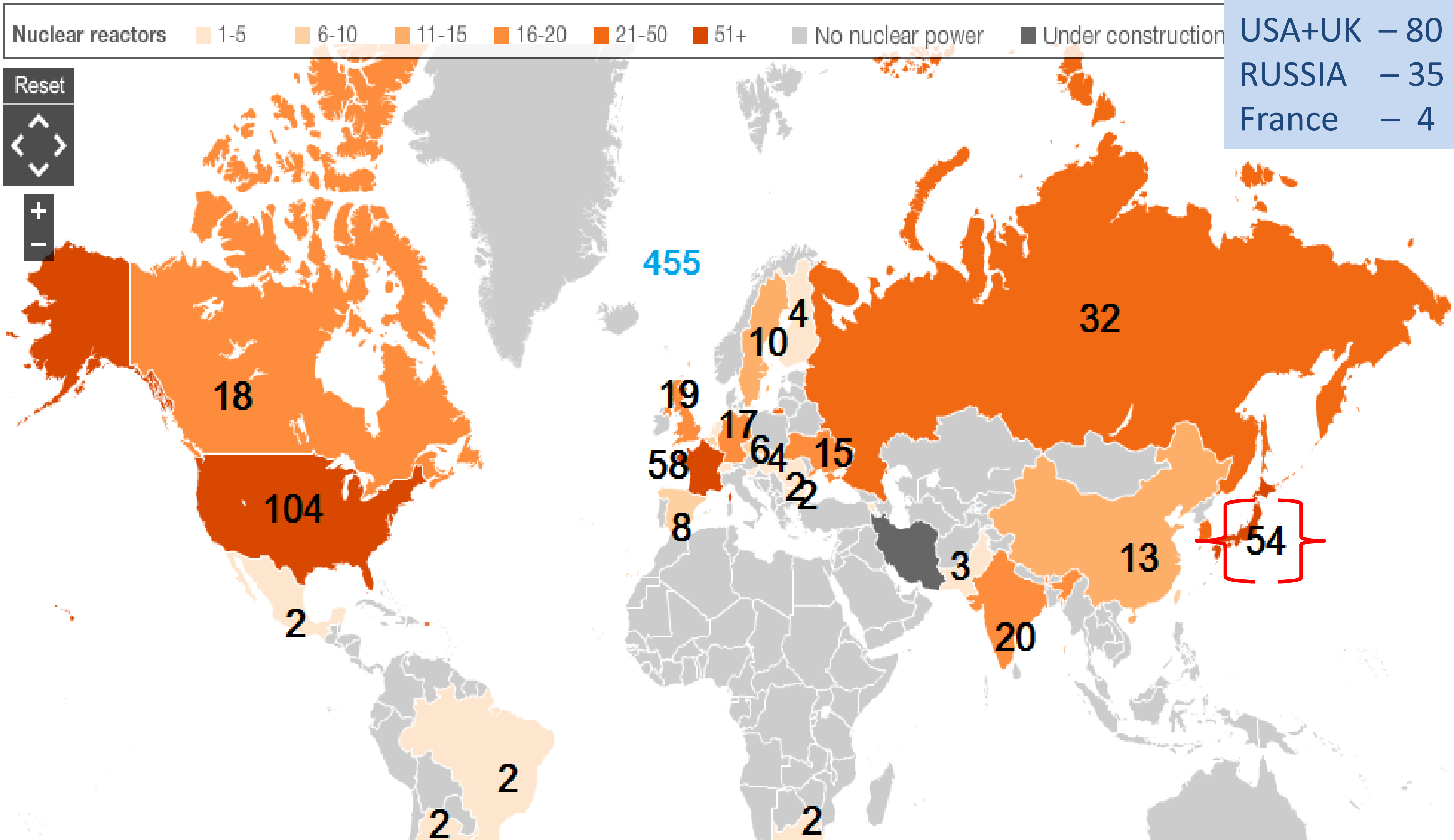
- Water-water (WWER)
- Boiling water (BWR)
- Heavy water
- Gas cooled (MAGNOX, AGR)
- Graphite-water
- High temperature gas cooled
- Heavy water gas cooled
- Heavy water cooled
- Boiling heavy water

Fast neutrons reactors

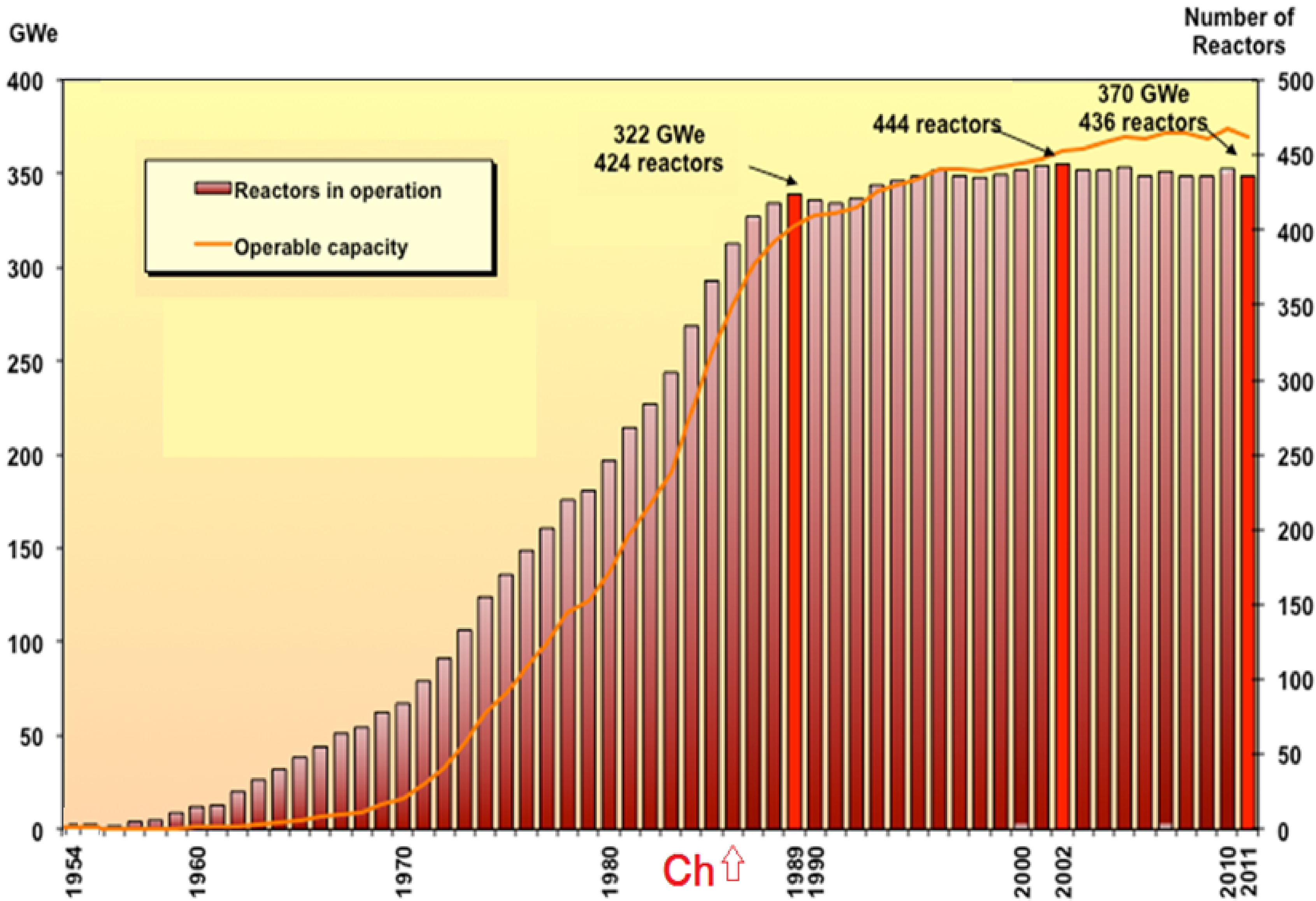
- Sodium cooled (BN-300, 600, BN-800)
- Pb or Pb-Bi cooled (BN-1200)

- OTHER REACTOR TYPES EXIST
- Molten salt
- Homogeneous
- Research reactors
- …

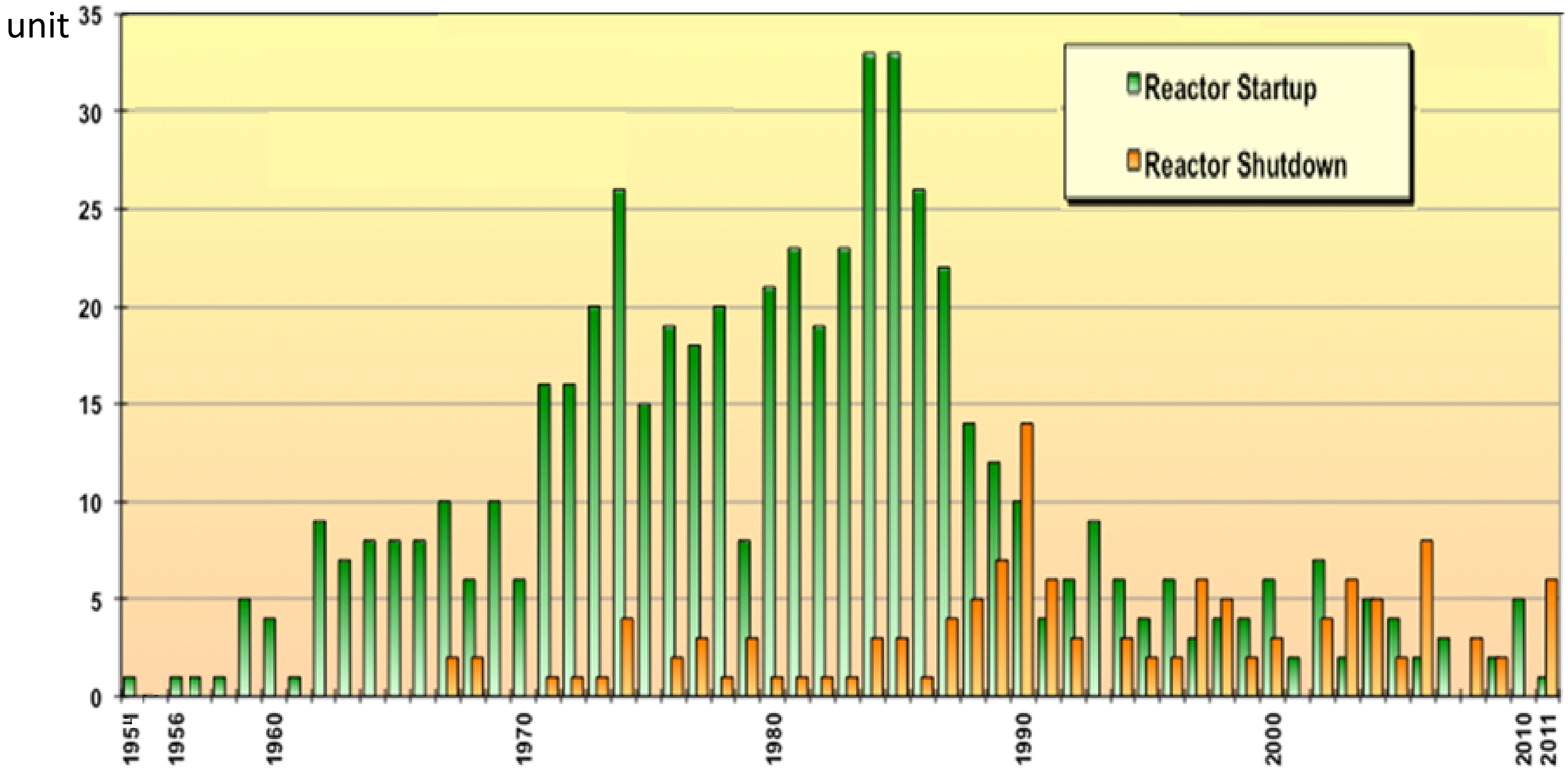
NPP Reactors worldwide in 2011: 443 NSubmarine & NS-icebreaker reactors: 455



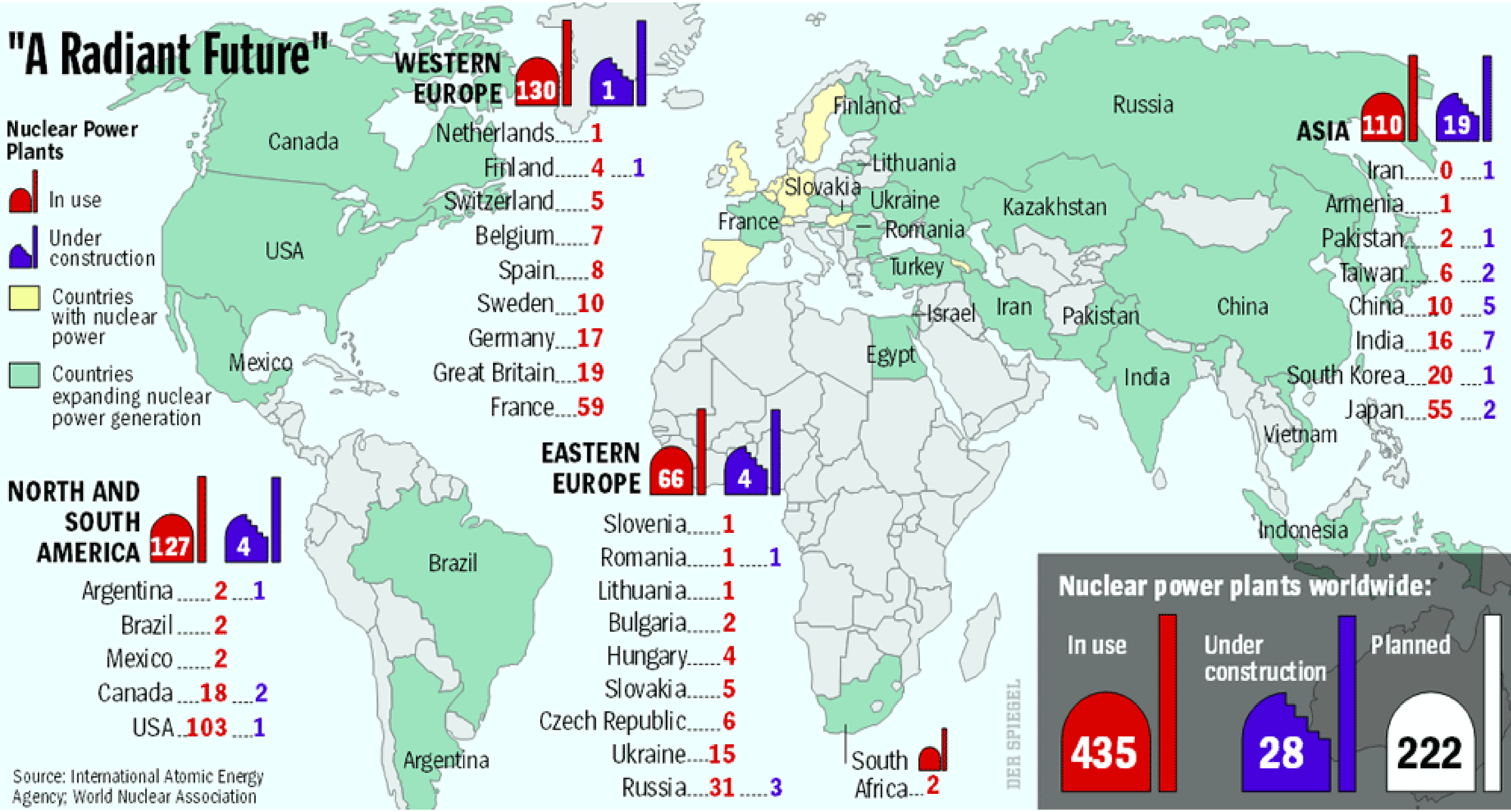
Civil NPP Nuclear reactors and Net Operating Capacity in the World (1954 – 2011), GWe



Civil NPP Reactor startups and shutdowns in the world (1954 – 2011)

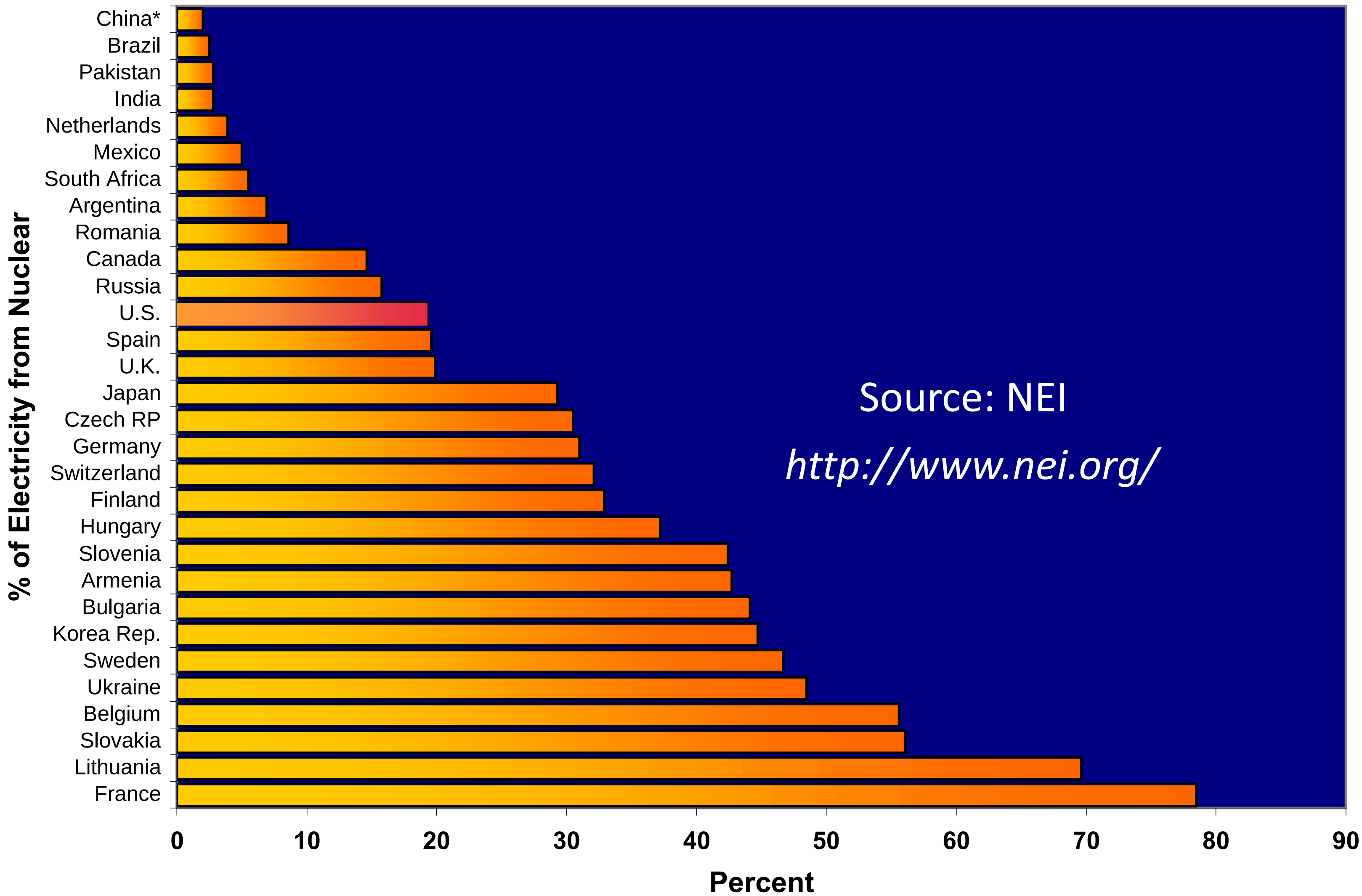


Global Growth of Nuclear Power in Progress (2010)



www.spiegel.de/international/spiegel/0.1518.460011.10.html

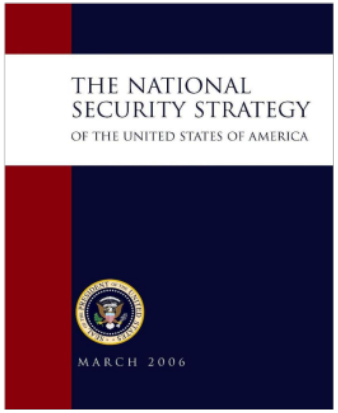
Nuclear Energy Provided in 2005 - % of Electricity in: 77% in France, 55 % in Belgium, 45 % in South Korea, 20% in USA

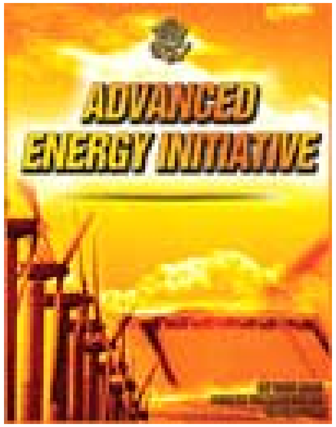


The AFCI is the Technology Development Component of the U.S. Nuclear Energy Program

AFCI Research Campaigns:

- Transmutation Fuels
- Fast Reactors
- Advanced Separations
- Waste Forms
- Safeguards
- Systems Analysis
- Grid-appropriate Reactors





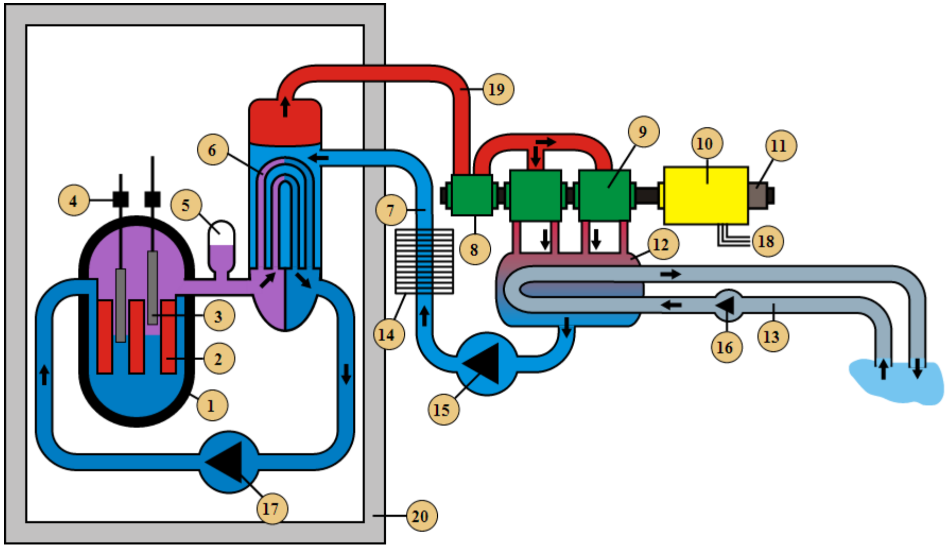
** - Gordon Jarvinen VIII International Workshop - Fundamental Plutonium Properties . September 8-12, 2008*

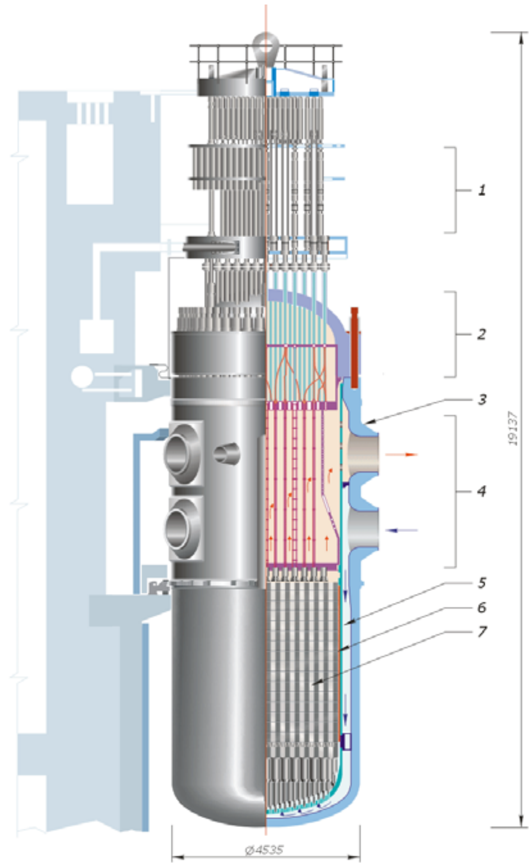
NPPs in Russia

- 2012 – Russian NPPs produced 170*109 kWt*hour
- The fraction of nuclear power in total electric power = 16 % in Russia, of total power = 11%

Water-water reactors

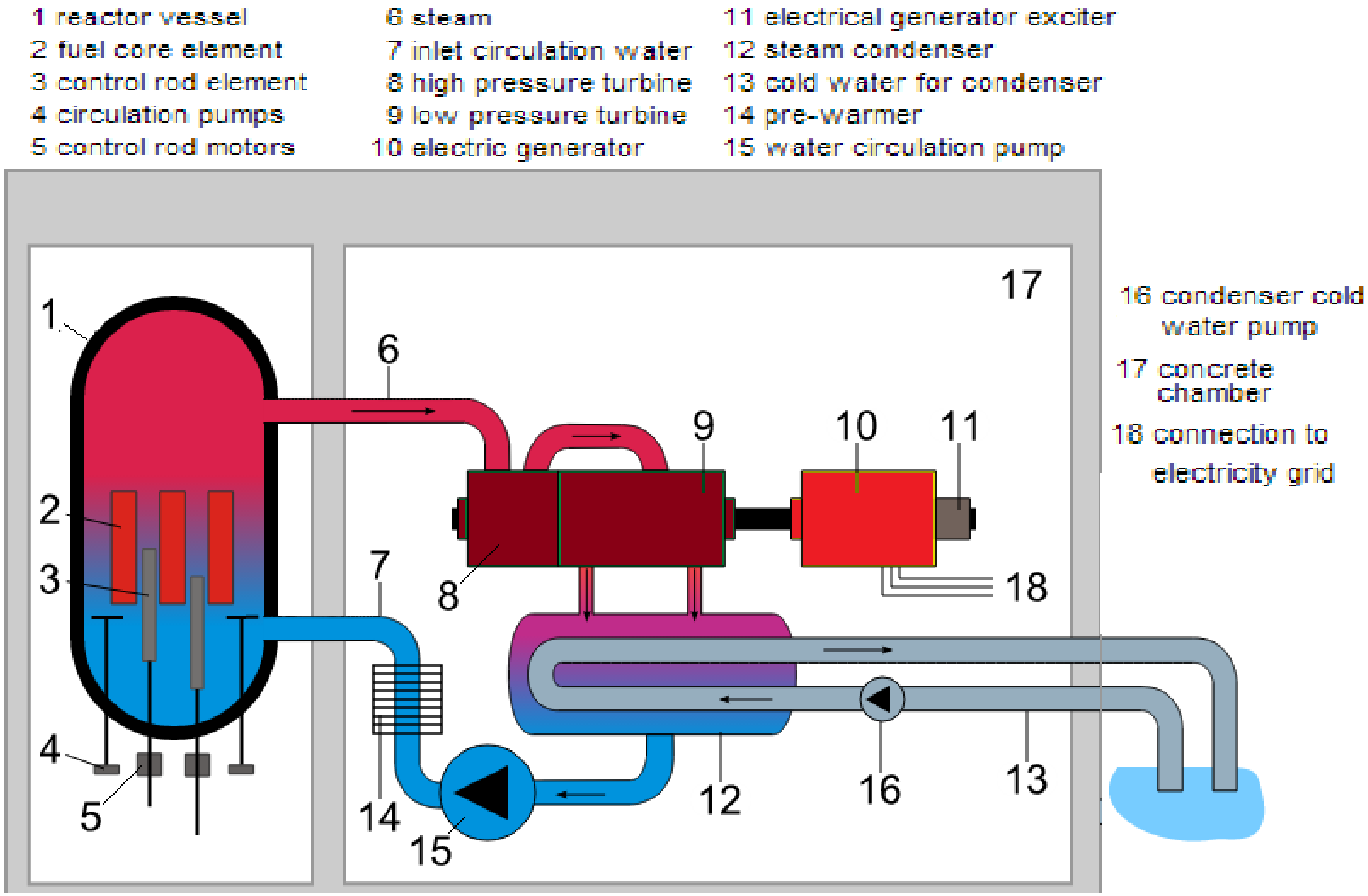
WWER-1000 (31 reactors in operation)



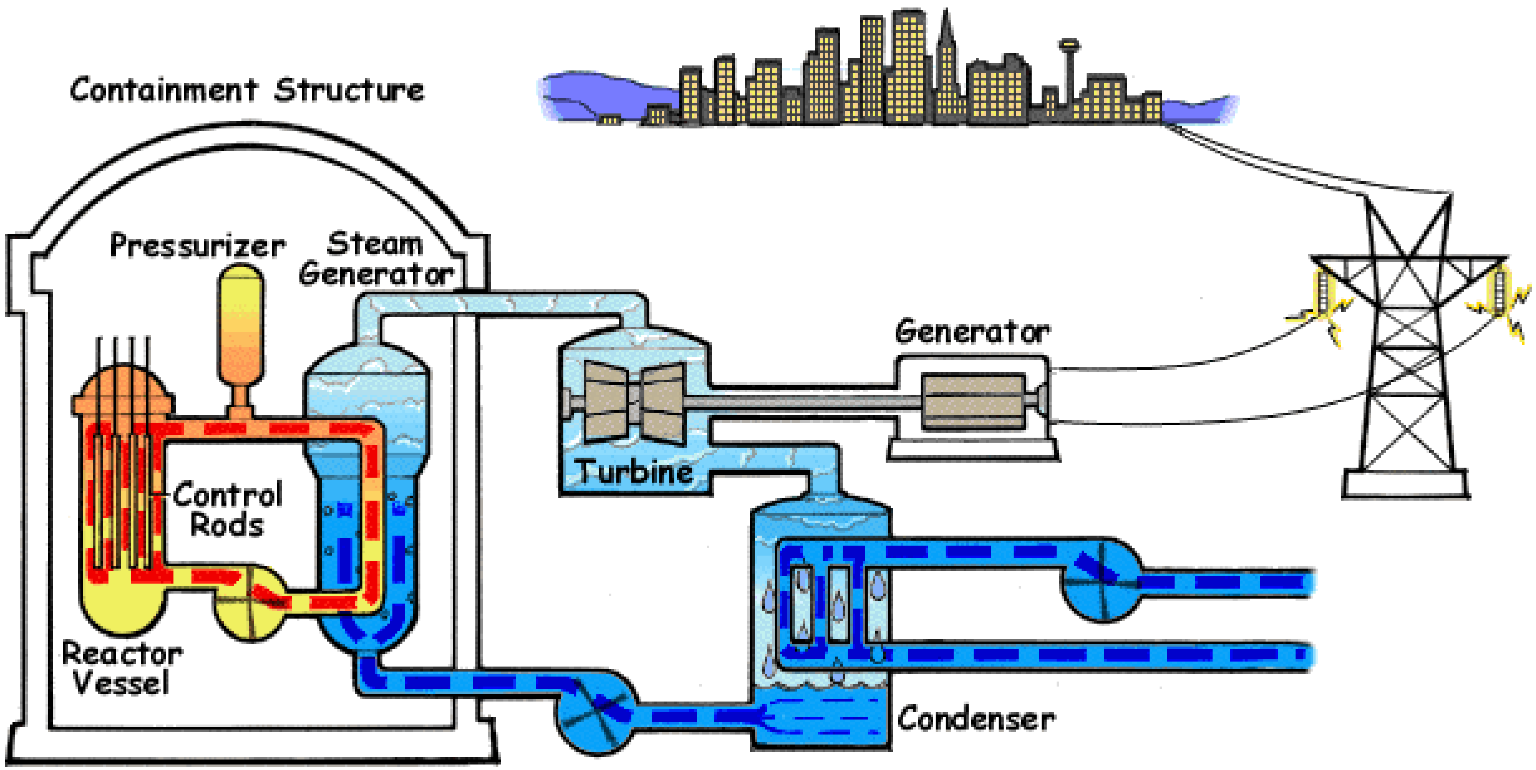


1 — реактор, 2 — топливо, 3 — регулирующие стержни, 4 — приводы СУЗ, 5 — компенсатор давления, 6 — теплообменные трубки парогенератора, 7 — подача питательной воды в парогенератор, 8 — цилиндр высокого давления турбины, 9 — цилиндр низкого давления турбины, 10 — генератор, 11 — возбудитель, 12 — конденсатор, 13 — система охлаждения конденсаторов турбины, 14 — подогреватели, 15 — турбопитательный насос, 16 — конденсатный насос, 17 — главный циркуляционный насос, 18 — подключение генератора к сети, 19 — подача пара на турбину, 20 — гермооболочка

Boiling water reactor

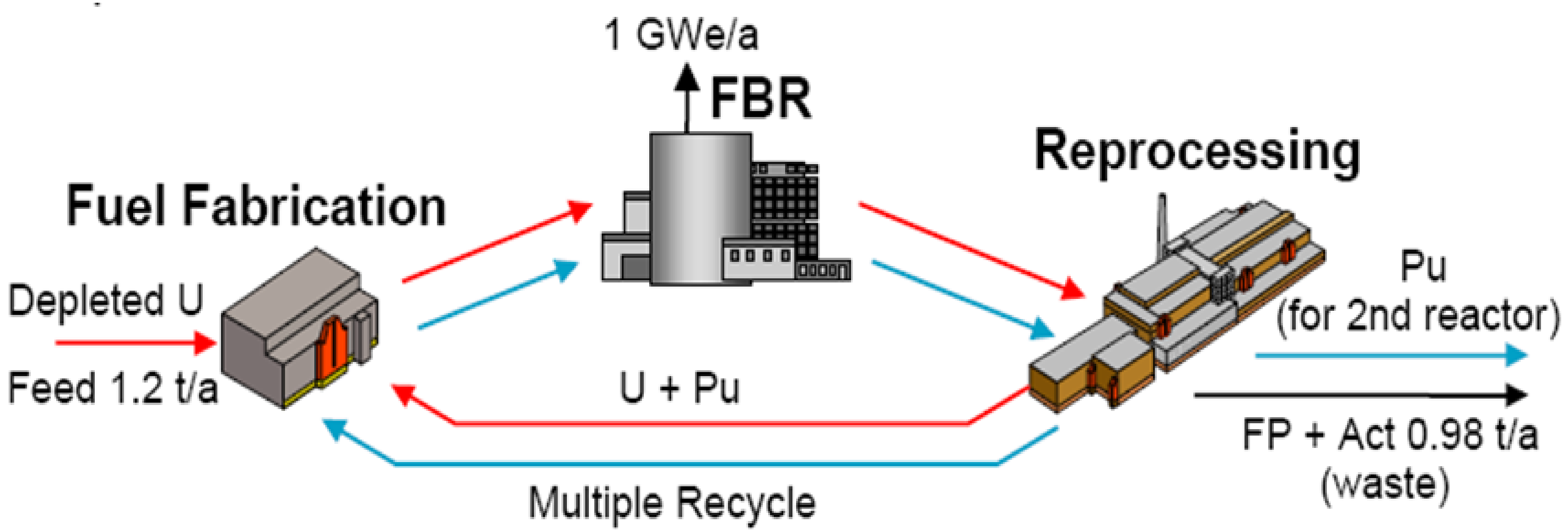


Pressurized Water Reactor



Potential of nuclear

- To relise the full potential of U and Pu bred from it requires **fast-neutron reactors**
- The stock of depleted UO2 in the world when used in fast reactors will provide the energy equivalent to $4^{X}10^{11}$ t oil



http://www.world-nuclear-news.org

Fast reactors

- BN-60
- BN-300
- BN-600
- Shevchenko
- Phoenix
- Superphenix
- BN-800
- BN-1200 - project

- FR = the key to really closed nuclear fuel cycle

Fast reactors in Russia and China

Beloyarsk NPP

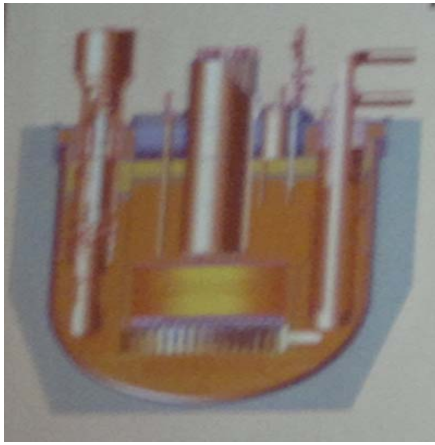
- The single reactor now in operation is a BN-600 fast breeder reactor, generating **600 MWe**. (1980 – 2014)
- Liquid Sodium is a coolant.
- Fuel: 369 assemblies, each consisting of 127 fuel rods with an enrichment of 17–26% U-235.
- It is **the largest Fast reactor** in service in the world. Three turbines are connected to the reactor. Reactor core - 1.03 m tall , Diameter = 2.05 m.

CEFR - China

- **China's experimental fast neutron reactor CEFR has been connected to the electricity grid in 2011**
-

Fast BN-800 with mixed UO2-PuO2 fuel and sodium-sodium coolant will start by 2014 in Russia.

Fast BN-1200 reactor with breeding ratio of 1.2 to 1.3-1.35 for mixed uranium-plutonium oxide fuel and 1.45 for nitride fuel, Mean burn-up 120 MWtxdxkg. BN-1200 is due for construction by 2020



http://www.world-nuclear-news.org

Fast Reactors Program in USA

- **Develop and demonstrate fast reactor technology that can be commercially deployed**
- **Focus on sodium fast reactors because of technical maturity**
- **Improve economics by using innovative design features, simplified safety systems, and improved system reliability**
- **Advanced materials development**
- **Nuclear data measurements and uncertainty reduction analyses for key fast reactor materials**
- **Work at Los Alamos focuses on advanced materials development, nuclear data measurements, and safety analyses**

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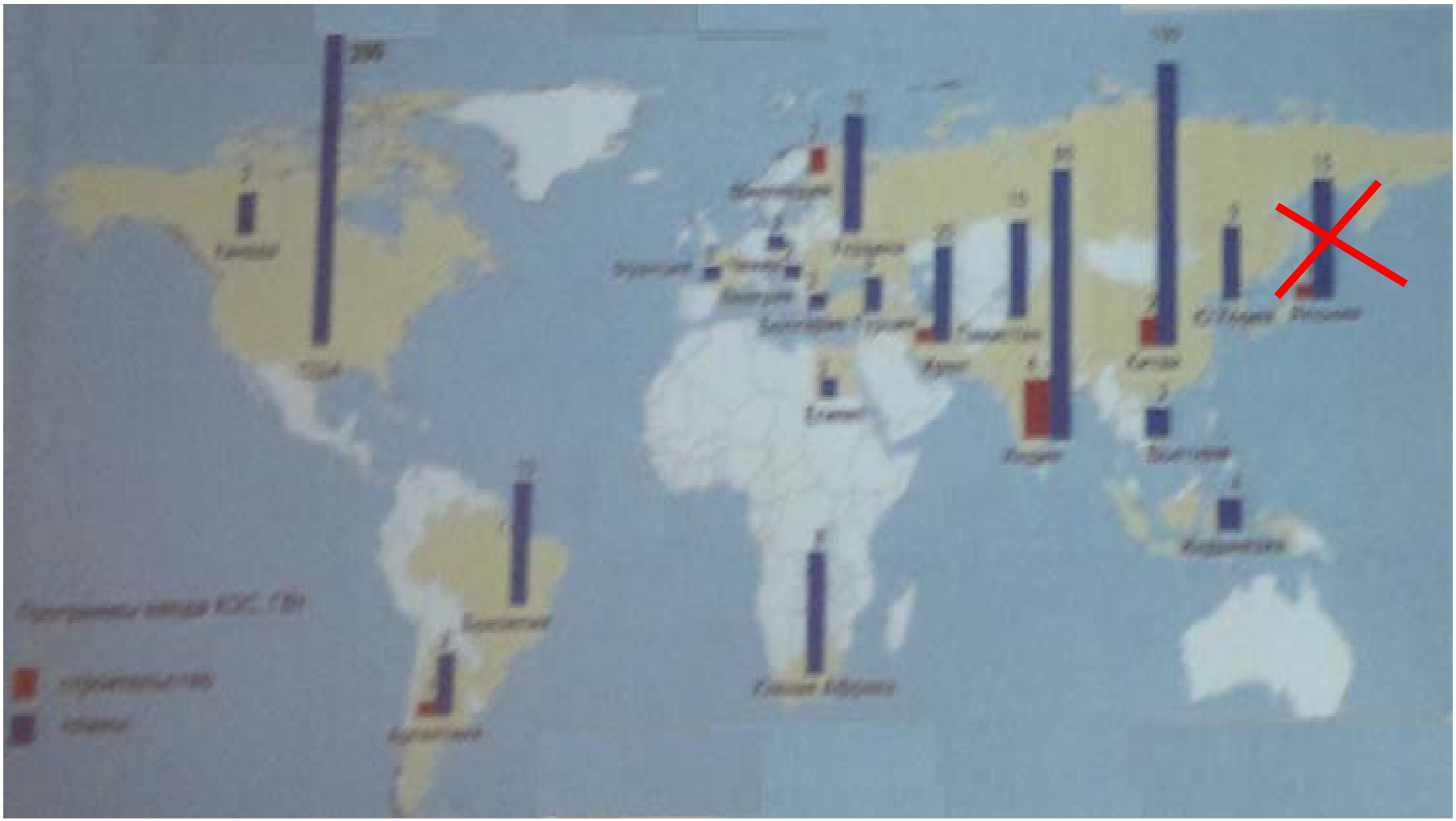
World program for new NPPs installations as seen in 2009

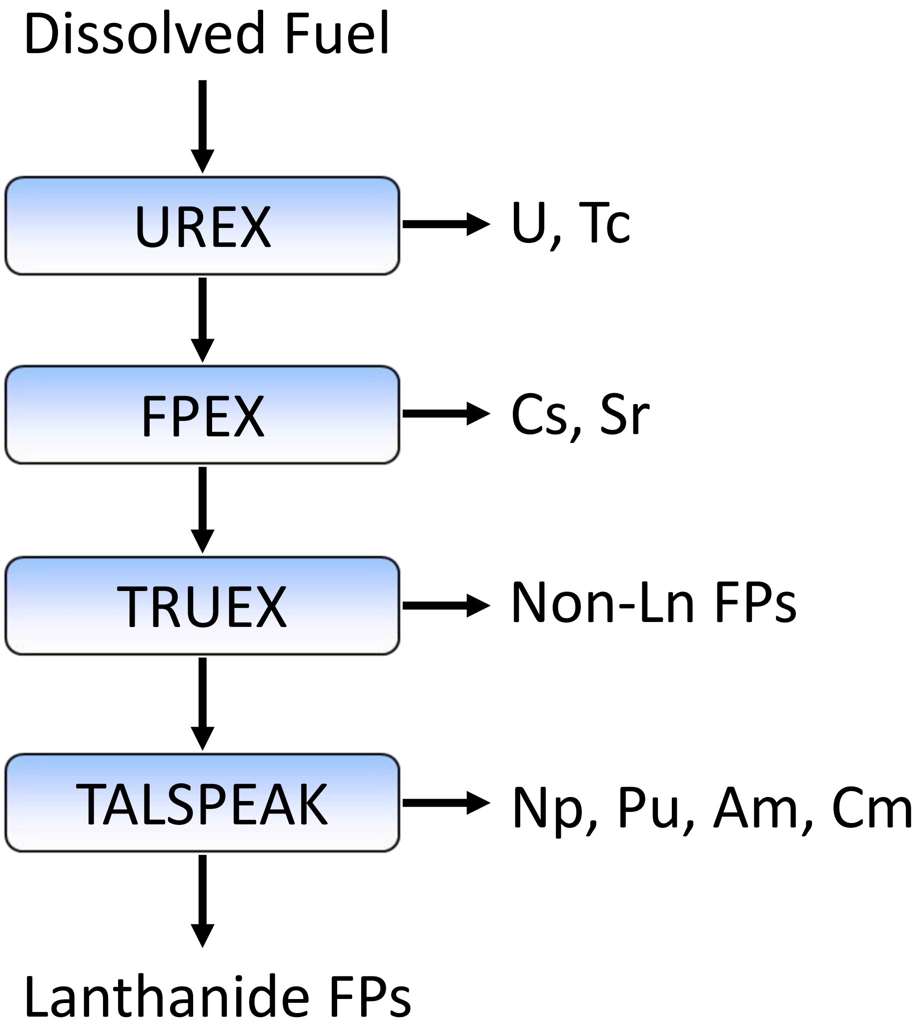


PERFORMANCE FACTORS BY REACTOR CATEGORY, 2010 to 2012

Reactor category	Reactors reporting to IAEA PRIS (see no						
	Number of units	Availability factor (%)	Planned cap. loss factor (%)	Capability factor (%)	Forced loss rate (%)	Operating factor (%)	Load factor (%)
PWR	274	80.5	14.5	81.5	2.6	81.1	79.7
PWR > 600 MWe	47	77.7	20.5	78.1	1.5	79.1	76.5
PWR ≥ 600 MWe	227	80.8	13.9	81.8	2.7	81.5	80.0
BWR	92	69.8	23.4	71.0	5.0	69.1	67.5
BWR < 600 MWe	11	54.4	31.6	57.2	13.7	58.6	54.2
BWR ≥ 600 MWe	81	70.6	23.0	71.7	4.6	70.5	68.3
PHWR	49	79.1	13.5	82.4	3.8	81.9	78.8
PHWR < 600 MWe	26	71.5	12.6	80.6	6.8	80.9	70.9
PHWR ≥ 600 MWe	23	82.8	13.9	83.3	2.3	83.1	82.6
LWGR	15	77.9	19.0	78.2	2.7	76.5	78.9
LWGR < 600 MWe	4	78.6	21.2	78.6	0.2	66.3	32.0
LWGR ≥ 600 MWe	11	77.9	19.0	78.2	2.7	80.2	79.1
GCR	18	70.2	10.8	70.4	13.4	77.8	70.4
FBR	2	76.7	22.1	76.7	1.0	77.4	78.3
TOTAL	450	77.8	16.4	78.9	3.4	78.4	76.7

UREX+1a Process Outline

- Chop fuel and dissolve in HNO_3; U and Tc extracted in UREX step with TBP in hydrocarbon (HC) solvent
- Cs/Sr extracted with calix-crown and crown ether in FPEX process
- Transuranics and lanthanide fission products extracted in TRUEX step with CMPO and back extracted from CMPO with DTPA-lactic acid solution
- Lanthanide fission products extracted into di-2-ethylhexyl-phosphoric acid in HC solvent leaving TRU elements in aqueous phase in TALSPEAK process



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Technetium is a Long-term Threat to the Biosphere

- Technetium is a key dose contributor in Yucca Mountain repository modeling if TRU elements are greatly reduced by UREX+ recycling. The long half-life of Tc ($t_{1/2} = 2.14 \times 10^5$ years) and its high mobility and solubility as pertechnetate create a long-term threat to the biosphere.
- UREX process produces a separated stream of pure uranium and technetium recovering >95% of the Tc in the dissolved LWR spent fuel. Most remaining Tc is found in noble metal inclusions of Mo-Tc-Ru-Rh-Pd found in the undissolved solids (UDS) from the dissolution of the spent fuel in nitric acid.
- Los Alamos workers have developed an anion exchange process to remove the Tc from the U, recover the Tc by elution with ammonium hydroxide, and convert the pertechnetate to metal or TcO_2.
- Alloys of Tc with UDS metal inclusions, Zircaloy hulls or other metals (e.g., INL Metal Waste Form: Tc, 15% Zr, 85% stainless steel) and also oxide phases with the lanthanide and transition metal fission products are being studied as potential disposal forms.

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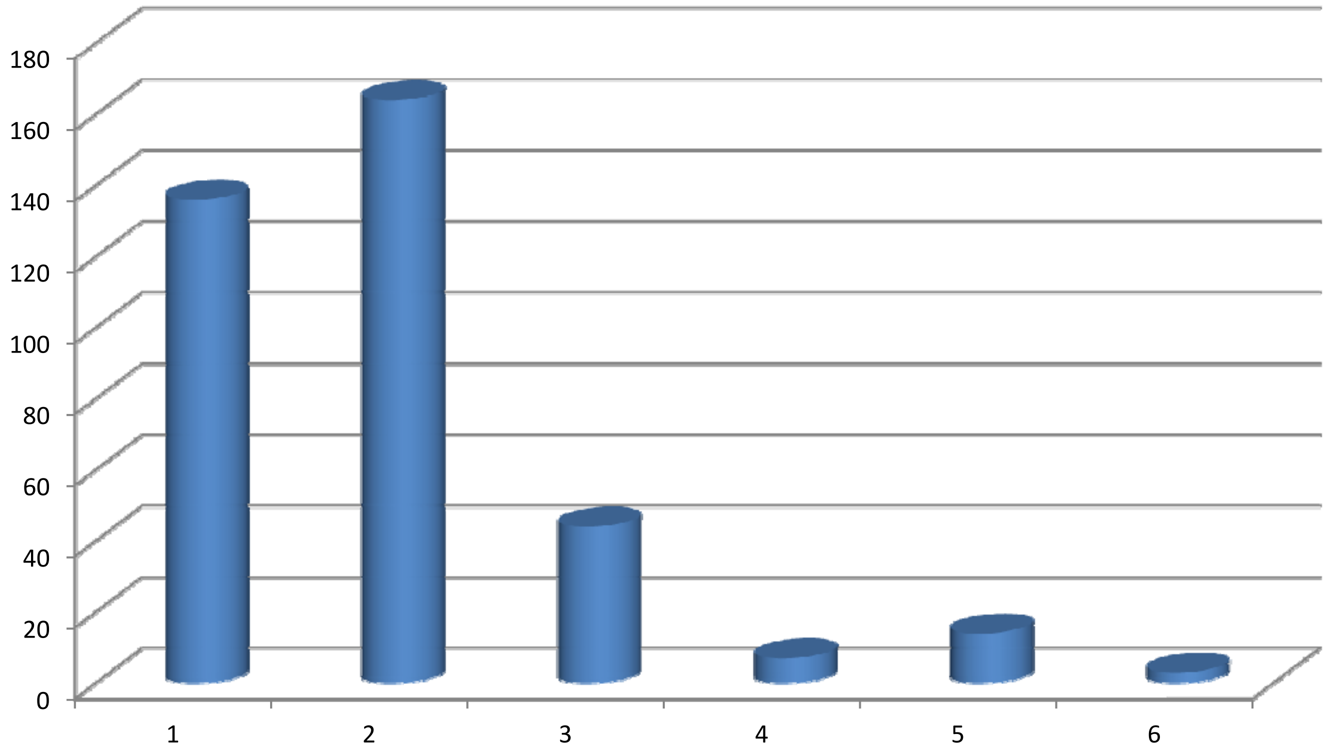
Effect of the power production mode on the health of European population

Lost Years of Life,

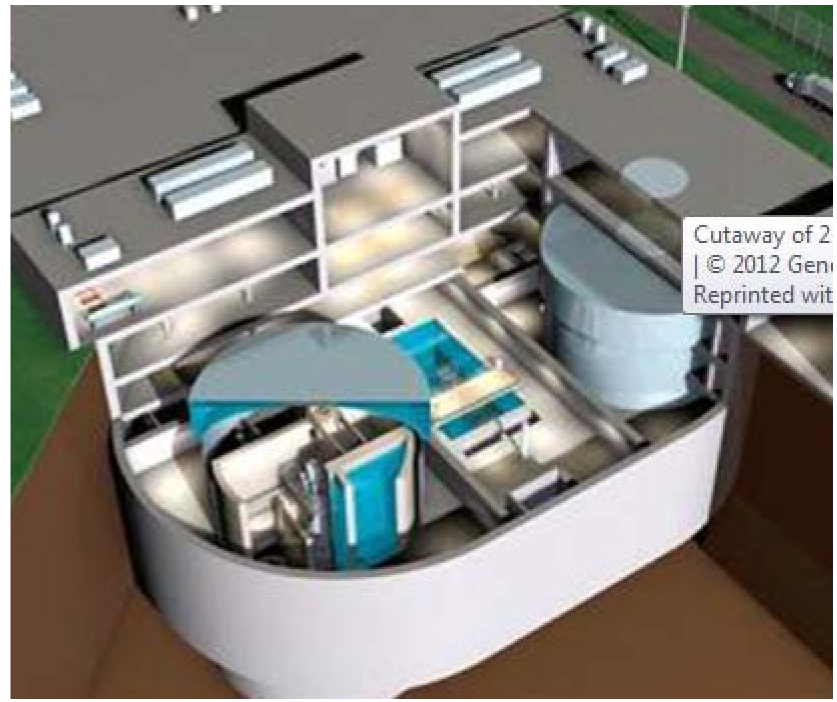
Man-year per GWt*H produced



1. Brown coal
2. Black coal
3. Gas
4. Nuclear power
5. Sunlight power
6. Wind power

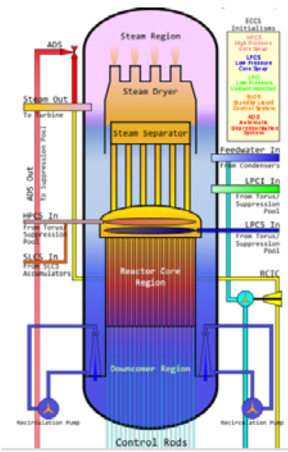
Small Modular Reactors (SMRs)

- Small Modular Reactors (SMRs) are nuclear power plants that smaller in size (300 MWe or less) than current generation base load plants (1,000 MWe or higher).
- These smaller, compact designs are factory-fabricated reactors that can be transported by truck or rail to a nuclear power site.



NPPs & Water - location problem

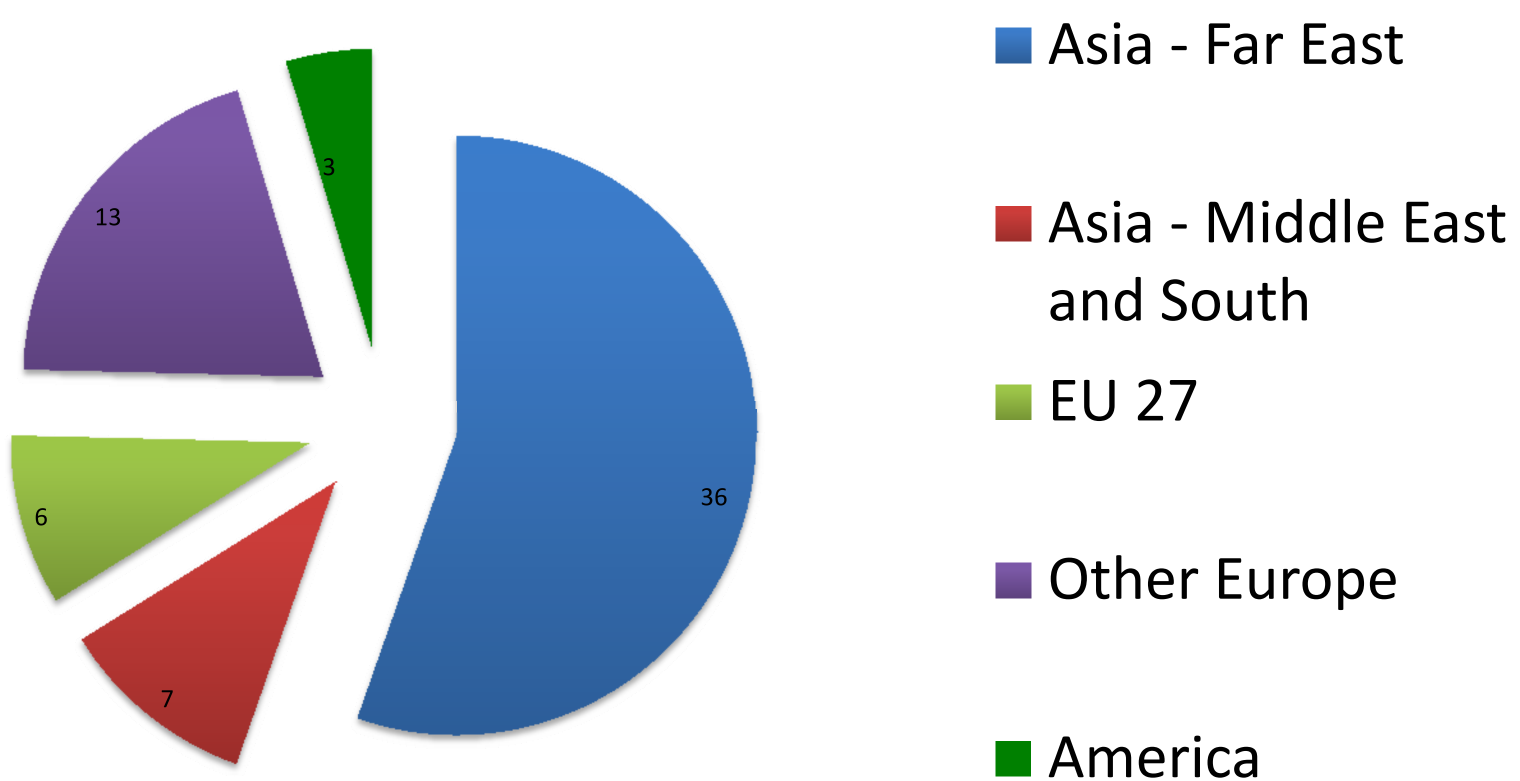
Fukushima Daiichi nuclear **Disaster - BWR-RPV**



Other cases

Corps of Engineers photo of the Fort Calhoun Nuclear Generating Station on June 16, 2011 during the 2011 Missouri River Floods. Vital buildings *were protected* using AquaDams, a type of water-filled perimeter flood barriers

65 Reactors for NPPs Under Construction - by region:



Sources: IAEA-PRIS, MSC 2011

Nuclear powered propulsion

Nuclear-powered icebreakers and complex usage ships

Typhoon3 RF VMF submarine

Nimitz US Navy aircraft carrier

Nuclear-powered icebreakers

Icebreaker *Lenin* in 1959 was both the world's first nuclear-powered surface ship and the first nuclear-powered civilian vessel.

The second was NS *Arktika*. In service since 1975, she was the first *surface* ship to reach the North Pole, on August 17, 1977.

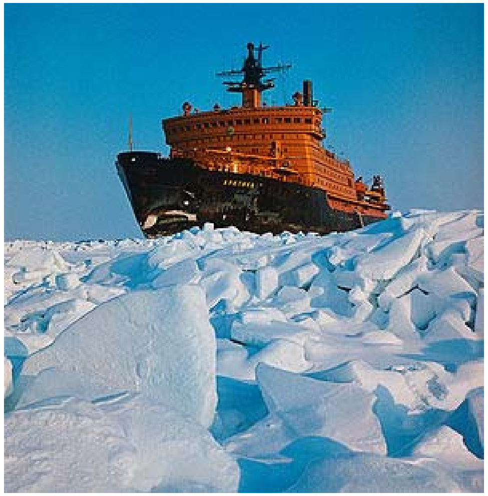
NS Yamal and Taimyr

Ice to break :
2.25 m – 3.5 m

Installed power:	Two OK-900 nuclear reactors (2 × 171 MW), 90% enriched, zirconium-clad, Uranium fuel.
Propulsion:	Nuclear-turbo-electric Three shafts, 52 MW (comb.)
Speed:	20.6 knots (38.2 km/h)

Northern sea route

- Map of Northern Sea Route
- Consume up to 200 gramms of fuel a day when breaking ice.
- 500 kg of Uranium in each reactor, allowing for up to four years between changing reactor cores



OTHER APPLICATIONS
Science & Technology

- Water resource management: Isotope hydrology
- Pest control: Sterile insect technique
- Food safety: Irradiation
- Environmental management: Pollution control
- Cancer treatment: Radiotherapy
- Nuclear Medicine: Diagnostics

Technical Cooperation with IAEA:

Addresses critical problems in developing nations

- Contaminated drinking water
- Infectious diseases: TB, AIDS
- Malaria and Sleeping Sickness
- Malnutrition and food scarcity
- Pollution
- Shortage of knowledge and skills

Radioisotope battery

- Nuclear battery or radioisotope battery is a device which uses the **radioactive decay to generate electricity**. These systems use radioisotopes that produce low energy beta particles or alpha particles of varying energies.
- Low energy beta particles – prevention of high energy Bremsstrahlung radiation that would require heavy shielding.
- Radioisotopes such as tritium, Ni-63, Pm-147, Tc-99 have been tested.
- **Pu-238,** Cm-242, Cm-244, **Sr-90** have been used.
- Two main categories of atomic batteries: **thermal** and **non-thermal**.
- The non-thermal atomic batteries exploit charged α and β particles. These designs include the direct charging generators, betavoltaics, the optoelectric nuclear battery, and the radioisotope piezoelectric generator.
- The thermal atomic batteries on the other hand, **convert the heat from the radioactive decay to electricity**. These designs include thermionic converter, thermophotovoltaic cells, alkali-metal thermal to electric converter, and the **most common design, the radioisotope thermoelectric generator.**

Radioisotope batteries by radioisotopes

- **Tritium**
- lightening in phosphors
- Product of SNF dissolution

- **Tc-99**
- U-235(n,f)Mo-99(β)Tc-99m(γ)Tc-99
- separated from spent nuclear fuel (SNF) reprocessing solutions

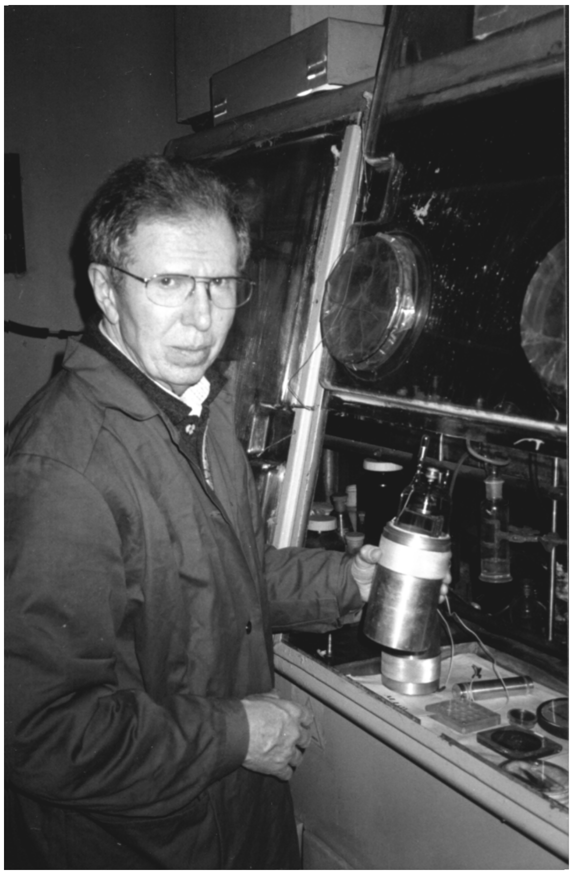
- **Pm-147**
- Heart battery
- Product of SNF dissolution

- **Cm-242, Cm-244**
- Pu-239(n,γ)Pu-240(n,γ)Pu-241(n,γ)Pu-242
- Space RTG&RTU batteries
- SNF dissolution, special targets

- **Pu-238**
- Np-237(n,γ)Pu-238
- From SNF
- Space RTG&RTU batteries
- Product of SNF dissolution

- **Sr-90**
- U-235(n,f)Sr-90
- Separated from spent nuclear fueul reprocessing solutions,)

Attempts of ^{99}Tc application in IPCE RAS (1975-1987)



- Electric battery based on **b**-emission of Tc (1978-1983, O.Balakhovsky)
- β - Sources for eyeball medical treatment and defectoscopy (1983 – 1993, K. Bukov)
- Corrosion protection (1960-1975, Kuzina)
- Antifouling protection (1975 – 1987, S.Bagaev, S.Kryutchkov, K.German)
- Tc catalysts at ceramic supports (1975 – 2000, G. Pirogova)

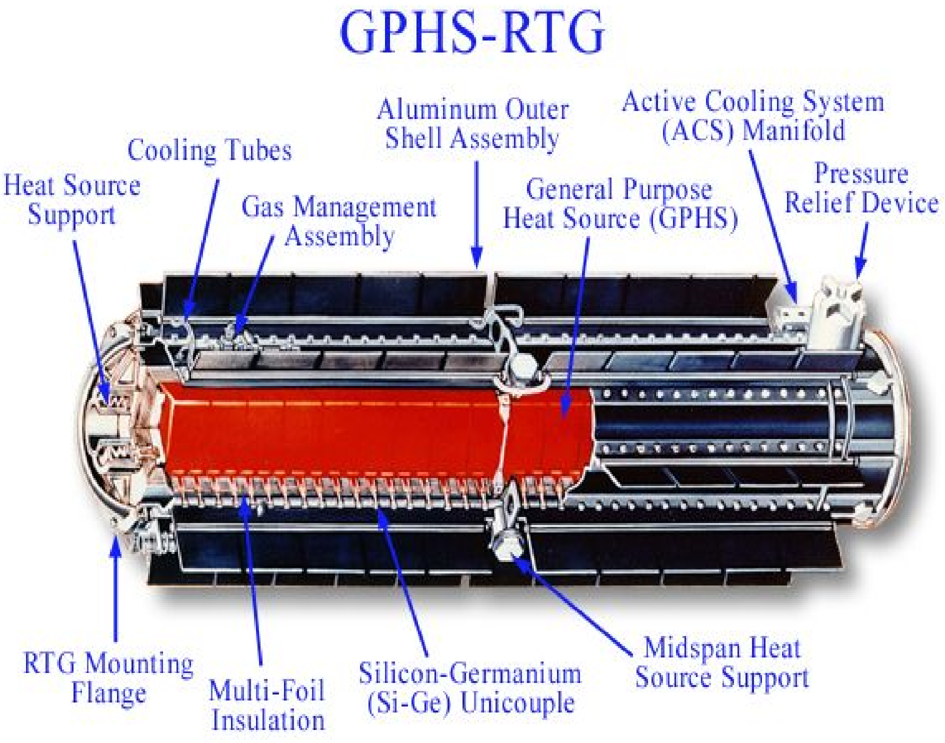
Prof. V. Peretroukhin checks the electric battery based on β-emission of technetium-99

A **radioisotope thermoelectric generator** (**RTG, RITEG**) is an electrical generator that obtains its power from radioactive decay. The heat released by the decay of a suitable radioactive material is converted into electricity by the Seebeck effect using an array of thermocouples.

RTGs have been used as power sources in satellites, space probes and **unmanned remote facilities**, such as a series of lighthouses built by the former Soviet Union inside the Arctic Circle.

RTGs are usually the most desirable power source for robotic or unmaintained situations needing a few hundred watts (or less) of power for durations too long for fuel cells, batteries, or generators to provide economically, and in places where solar cells are not practical.

Safe use of RTGs requires containment of the radioisotopes long after the productive life of the unit.



RTG use

Implanted heart pacemakers

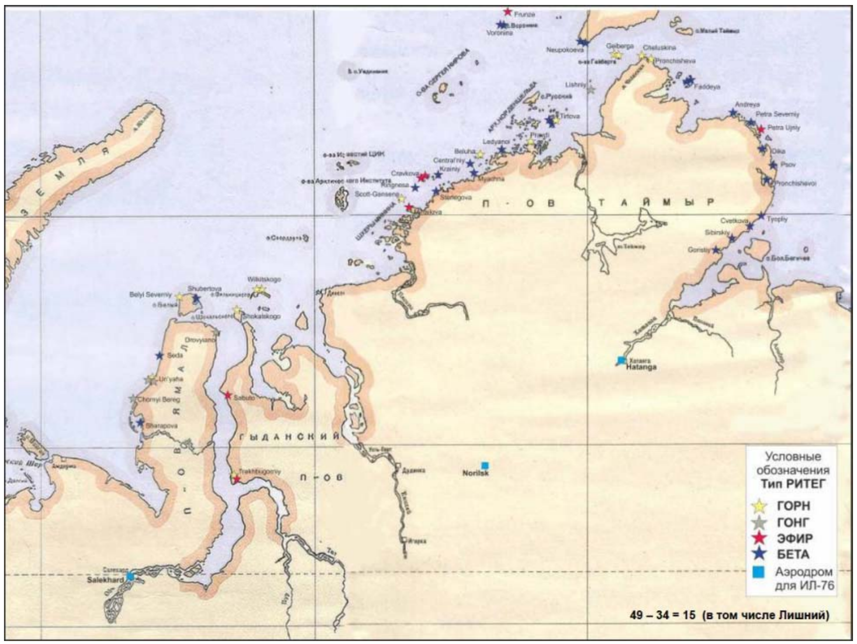
- In the past, small "plutonium cells" (very small ^{238}Pu-powered RTGs) were used in implanted heart pacemakers to ensure a very long "battery life".[9]
- As of 2004, about 90 patients were alive and the batteries were still in use.

Lighthouses and navigation beacons

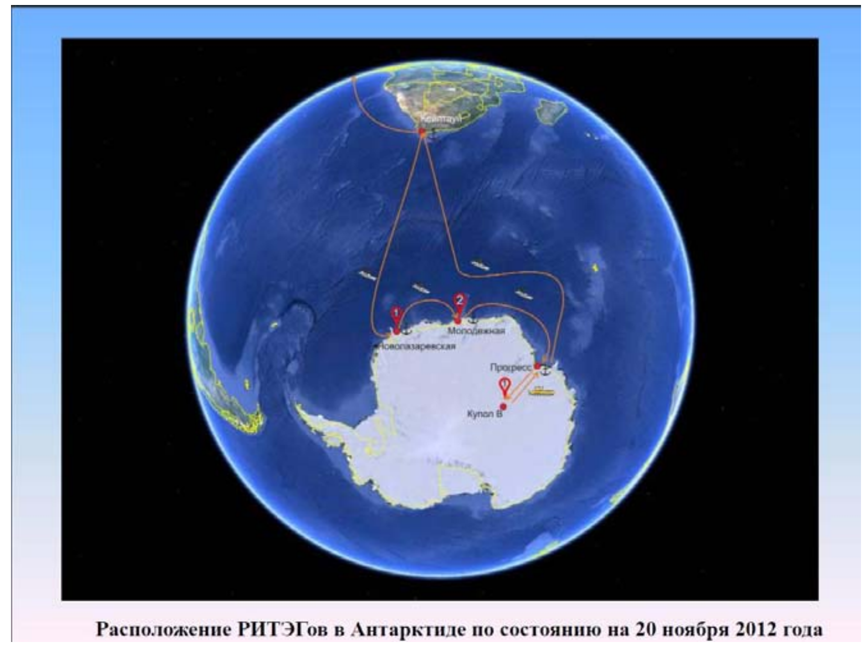
- The USSR constructed many unmanned lighthouses and navigation beacons powered by RTGs .
- Powered by strontium-90 (^{90}Sr), they were very reliable and provided a steady source of power.
- Thermal regime at outer planet instruments (cars)
- Now …

Dislocation of some RITEGs lighthouses in Russia and Antarctica

Northern Sea Route

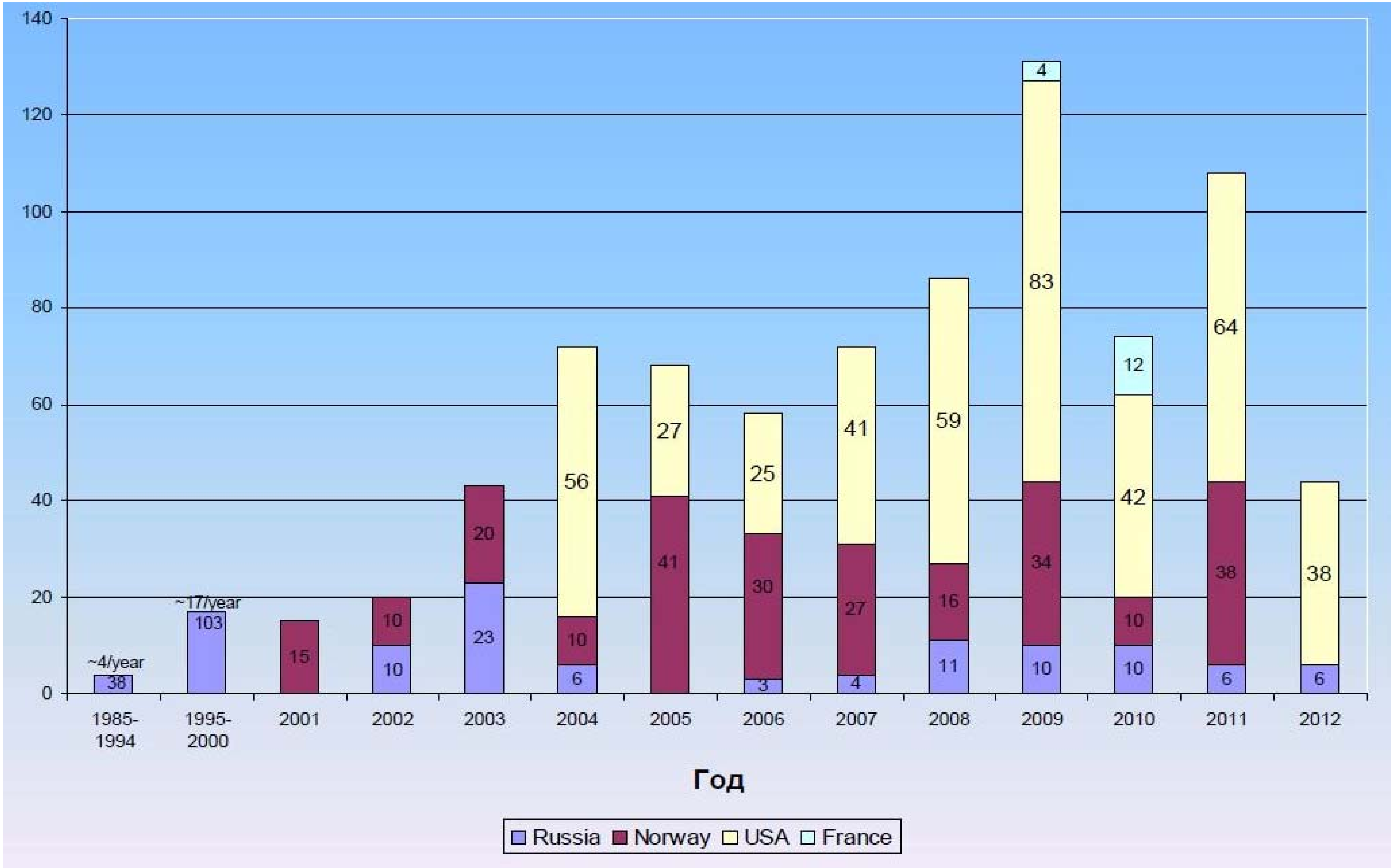


Antarctica

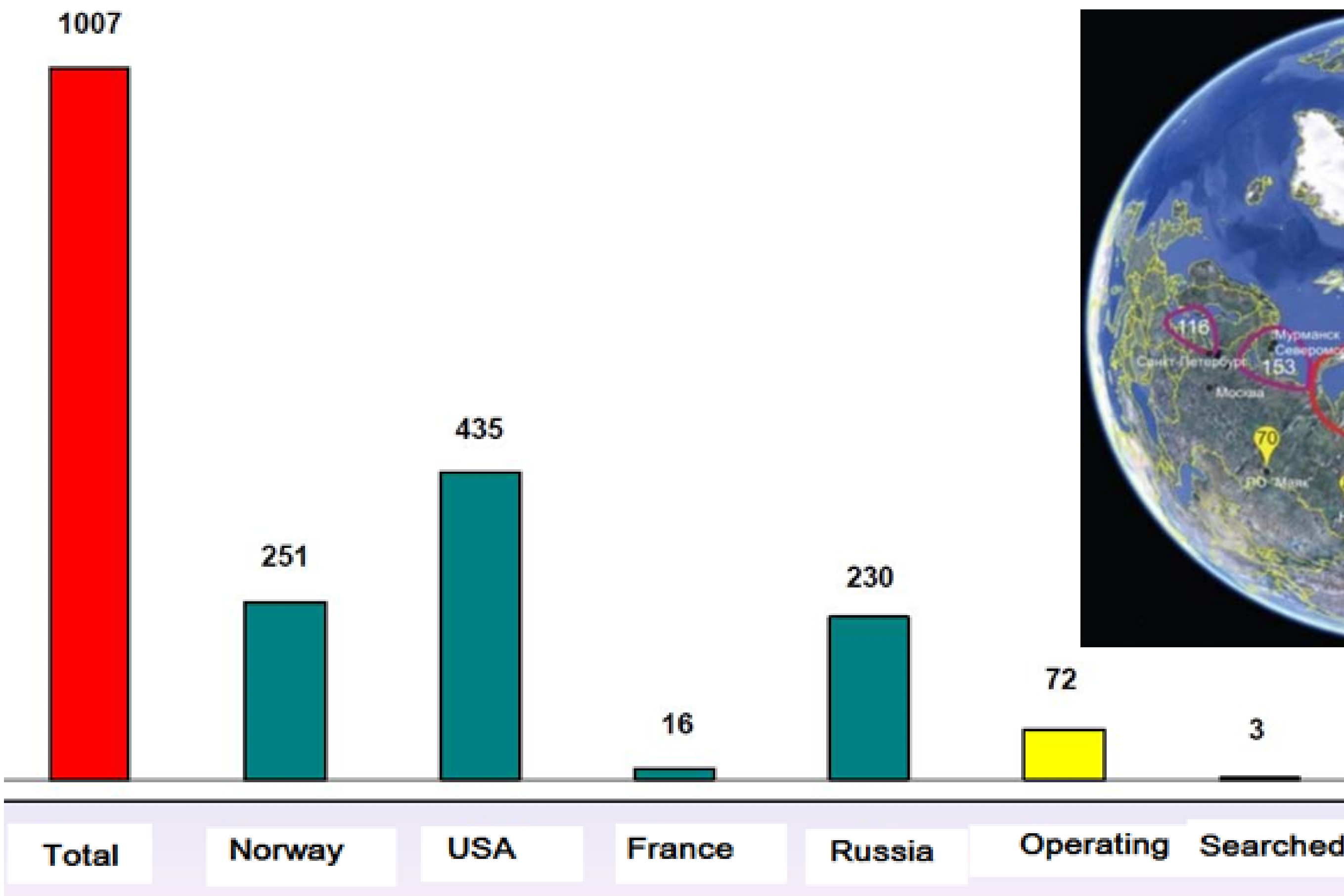


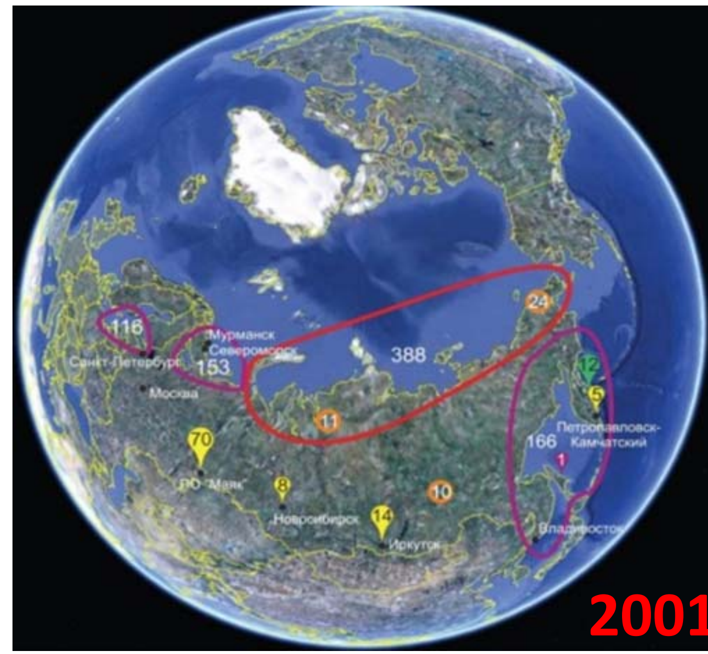
Nowadays when satellite system are used for navigation control RITEGs at NSR are considered nor more useful and special program of decommissioning was run

Decommissioning of RITEGs - partners impact



Decomission fondings of RITEG as assisted by the partners by Dec. 2012 (in units)





RITEG BETTA_M at FADDEY CITE damaged with frozen ice

MOST OF RITEGS WERE SHIPPED TO RUSSIAN REPROCESSING FACILITIES

General veiw

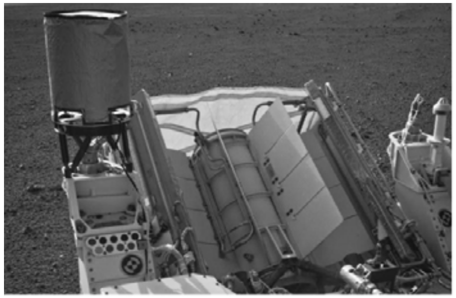
RITEG EFIR MA

VIEW OF THE RITEG DISTROYED BY THE STORM

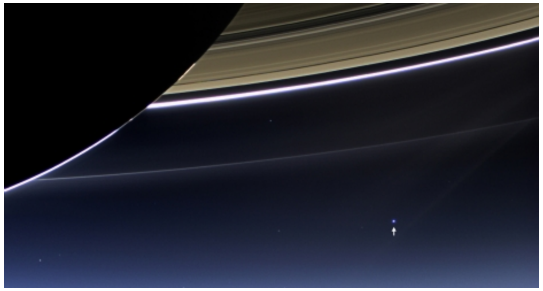
SPACE POWER SYSTEMS (RPS)

- RPSs safely enabled deep space exploration and national security missions.
- RPSs convert the heat from the decay of the radioactive isotope Pu-238 into electricity.
- RPSs are capable of producing heat and electricity under the harsh conditions encountered **in deep space for decades.**
- Safe, reliable, and maintenance-free in missions to study the moon and all of the planets in the solar system except Mercury.
- The Mars Science Laboratory rover, Curiosity, launched 2011, landed successfully at Mars on August 5, 2012.
- 1st mission to use the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG).
- The RPS-powered **New Horizons spacecraft** is three quarters of the way to a planned Pluto encounter in 2015

At Moon



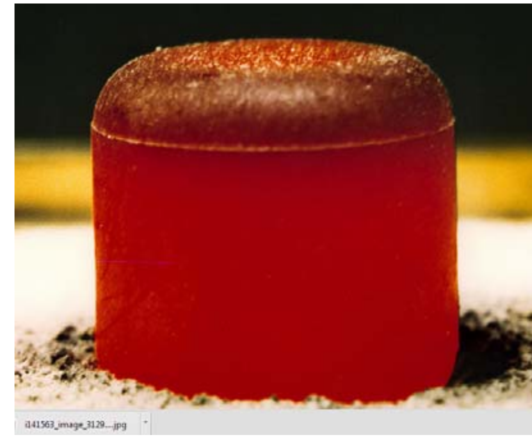
“Cassini's photo of the Earth



COOPERATION FOR SPACE EXPLORATION : Np-237 for production of Pu-238 was provided to US DOE by Russian RT-1. Np-237 is a product of PO MAYAK RT-1 plant that reprocess RBMK – 1000 spent nuclear fuel

Radioisotope thermoelectric generators

- A **glowing red** hot pellet of **plutonium-238 dioxide** made by US DOE at the Department's of *Los Alamos National Laboratory* to be used in a RTG for the "Cassini" mission to Saturn
- Each pellet produces 62 watts of heat and when thermally isolated, can glow brilliant orange

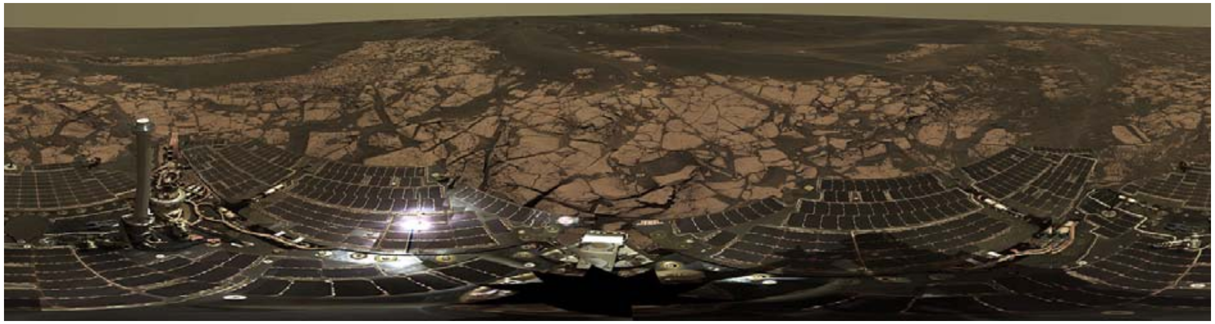


10 L container filled in with metal technetium-99 could produce about 1 watt of heat energy during the time up to 212000 years

Radioisotope Heater Units (RHUs)

- RHUs use the heat generated by Pu-238 to keep a spacecraft's instruments within their designed operating temperatures.
- Plutonium is produced by nuclear reaction :
- Np-237(n,γ)Pu-238
- U-235 – U-236 – U237

Radioisotope Heater Units (RHUs)



- **Radioisotope Heater Units (RHUs)** — RHUs use the heat generated by Pu-238 to keep a spacecraft's instruments within their designed operating temperatures.
- In June and July 2003, NASA launched the Mars exploration rovers, Spirit and **Opportunity**, to explore evidence of water on Mars. **Each rover has eight RHUs to keep the rover instruments warm during the cold Martian nights**.
- The rovers landed at separate sites on Mars in January 2004 on a planned 90-day mission. Spirit roved the surface of Mars for over 6 years until it became stuck in a sand trap. Opportunity is still exploring the Martian surface and transmitting data after 7 years of operation. NASA has also identified several new missions potentially requiring RHUs.

RTGs and RHUs for space exploration

- Through a strong partnership between the Energy Department's office of Nuclear Energy and NASA, Radioisotope Power Systems have been providing the energy for deep space exploration.
- The Department of Energy (DOE) and its predecessors have provided radioisotope power systems that have safely enabled deep space exploration and national security missions for five decades.
- Radioisotope power systems (RPSs) convert the heat from the decay of the radioactive isotope plutonium-238 (Pu-238) into electricity. RPSs are capable of producing heat and electricity under the harsh conditions encountered in deep space for decades. They have proven safe, reliable, and maintenance-free in missions to study the moon and all of the planets in the solar system except Mercury. The RPS-powered New Horizons spacecraft is three quarters of the way to a planned Pluto encounter in 2015.
- DOE maintains the infrastructure to develop, manufacture, test, analyze, and deliver RPSs for space exploration and national security missions. DOE provides two general types of systems – power systems that provide electricity, such as radioisotope thermoelectric generators (RTGs), and small heat sources called radioisotope heater units (RHUs) that keep spacecraft components warm in harsh environments. DOE also maintains responsibility for nuclear safety throughout all aspects of the missions and performs a detailed analysis in support of those missions.
- **SPACE AND DEFENSE INFRASTRUCTURE**
- DOE has successfully accomplished nuclear power system missions by maintaining a unique set of capabilities through highly skilled engineers and technicians and specialized facilities at DOE national laboratories. Oak Ridge National Laboratory provides unique materials and hardware. Plutonium-238 is purified and encapsulated at Los Alamos National Laboratory. Idaho National Laboratory assembles the encapsulated fuel into a heat source designed to contain the fuel in potential accident situations, integrates the heat source and power conversion system into the final power system, and assures their final delivery. DOE maintains unique shipping containers and trailers to safely transport components and power systems across the DOE complex and to user agencies. DOE also maintains the unique ability to evaluate and characterize the safety of these systems. Sandia National Laboratories leads the development and maintenance of the required analytical tools, database, and capabilities. Power system design, development, manufacturing, and non-nuclear testing are performed by competitively-selected system integration contractors.
- **Radioisotope Thermoelectric Generators (RTGs) —** The RTG systems are ideal for applications where solar panels cannot supply adequate power, such as for spacecraft surveying planets far from the sun. RTGs have been used on many National Aeronautics and Space Administration (NASA) missions, including the following.
- ***Mars Science Laboratory Mission, Curiosity Rover***
- The Mars Science Laboratory rover, named Curiosity, launched on November 26, 2011, landed successfully on Mars on August 5, 2012. It is the first NASA mission to use the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). Curiosity is collecting Martian soil samples and rock cores, and is analyzing them for organic compounds and environmental conditions that could have supported microbial life now or in the past. Curiosity is the fourth rover the United States has sent to Mars and the largest, most capable rover ever sent to study a planet other than Earth.
- ***New Horizons Mission to Pluto***
- The New Horizons spacecraft was launched on January 19, 2006. The fastest spacecraft to ever leave Earth, New Horizons has already returned images and scientific data from Jupiter and will continue its journey of three billion miles to study Pluto and its moon, Charon, in 2015. It may also go on to study one or more objects in the vast Kuiper Belt, the largest structure in our planetary system. DOE supplied the RTG that provides electrical power and heat to the spacecraft and its science instruments.
- *Cassini Mission Orbiting Saturn*
- In July 2004, the Cassini mission entered the orbit of Saturn. Launched in October 1997, the Cassini spacecraft uses three DOE-supplied RTGs and is the largest spacecraft ever launched to explore the outer planets. It is successfully returning data and images of Saturn and its surrounding moons, using a broad range of scientific instruments. This mission requires RTGs because of the long distance from the sun, which makes the use of solar arrays impractical. The RTGs have allowed the mission to be extended twice; the mission is expected to last at least until 2017.
- *Voyager Mission to Jupiter, Saturn, Uranus, Neptune and the Edge of the Solar System*
- In the summer of 1977, Voyager 1 and 2 left Earth and began their grand tour of the outer planets. Both spacecraft use two RTGs supplied by DOE to generate electricity. In 1979, the spacecraft passed by Jupiter; in 1981, it passed by Saturn. Voyager 2 was the first spacecraft to encounter Uranus (1986) and Neptune (1989). Voyager 1 and 2 are currently exploring the heliosheath on the edge of the solar system, seeking out the boundary of interstellar space. Voyager 1 is presently the farthest human-made object from Earth. It is currently more than 11 billion miles from earth. Both spacecraft remain operational and are sending back useful scientific data after over 35 years of operation. The RTGs are expected to continue producing enough power for spacecraft operations through 2025, 47 years after launch.

PLANNED PROGRAM ACCOMPLISHMENTS AT US DOE - FY 2013

- Maintain operability of Space and Defense Power Systems related facilities to achieve DOE and Work-for-Others milestones.
- Continue development of the ASRG in support of a potential NASA mission.
- Complete fabrication of Pu-238 fuel at LANL for a potential NASA mission.
- Maintain current RPS safety analysis capability and methods as new information becomes available.
- Complete the upgrade of an environmental control system for power system assembly glovebox at INL.
- Continue to support development of the Nuclear Cyrogenic Propulsion Stage (Nuclear Thermal Rocket) with NASA's Marshall Space Flight Center.

U.S. DEPARTMENT OF ENERGY

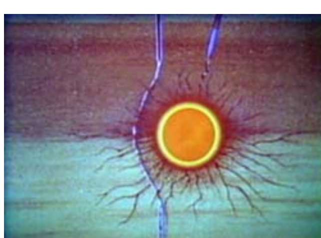
NASA

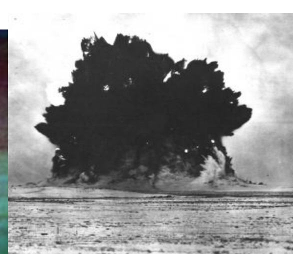
Peaceful use of nuclear explosions

Historical (1965-1988)

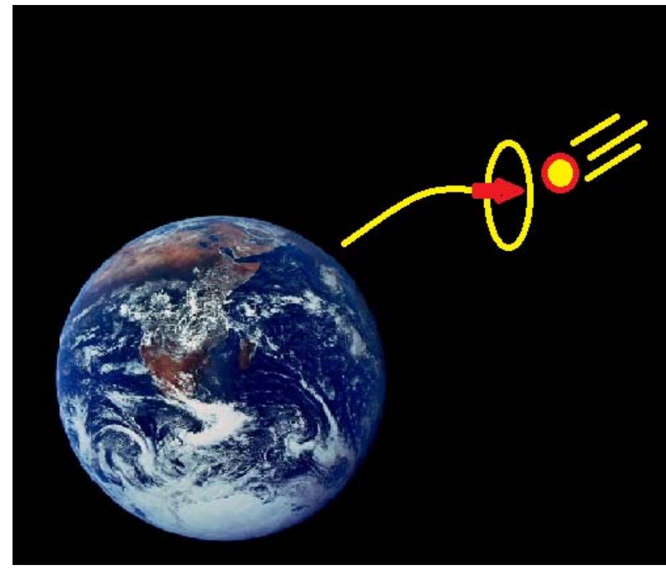
As part of Operation Plowshare USA and Programs 6&7 in USSR. ***Objectives:***

- water reservoir development,
- dam & canal construction.
- creation of underground cavities for toxic wastes storage
- Searching for mineral resources with reflection seismology from ultrasmall bombs
- breaking up ore bodies,
- stimulating the production of oil and gas,
- forming underground cavities for storing the recovered oil and gas, gas-fire stop.



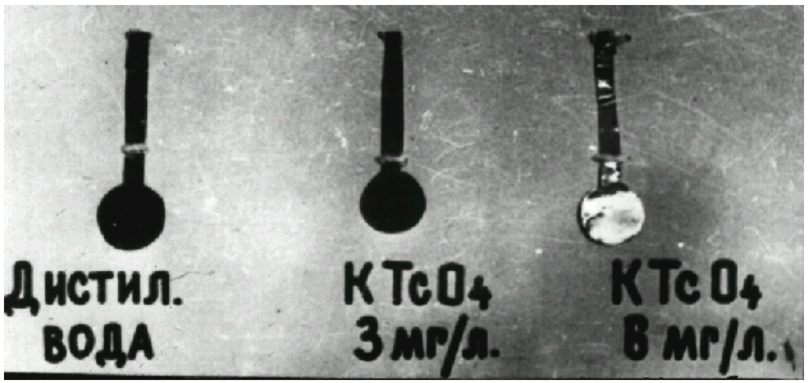


Prospective



Large meteorite destruction or redirection

Corrosion protection by Tc-99

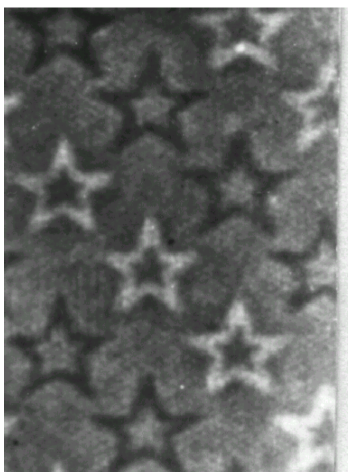


6 mg of $KTcO_4$
added to water
inhibits corrosion
of Armco iron
during 3 months

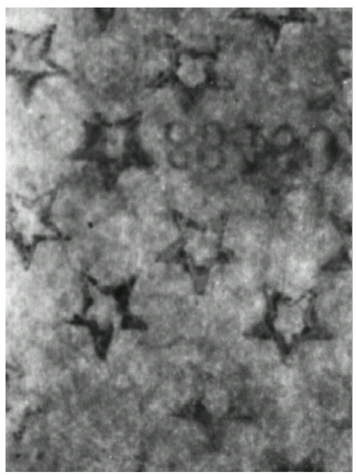
- In 1966-76 Cartledge, Kuzina and others have -shown Tc to be a more powerful corrosion protector compared to CrO_4^{2-}
- Tc improves also chemical resistance, when added as a component of alloy to stainless steel

Detectoscopy and defectoscopy of light materials

- Water signs at ex-USSR banknotes

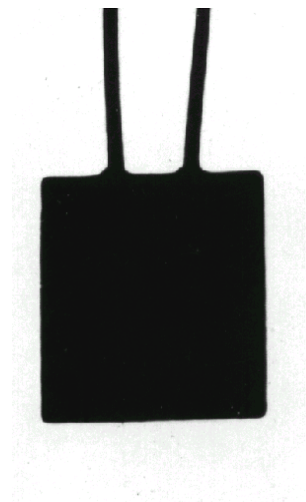


True, alteration of heavy and light

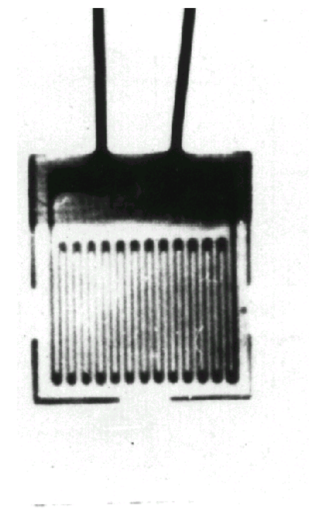


Forged, only heavy

- Tensometric detector



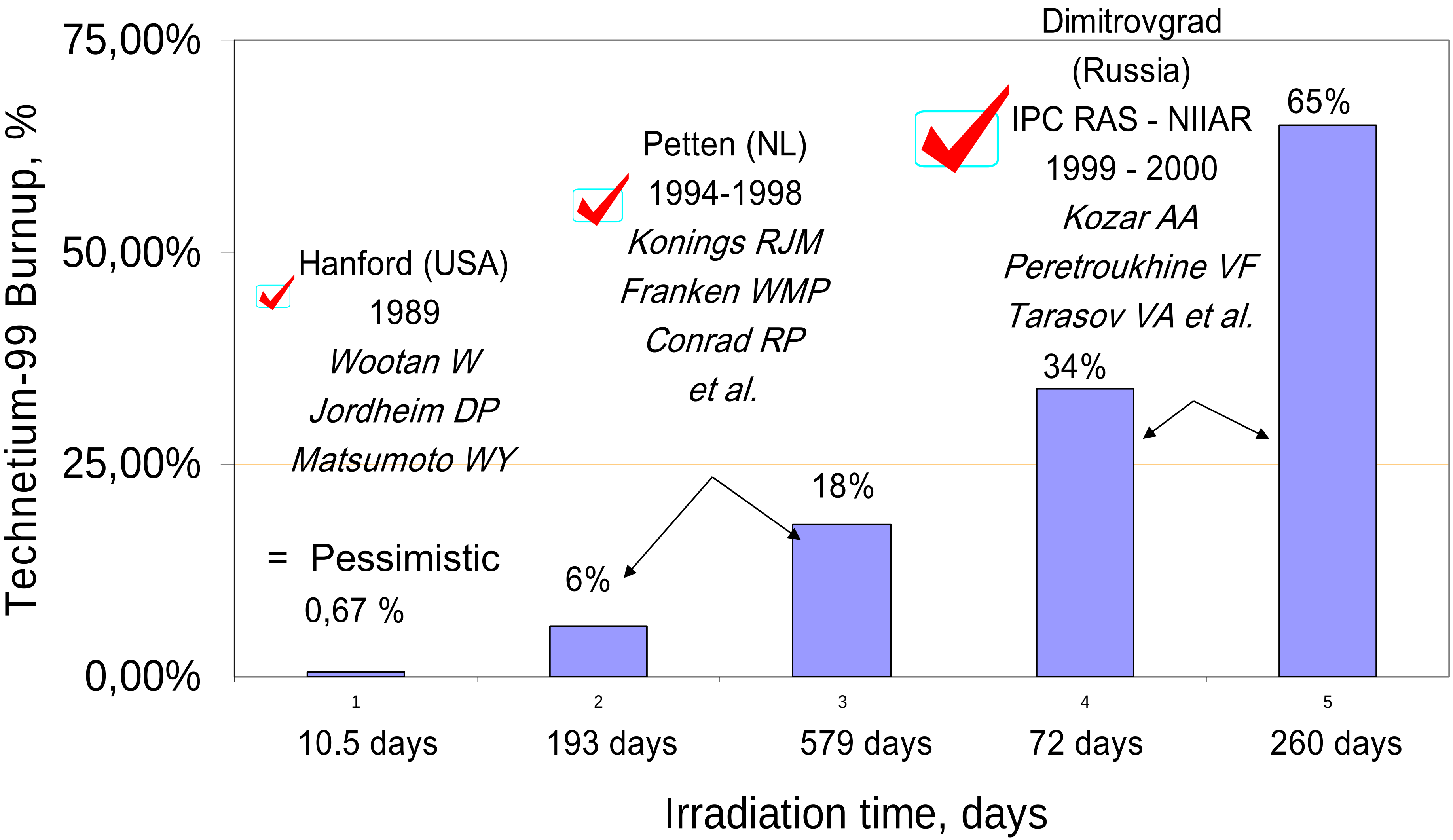
Painted - at a glance



Same in Tc β-rays

Russian Tc - Transmutation program (1992-2003)

$^{99}Tc(n,\gamma)^{100}Tc(\beta)^{100}Ru$



Tc transmutation experiment (IPCE RAS – NIIAR, 1999-2008)

In IPC RAS a set of metal disc targets (10x10x0.3 mm) prepared and assembled in two batches with total weight up to 5 g. Transmutation experiment was carried out at high flux SM-3 reactor (NIIAR, Dimitrovgrad)

2nd batch: $F_t > 2\times 10^{15}$ cm^{-2}s^{-1}
1st batch: $F_t = 1.3\times 10^{15}$ cm^{-2}s^{-1}

^{99}Tc burnups have made:

34 ± 6 % and 65 ± 11 %

for the 1st and 2nd targets batches

- The high ^{99}Tc burn-ups were reached and about 2.5 g of new matter - transmutation ruthenium were accumulated as a result of experiments on SM-3 reactor
- These values are significantly higher of burnups 6 and 16 % achieved on HFR in Petten earlier

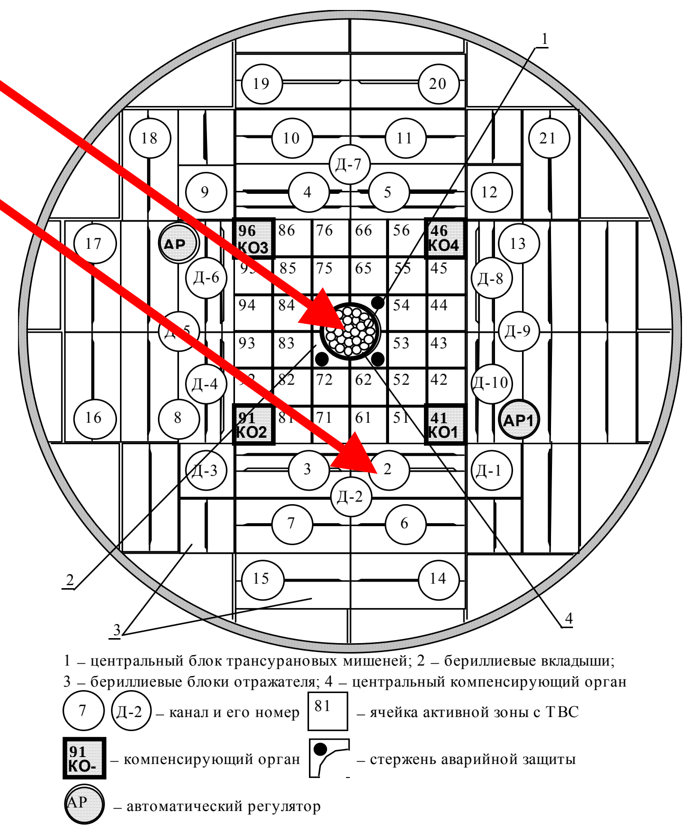


Рис.5. Картограмма реактора СМ

Preparation of artificial stable Ruthenium by transmutation of Technetium

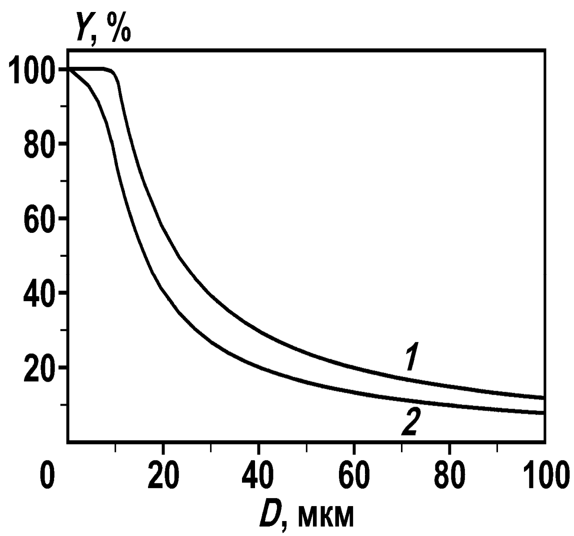


Table 2. Content of isotopes in natural and artificial ruthenium (at. %)

Isotope	Natural Ru [6]	Ru from indicated sample	
		Tc–19% Ru	Tc–45% Ru
^{96}Ru	5.46±0.01	–	–
^{98}Ru	1.868±0.005	–	–
^{99}Ru	12.63±0.02	0.06	0.003
^{100}Ru	12.53±0.02	98.93±0.02	97.94±0.02
^{101}Ru	17.02±0.03	0.54±0.02	1.35±0.02
^{102}Ru	31.63±0.06	0.45±0.01	0.71±0.01
^{104}Ru	18.87±0.04	0.02	0.002

- **Tc target material:**
- **Tc metal powder / Kozar (2008)**
- **Tc – C composite Tc carbide / German (2005)**

- **Rotmanov K. et all. *Radiochemistry,* 50 (2008) 408 : New Ruthenium is almost monoisotopic Ru-100, it has different spectral properties**
- **It is available only to several countries that develop nuclear industry**

Nuclear medicine

- Radiodiagnostics
- Radiotherapy

- **Radiation use for**
- **metastases treatment,**
- **sterilization of medical instruments, drugs and clothes**

Advantages:
Nuclear medicine tests differ from most other imaging modalities in that diagnostic tests primarily show the **physiological function of the system being investigated** as opposed to traditional anatomical imaging such as CT or MRI.

Nuclear medicine

Practical concerns in nuclear imaging

- Although the risks of low-level radiation exposures are not well understood, a cautious approach has been universally adopted that all human radiation exposures should be kept **As Low As Reasonably Practicable**, "ALARP".
- The radiation dose from nuclear medicine imaging varies greatly depending on the type of study.

Tc-99

- Among many radionuclides that were discovered for medical-use, none were as important as the discovery and development of Technetium-99m.
- It was first discovered in 1937 by C. Perrier and E. Segre as an artificial element to fill space number 43 in the Periodic Table.
- The development of a generator system to produce Technetium-99m in the 1960s became a practical method for medical use.
- Today, Technetium-99m is the most utilized element in nuclear medicine and is employed in a wide variety of nuclear medicine imaging studies.

Nuclear medicine

Mo-99 - Tc-99 Generator

- Problem of Mo99 – Tc99 generator inaccessibility
- Use of LEU for Mo-99 generators production
- Alternative methods for Mo-99

Tc symposiums

- Italian TERACHEM (Prof.Mazzi) 1985 – 2010
- IST / ISTR (Joshihara, Sekine …) 1993 – 2014 (Japan, Russia, S.Africa, Fr ance…)
- Radiopharmaceutical Soc. Symp.

Radionuclides in Nuclear Medicine

- **Nuclear diagnostics**

- **PET** – positron emission computer tomography (beta+, T1/2= sec-hours) Fluor-18…
- **SPECT** – single photon emission computer tomography - gamma emitters 100-200 keV, T1/2 = hours-days (Tc^{99m} etc…)

- **Nuclear therapy**

- Radiation
- Betta-emittes 200-2000 keV,
- Alpha-emitters
- EC- or IEC- radionuclides (electron capture of internal electron conversion)

Radionuclides for PET

Nuclear medicine

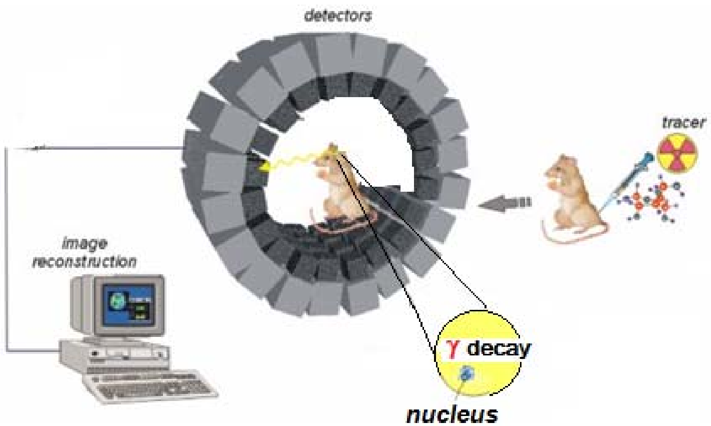
PET

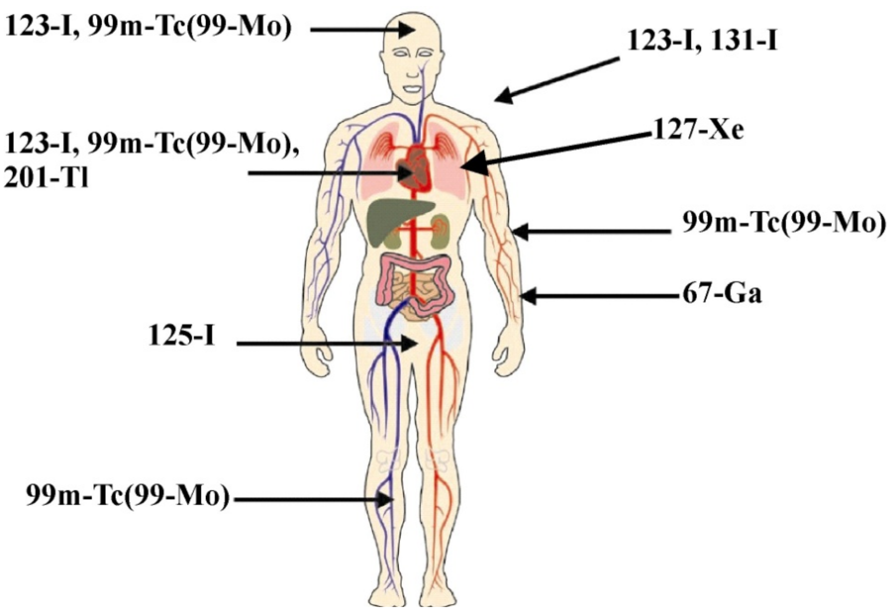
- More recent developments in nuclear medicine include the invention of the first positron emission tomography scanner (PET).
- The concept of emission and transmission tomography, later developed into single photon emission computed tomography (SPECT), was introduced by David E. Kuhl and Roy Edwards in the late 1950s
- Their work led to the design and construction of several tomographic instruments at the University of Pennsylvania.
- Tomographic imaging techniques were further developed at the Washington University School of Medicine.

PET/CT

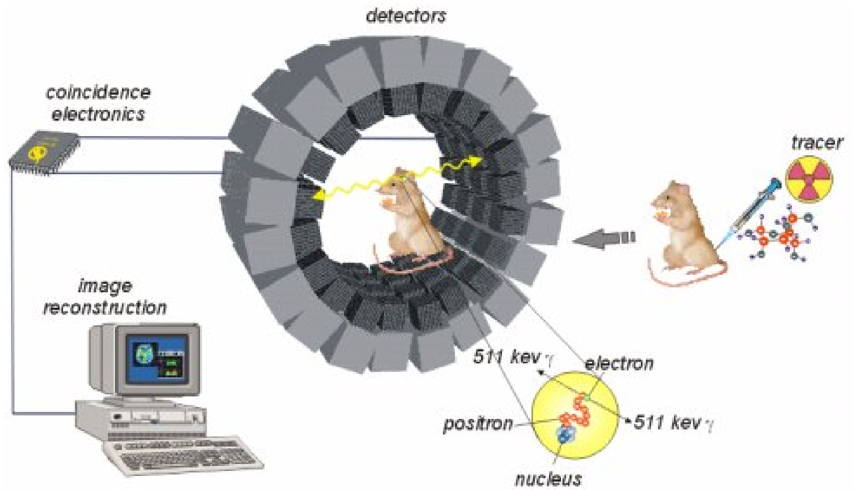
- These innovations led to fusion imaging with SPECT and CT by Bruce Hasegawa from University of California San Francisco (UCSF), and the first PET/CT prototype by D. W. Townsend from University of Pittsburgh in 1998.
- PET and PET/CT imaging experienced slower growth in its early years owing to the cost of the modality and the requirement for an on-site or nearby cyclotron.
- However, an administrative decision to approve medical reimbursement of limited PET and PET/CT applications in oncology has led to phenomenal growth and widespread acceptance over the last few years, which also was facilitated by establishing 18F-labelled tracers for standard procedures, allowing work at non-cyclotron-equipped sites.
- PET/CT imaging is now an integral part of oncology for diagnosis, staging and treatment monitoring. A fully integrated MRI/PET scanner is on the market from early 2011

SPECT





PET



F-18, Ga-68

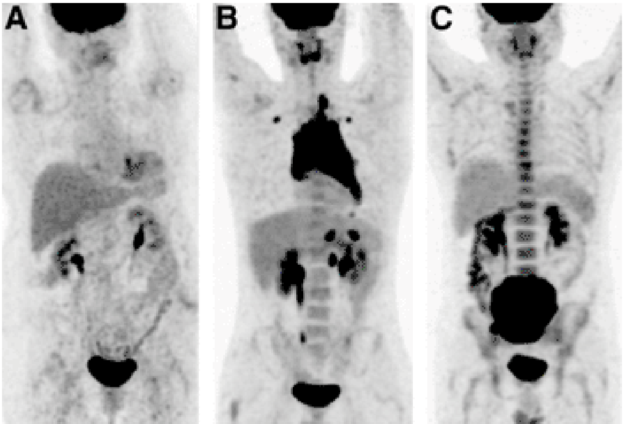
Short-lived !!!
cyclotron

PET/CT Better Choice Than Bone Marrow Biopsy for Diagnosis, Prognosis of Lymphoma Patients

By Medimaging International staff writers *13 Aug 2013*

Diffuse bone marrow uptake pattern in 1 FDG PET/CT. (A and B) Uptake lower than (A) or similar to (B) that in liver was considered negative for BMI.

(C) Uptake higher than that in liver was always linked to anemia or inflammatory processes and also considered negative for BMI (Photo courtesy of the Society of Nuclear Medicine and Molecular Imaging).



A more accurate technique for determining bone marrow involvement in patients with diffuse large B-cell lymphoma (DLBCL) has been identified by French researchers.

PET/CT Better Choice Than Bone Marrow Biopsy for Diagnosis, Prognosis of Lymphoma Patients

By Medimaging International staff writers *13 Aug 2013*

^{18}F-fluorodeoxyglucose (FDG) positron emission tomography/computed tomography (PET/CT) imaging when compared to bone marrow biopsy, was found to be more sensitive, demonstrated a higher negative predictive value, and was more accurate for diagnosing these patients— changing treatment for 42% of patients with bone marrow involvement.

DLBCL is the most frequent subtype of high-grade non-Hodgkin lymphoma, accounting for nearly 30% of all newly diagnosed cases in the United States. In recent decades, there has been a 150% increase in incidence of DLBCL. "In our study, we showed that in diffuse large B-cell lymphoma, ^{18}F-FDG PET/CT has better diagnostic performance than bone marrow biopsy to detect bone marrow involvement and provides a better prognostic stratification.

While bone marrow biopsy is considered the gold standard to evaluate bone marrow involvement by high-grade lymphomas,^{18}F-FDG PET/CT is in fact the best method to evaluate extension of the disease, as well as avoid invasive procedures," said Louis Berthet, MD, from the Centre Georges-Francois Leclerc (Dijon, France), and lead author of the study, which was published in the August 2013 issue of the *Journal of Nuclear Medicine.*

PET/CT Better Choice Than Bone Marrow Biopsy for Diagnosis, Prognosis of Lymphoma Patients *By Medimaging International staff writers* 13 Aug 2013

The retrospective study included 133 patients diagnosed with DLBCL. All patients received both a whole-body 18F-FDG PET/CT scan, as well as a bone marrow biopsy to determine bone marrow involvement. A final diagnosis of bone marrow involvement was made if the biopsy was positive, or if the positive PET/CT scan was confirmed by a guided biopsy, by targeted magnetic resonance imaging (MRI) or, after chemotherapy, by the concomitant disappearance of focal bone marrow uptake and uptake in other lymphoma lesions on ^{18}F-FDG PET/CT reassessment. Progression-free survival and overall survival were then analyzed.

Thirty-three patients were considered to have bone marrow involvement. Of these, eight were positive according to the biopsy and 32 were positive according to the PET/CT scan. 18FDG PET/CT was more sensitive (94% vs. 24%), showed a higher negative predictive value (98% vs. 80%) and was more accurate (98% vs. 81%) than bone marrow biopsy. Among the 26 patients with positive ^{18}F-FDG PET/CT results and negative biopsy results, 11 were restaged to stage IV by PET/CT, which changed their treatment plans.^{18}F-FDG PET/CT was also determined to be an independent predictor of progression-free survival.

“Our findings add to the literature to prove the significance of ^{18}F-FDG PET/CT in cancer evaluation and to democratize this imaging method,” concluded Dr. Berthet. “Molecular imaging is the best method to adapt targeted therapies to each patient. The emergence of PET/MRI and novel radiotracers predicts an exciting new future for our field.”

**Thank you
for the attention !**