# Nuclear Power

## Introduction. Basics of nuclear reactions. Conventional Nuclear Power Plants in the World.

*SPG course MJ2405*

Miro Petrov

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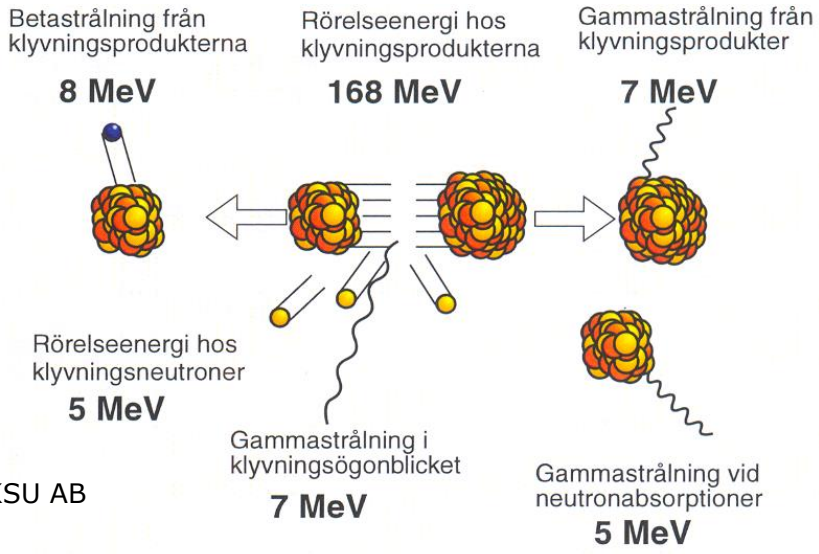


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# Historical Notes

- **Demokritos (~400 B.C.)** – the notion of the ”atom”
- **Martin Heinrich Klaproth** – discovers the Uranium in 1789
- **Wilhelm von Röntgen** – discovers the X-rays in 1895
- **Henri Becquerel** – discovers the natural radioactivity in 1896
- **John Joseph Thomson** – describes the electron in 1897
- **Marie & Pierre Curie** – isolate Radium and Polonium in 1898 and initiate the modern scientific work on radioactivity
- **Ernest Rutherford** – the α- and β-radiation in 1899
- **Paul Ulrich Villard** – the γ-rays (gamma-rays) in 1900
- **Hans Geiger & Ernest Marsden** – define the nucleus in 1909
- **Max Planck, Ludwig Boltzmann, Albert Einstein** – develop the quantum theory 1890 – 1910
- **Niels Bohr** – proposes the planetary model of the atom in 1913
- **James Chadwick** – discovers the neutron in 1932, based on work done by **Frederic Joliot-Curie**.

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# Milestones for Nuclear Power

- **1920-ies** – Albert Einstein: $E=mc^2$ (mass can be transformed into energy)
- **1938** – Otto Hahn & Lise Meitner describe the process of fission.
- **1942 -** Enrico Fermi – first operational nuclear reactor in Chicago.
- **1945** – the atom bomb – *The worst history lesson ever!*
- **1954 – 1956** – the first nuclear power plants in commercial operation in the USA, UK, USSR.
- **1954** – first research reactor in Sweden (right here in KTH).
- **1964** – first commercial tests in Sweden (Farsta, Stockholm).
- **1979** – the Three Mile Island (Harrisburg) accident.
- **1986** – the Chernobyl disaster.
- 1988 – 2002 – doldrums for nuclear power.
- ~2003 onwards… – revival of interest and new developments!
- **2011** – the Fukushima accident – and again a total halt!

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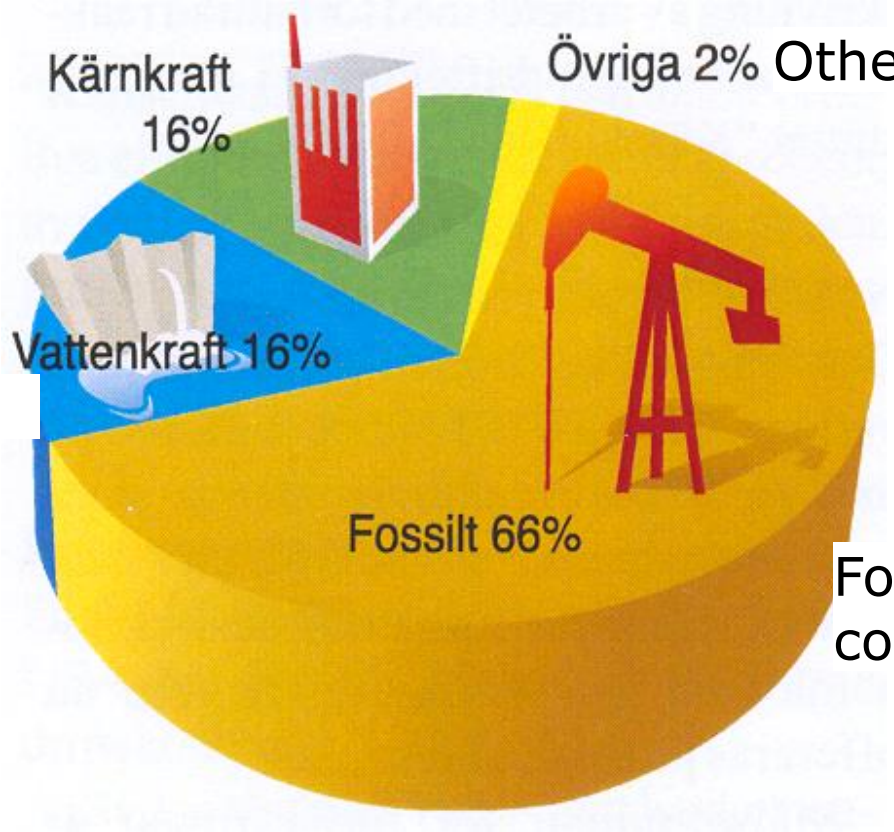
# Importance of Nuclear Power

Nuclear power

Hydropower




Fossil fuels: coal, oil, gas

Nuclear share of electricity production worldwide (2005)

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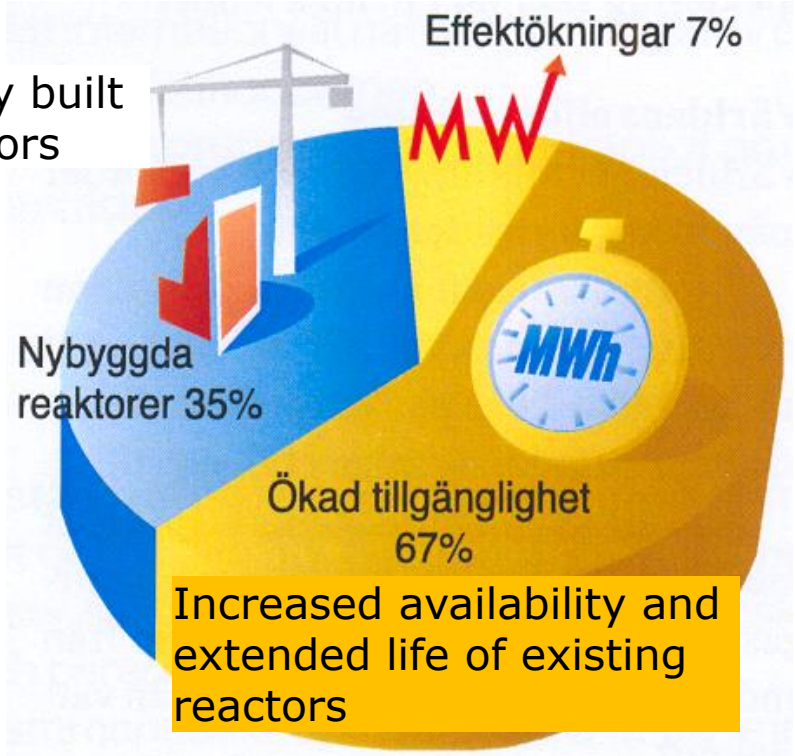
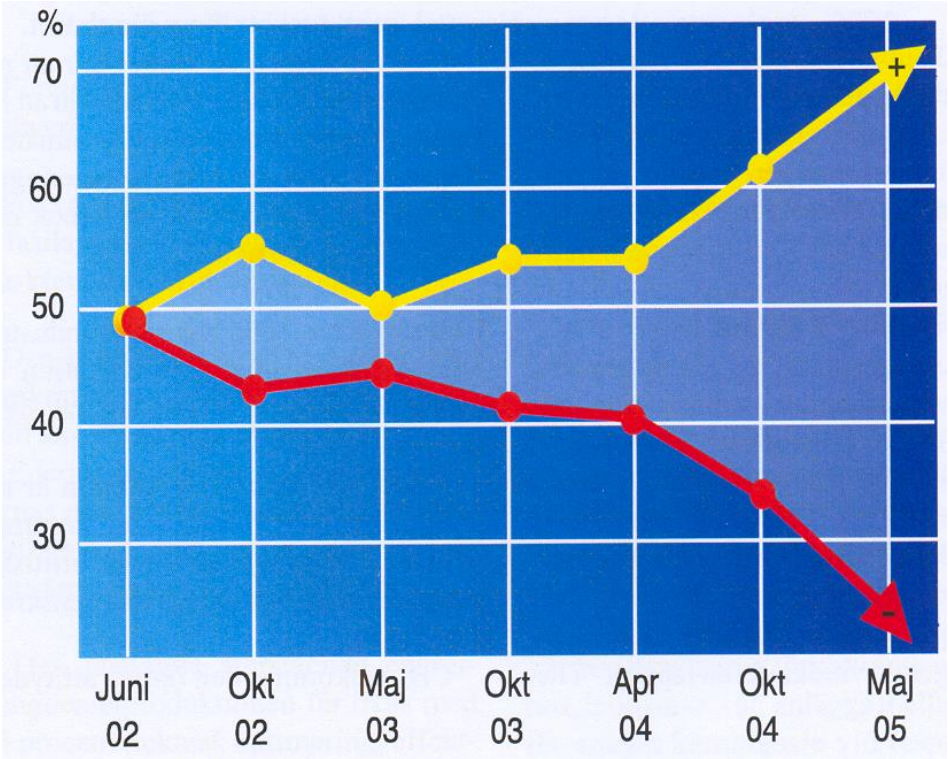
# The Future of Nuclear Power

Possible improvements
in existing reactors

Newly built
reactors




Increased availability and extended life of existing reactors




Recent increase of nuclear power as a result of several main upgrades (left)
Steady change in public opinion in favour of nuclear power - USA polls (right)

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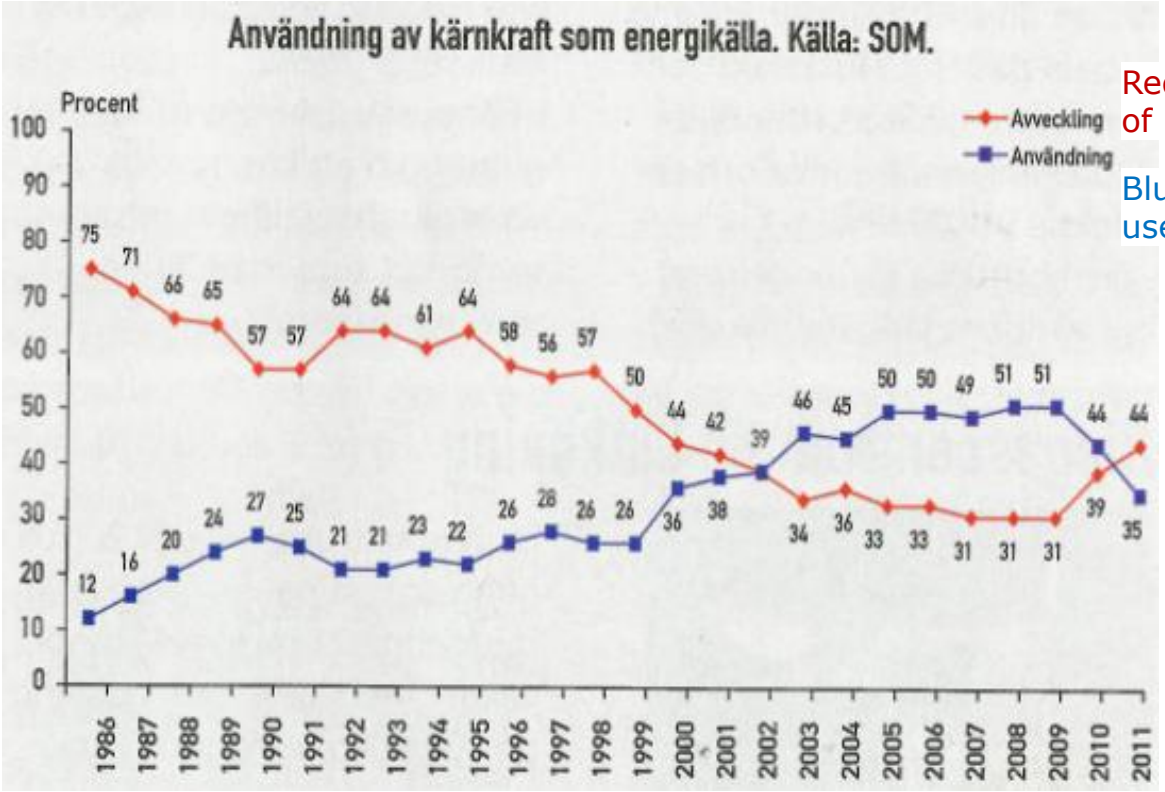
# Fluctuating public acceptance in Europe




Red line = for abandonment of nuclear power

Blue line = for continued use of nuclear power

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Example from Sweden: Slow recovery in public acceptance after the Chernobyl accident, then again a drop after Fukushima...

# ¿Is nuclear power Sustainable or NOT?

- **Opinions vary largely –** You should develop your own view!
- In the very long run: **Nuclear fission fuel is finite and would eventually be exhausted just like fossil fuels**.
- In the near future: The **$CO_2$-free nature of nuclear power** can be exploited for climate-neutral electricity.
- ***However:*** *Safety issues, radioactive hazard and the final storage of spent nuclear fuel remain as looming challenges!*
- **Both positive and negative qualities exist!**
- Learn to understand the nuclear technology first, and thereafter biuld up and defend your own opinion and your own standpoint for or against nuclear power.

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# The ATOM…

… is neither the smallest building block of matter, nor is unbreakable. It is also composed of smaller particles, however not important here. Its nucleus can split into two atoms or unite with another atom (that is a nuclear reaction) to form a completely different basic element – and in the process releasing enormous amounts of energy in the form of heat.

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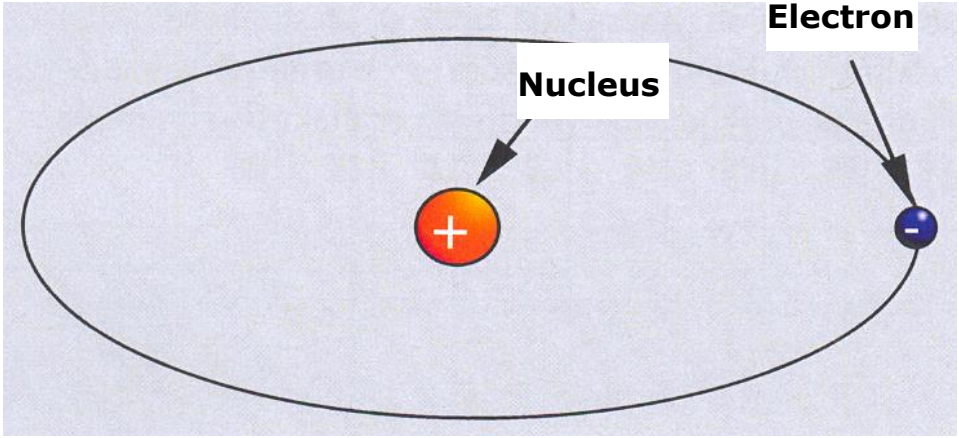



Mass units:

proton ~ 1

neutron ~ 1

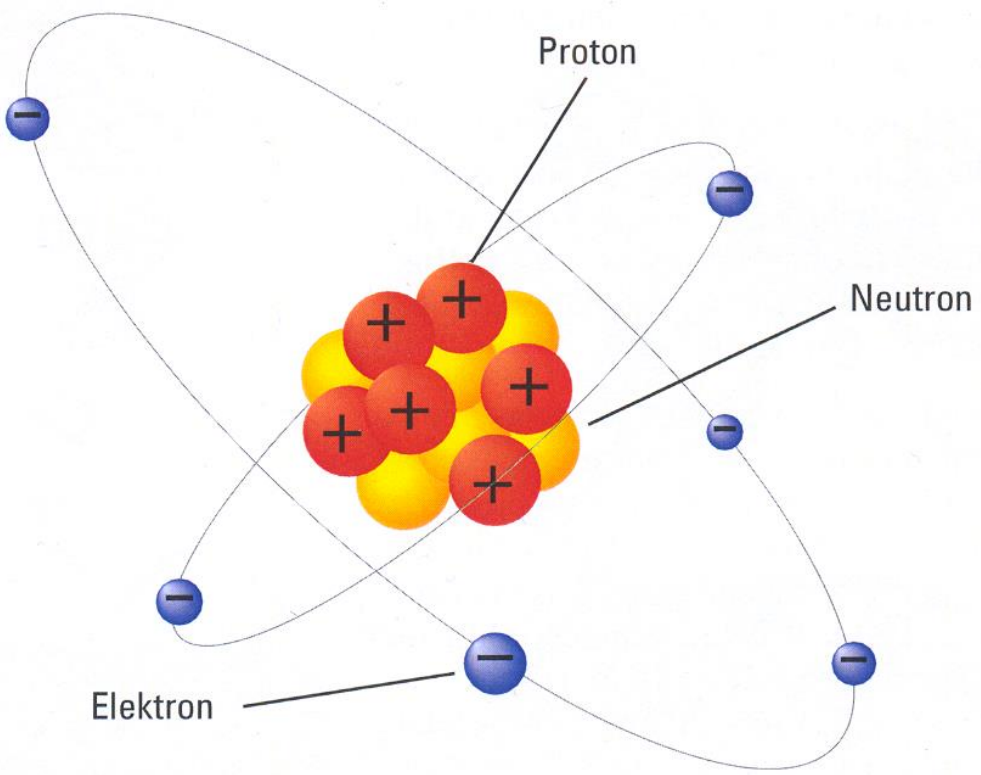
electron ~ 1/1800

Atom's diameter ~ $10^{-10}$ m

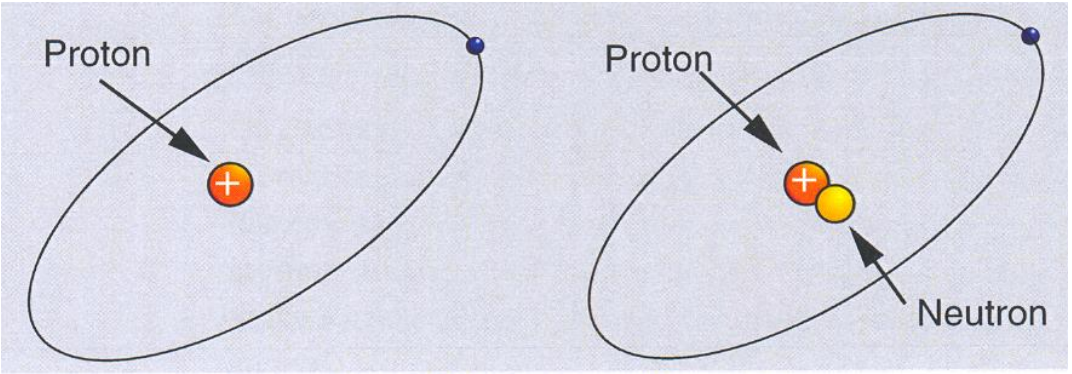
Nucleus' diameter ~ $10^{-14}$ m

The simplest atom is the hydrogen: 1 proton + 1 electron

# Isotopes of chemical elements



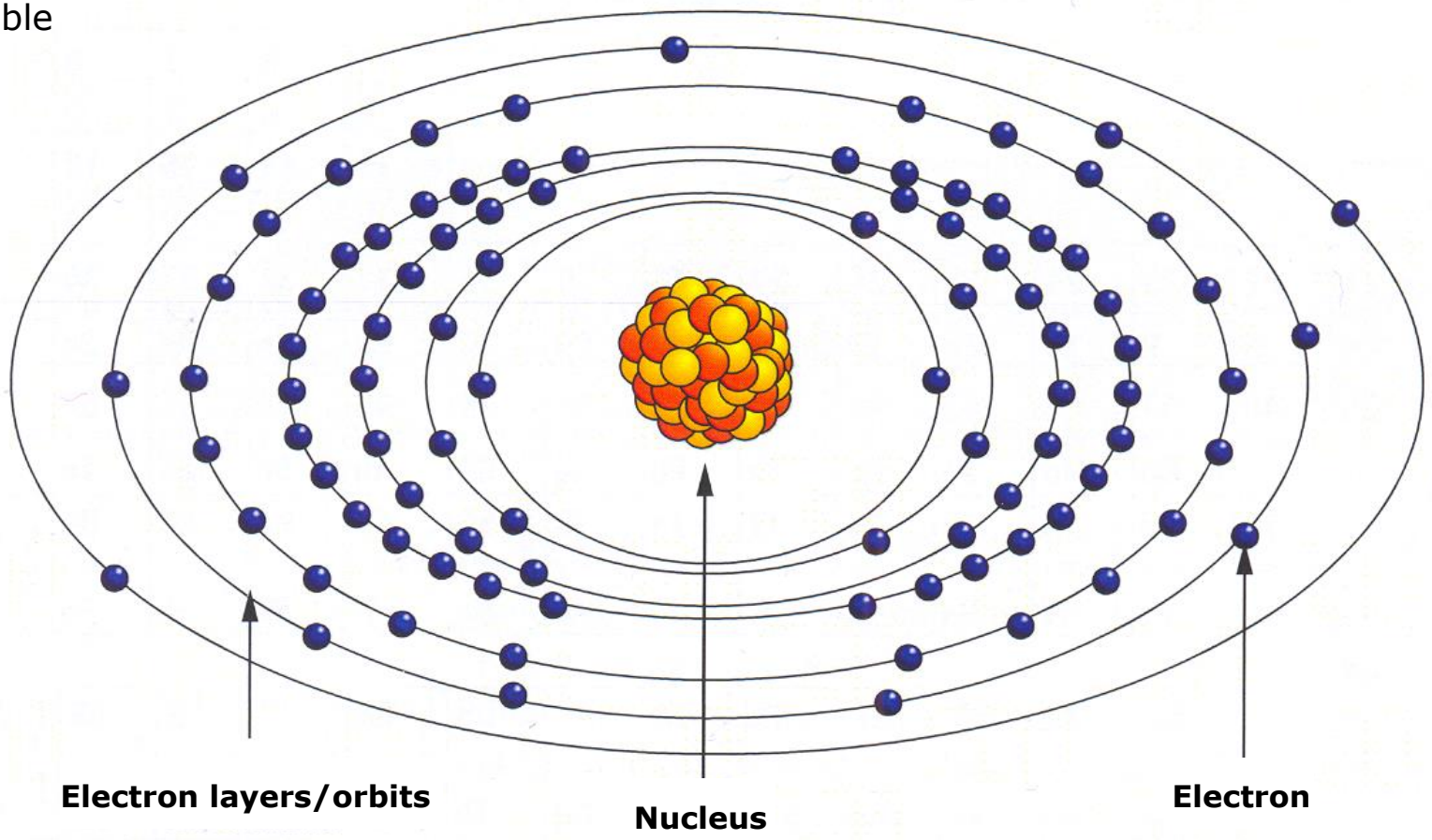

**Each basic element may have several isotopes depending on the number of neutrons in the atom…**




**A hydrogen atom** and **a deuterium atom**

# Uranium atom

Atoms can be very large and heavy – then they often are unstable

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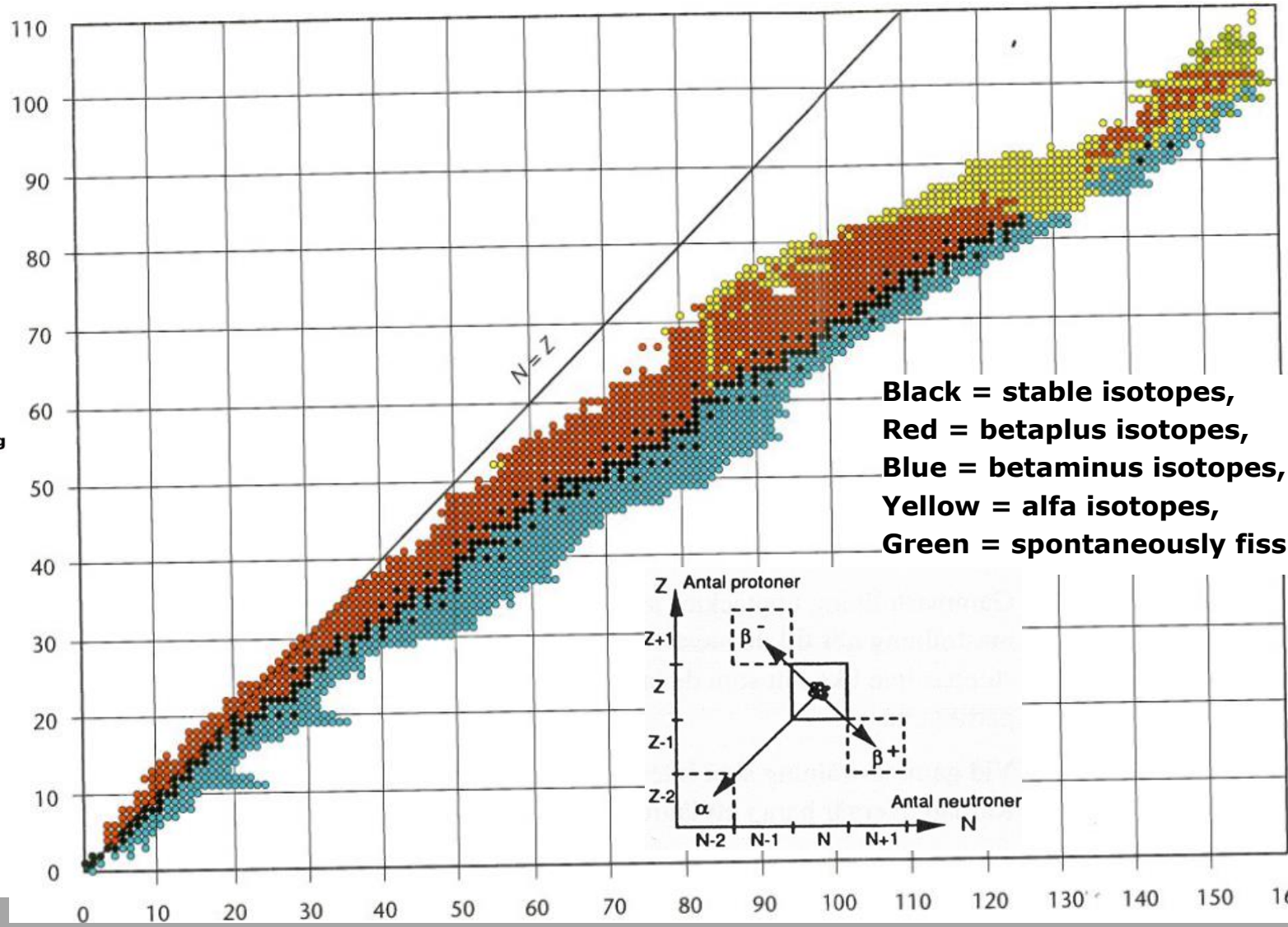
# Isotopes and their stability

**Atomic number = number of protons (Z)**




**Black = stable isotopes,**
**Red = betaplus isotopes,**
**Blue = betaminus isotopes,**
**Yellow = alfa isotopes,**
**Green = spontaneously fissile!**

**Number of neutrons (N)**

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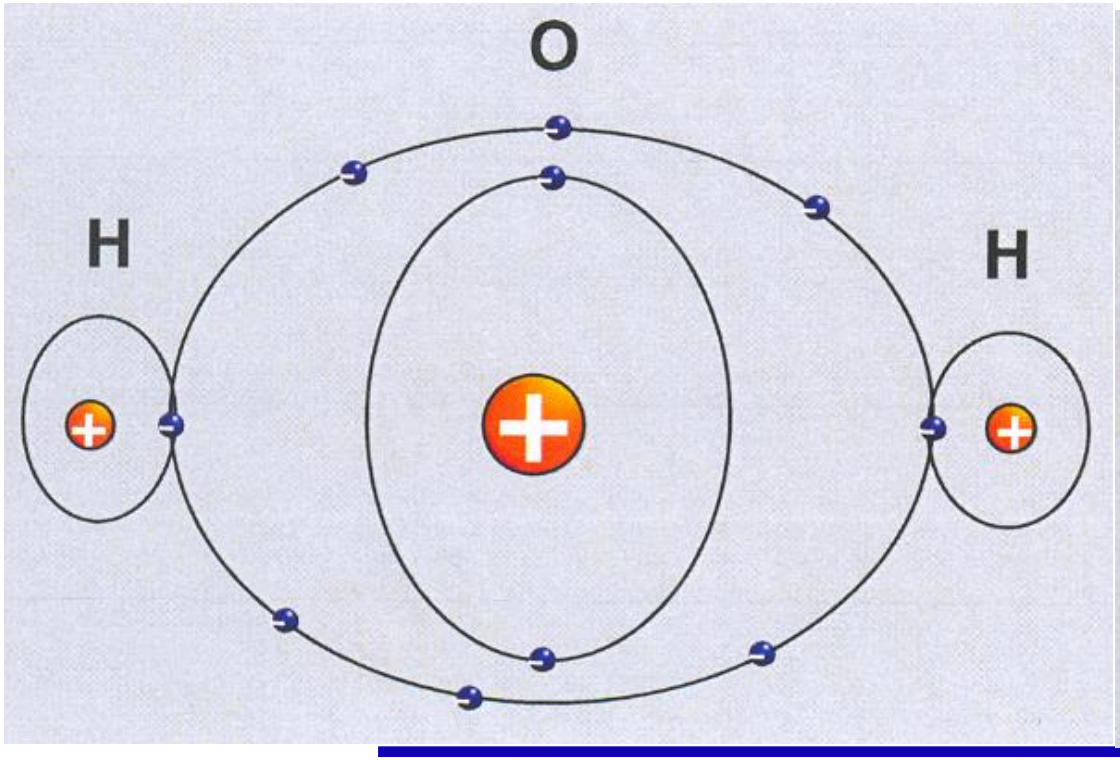
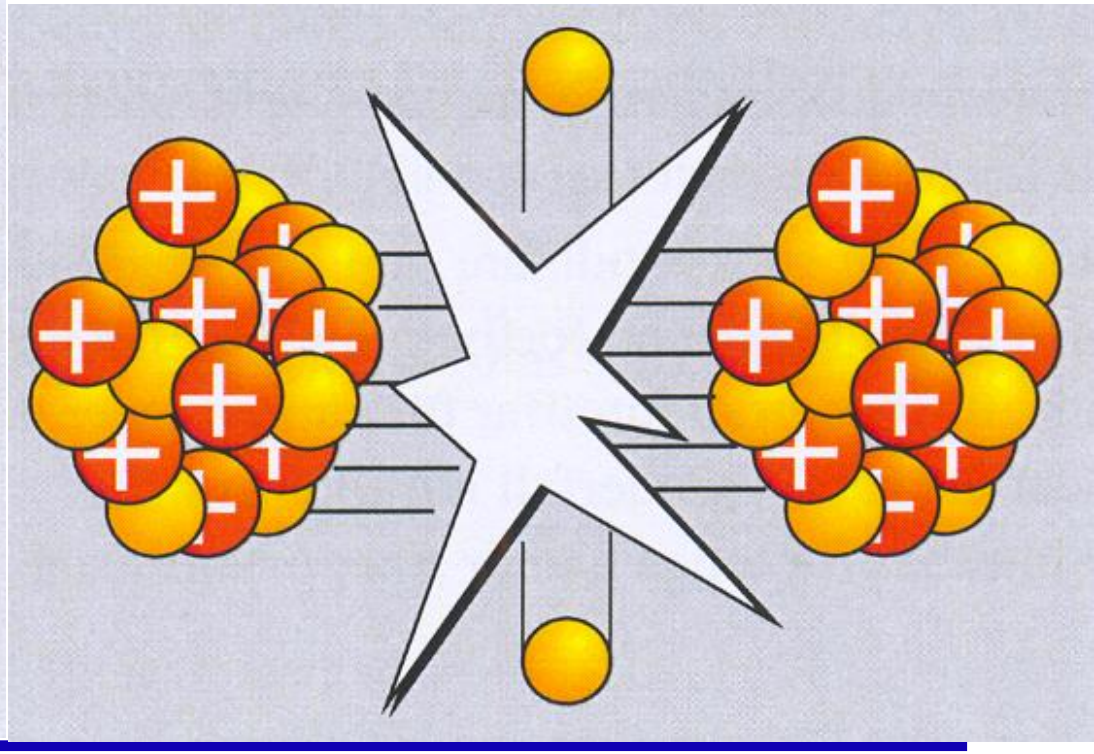
# Chemical vs. Nuclear reactions

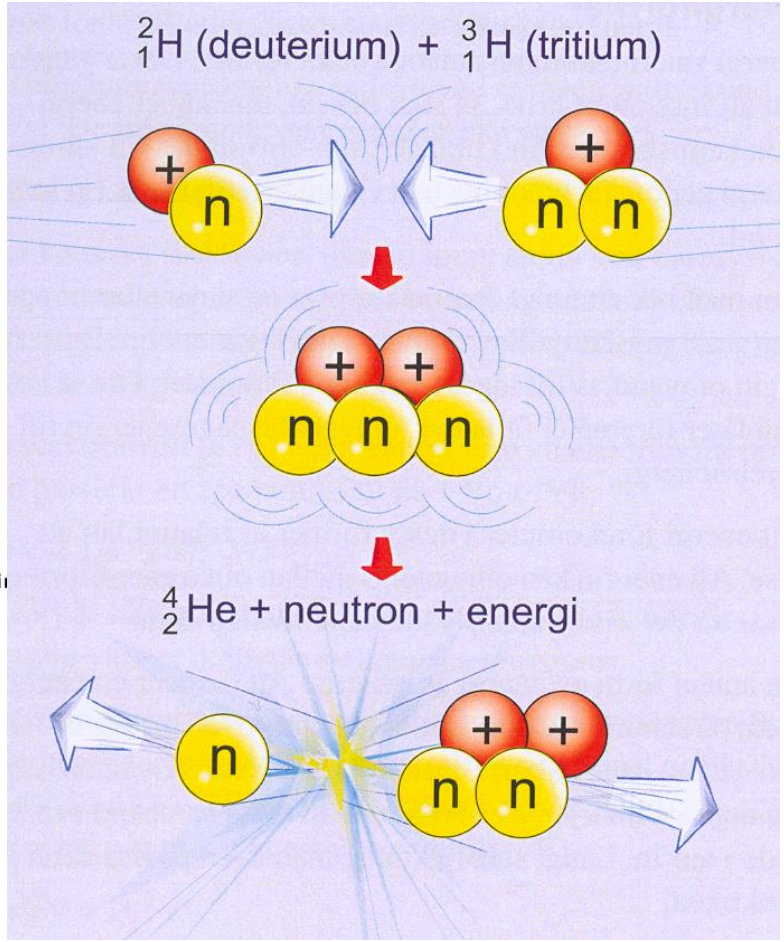
**A chemical reaction means exchange or sharing of electrons between atoms, forming together a molecule of another chemical substance, releasing or consuming some energy in the process but never loosing mass.**

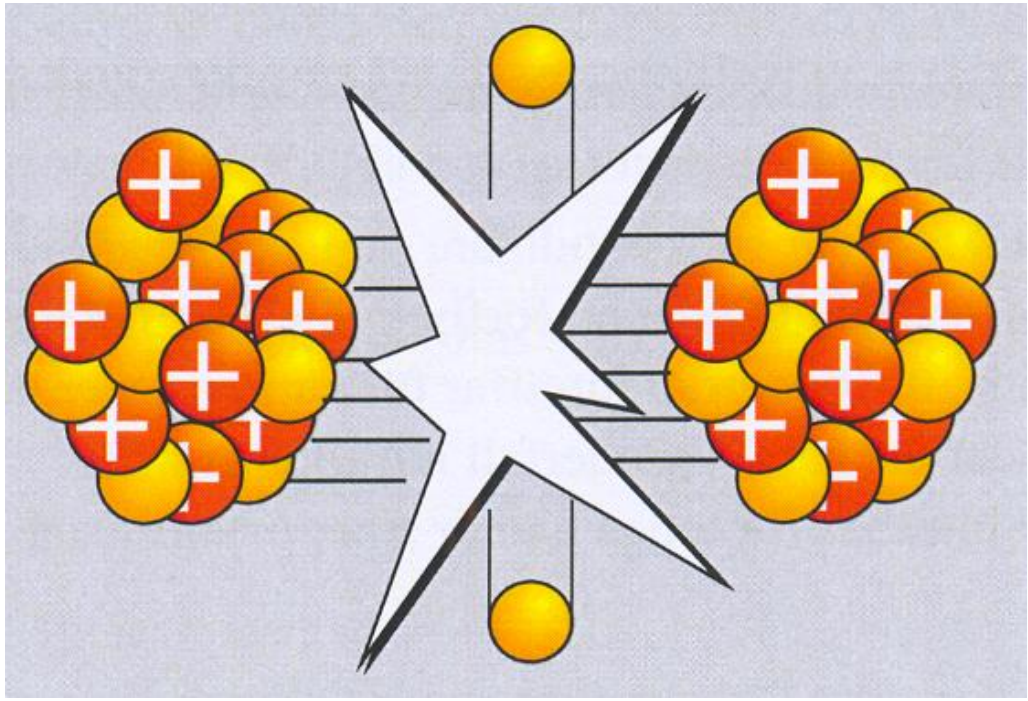
**A nuclear reaction involves fusion or fission of nuclei, producing other basic chemical elements, always releasing huge amounts of energy that is related to a loss of mass!**



# Types of nuclear reactions



**Fusion** (left) and **Fission** (right) – always releasing energy due to difference in mass between reactants and products!

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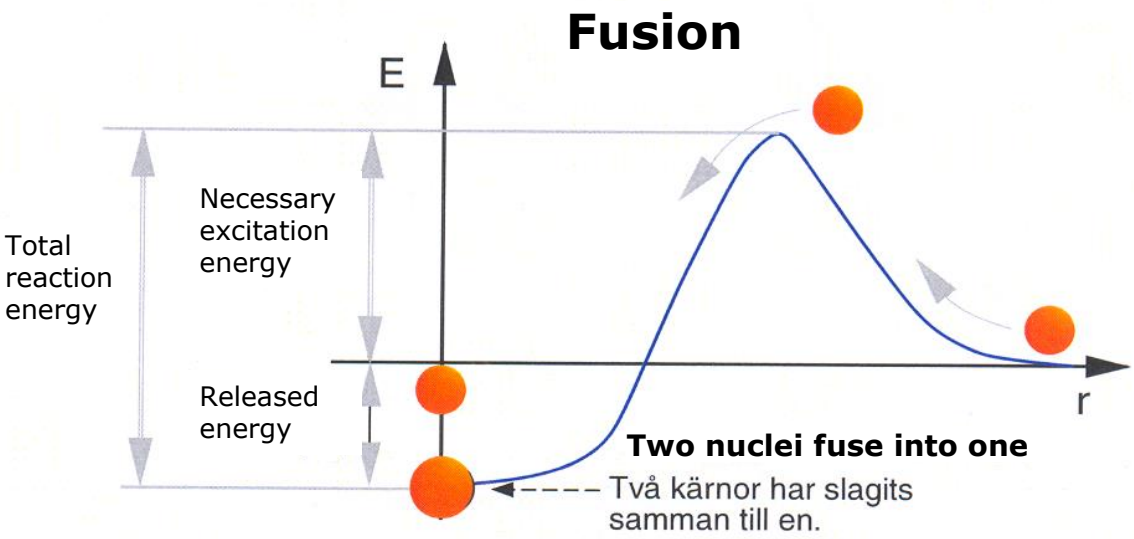
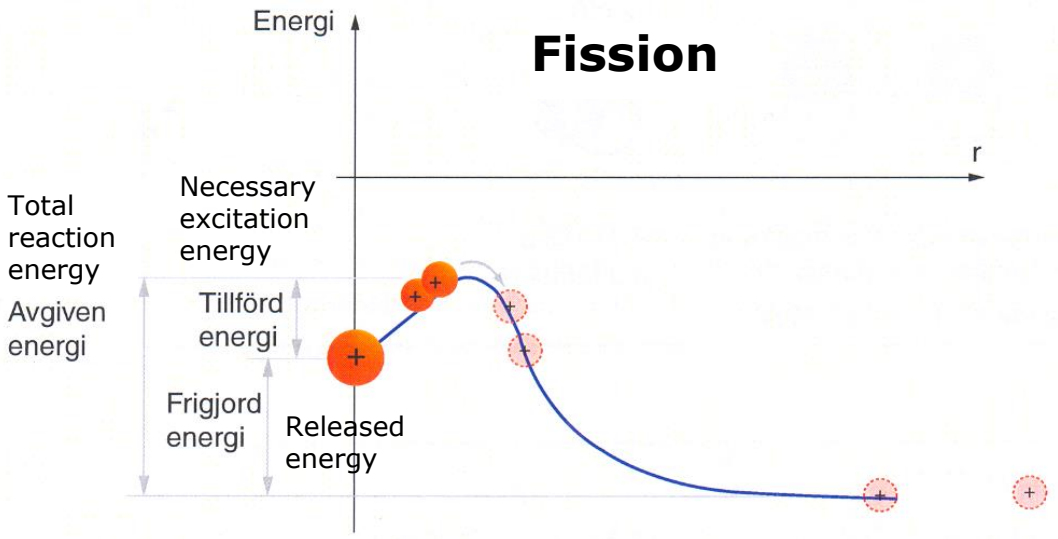
# Nuclear Energy




To initiate a nuclear reaction, the nuclei should be brought out of their equilibrium by input of energy. Once started, the nuclear reaction releases a massive amount of energy in the form of kinetic motion of the products, quickly transformed into heat by friction, etc.

# Origin of nuclear energy

**The ”mass defect”,** also expressed by the $E=mc^2$ relation

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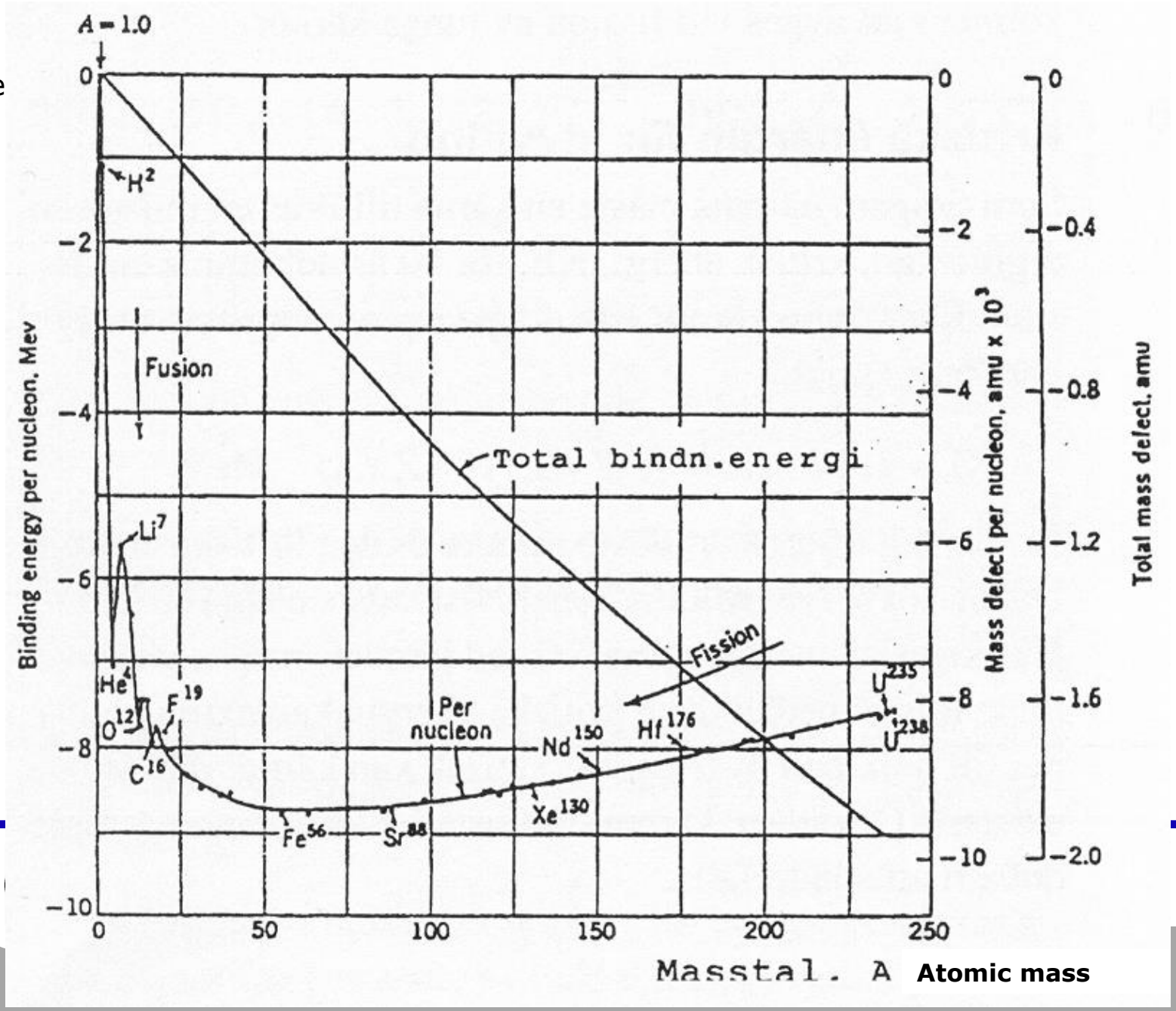


# Fission of Uranium

***Main fission products of Uranium:***

**Usually two new nuclei – one with atomic mass between 80 -110, the other one with atomic mass around 130 – 150.**

**Beta-radiation from fission products**

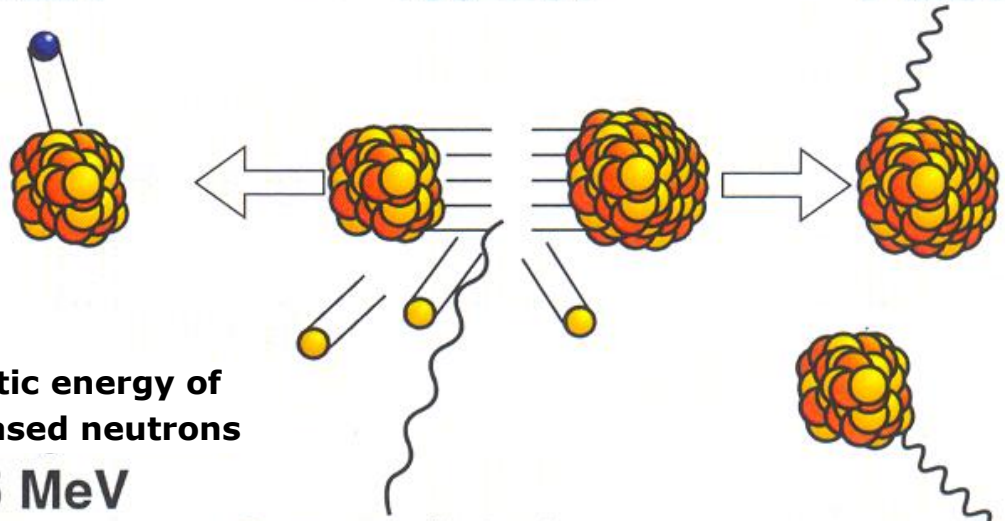
**8 MeV**

**Kinetic energy of fission products – converted to heat!**

**168 MeV**

**Gamma-radiation from fission products**

**7 MeV**



**Kinetic energy of released neutrons**

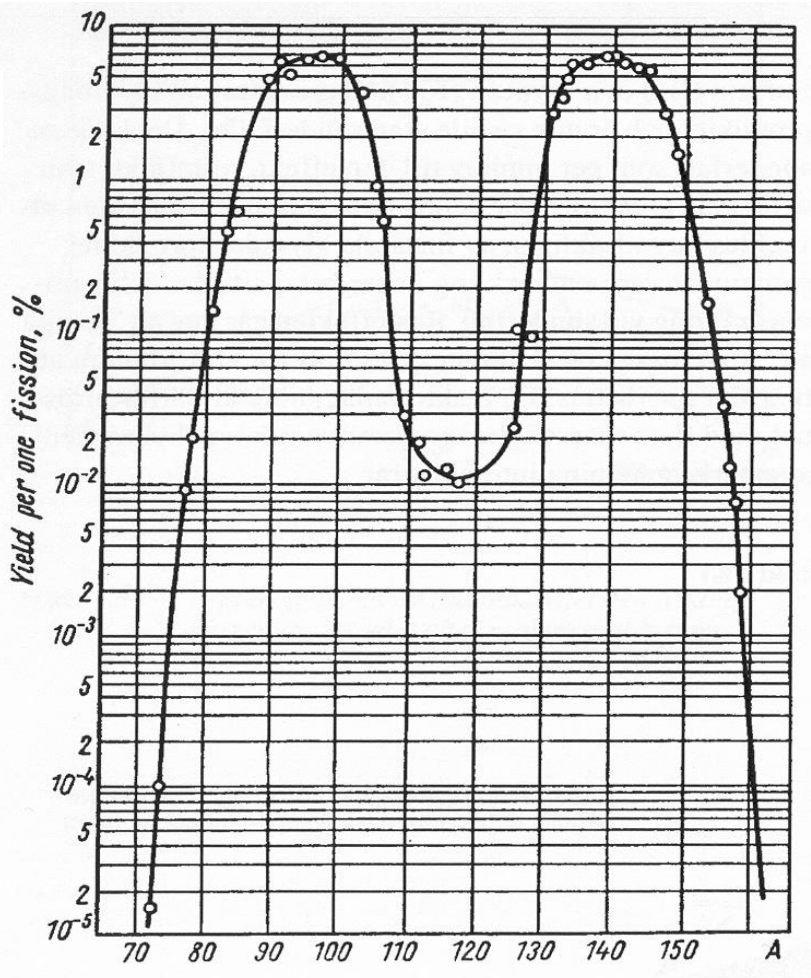
**5 MeV**

**Gamma-radiation in the moment of fission**

**7 MeV**

**Gamma-radiation from neutron absorption**

**5 MeV**

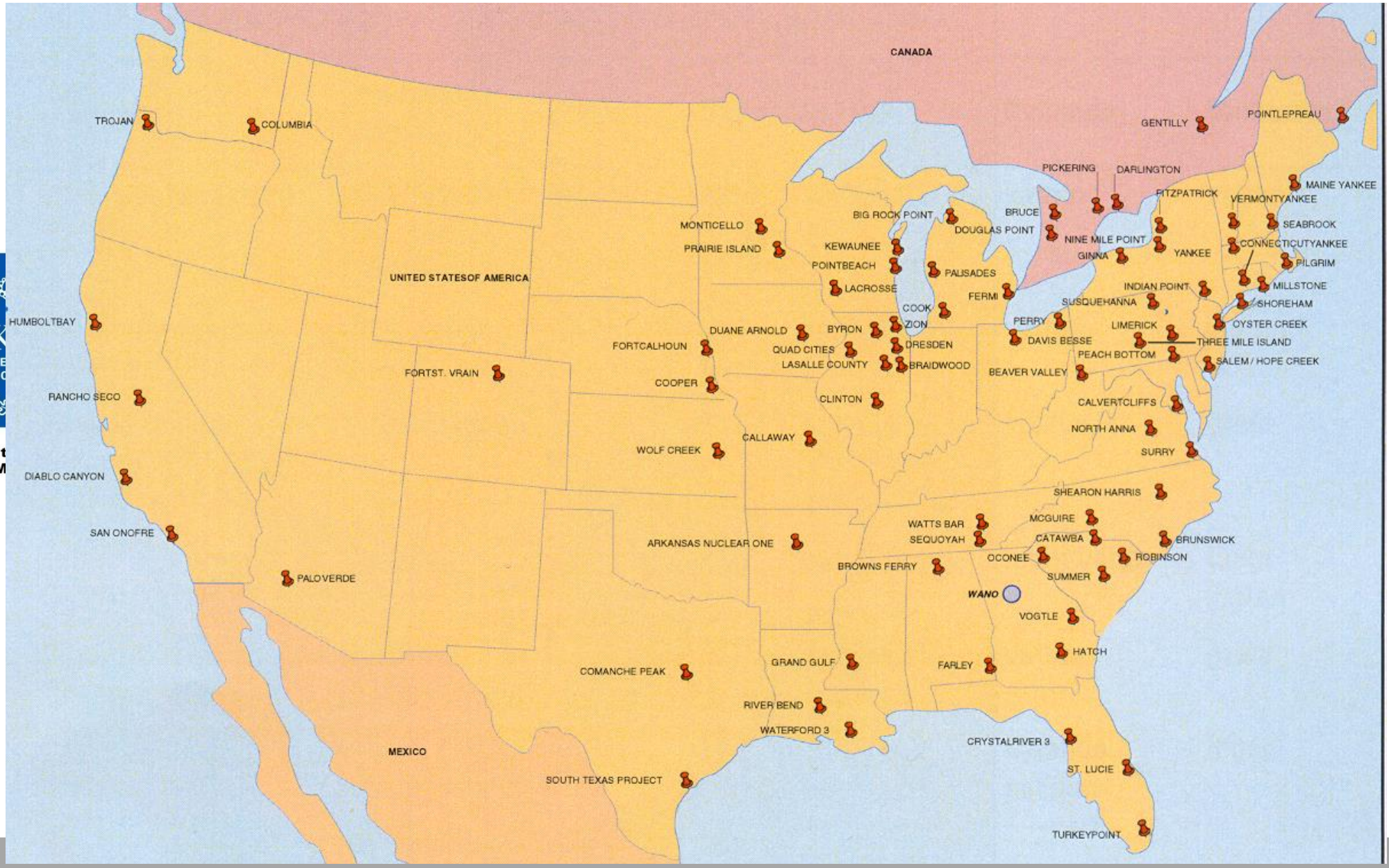


# Nuclear Power in Scandinavia


Source: www.insc.anl.gov

# Nuclear Power in Europe

# Nuclear Power in USA & Canada



# Nuclear Power in Japan & Korea

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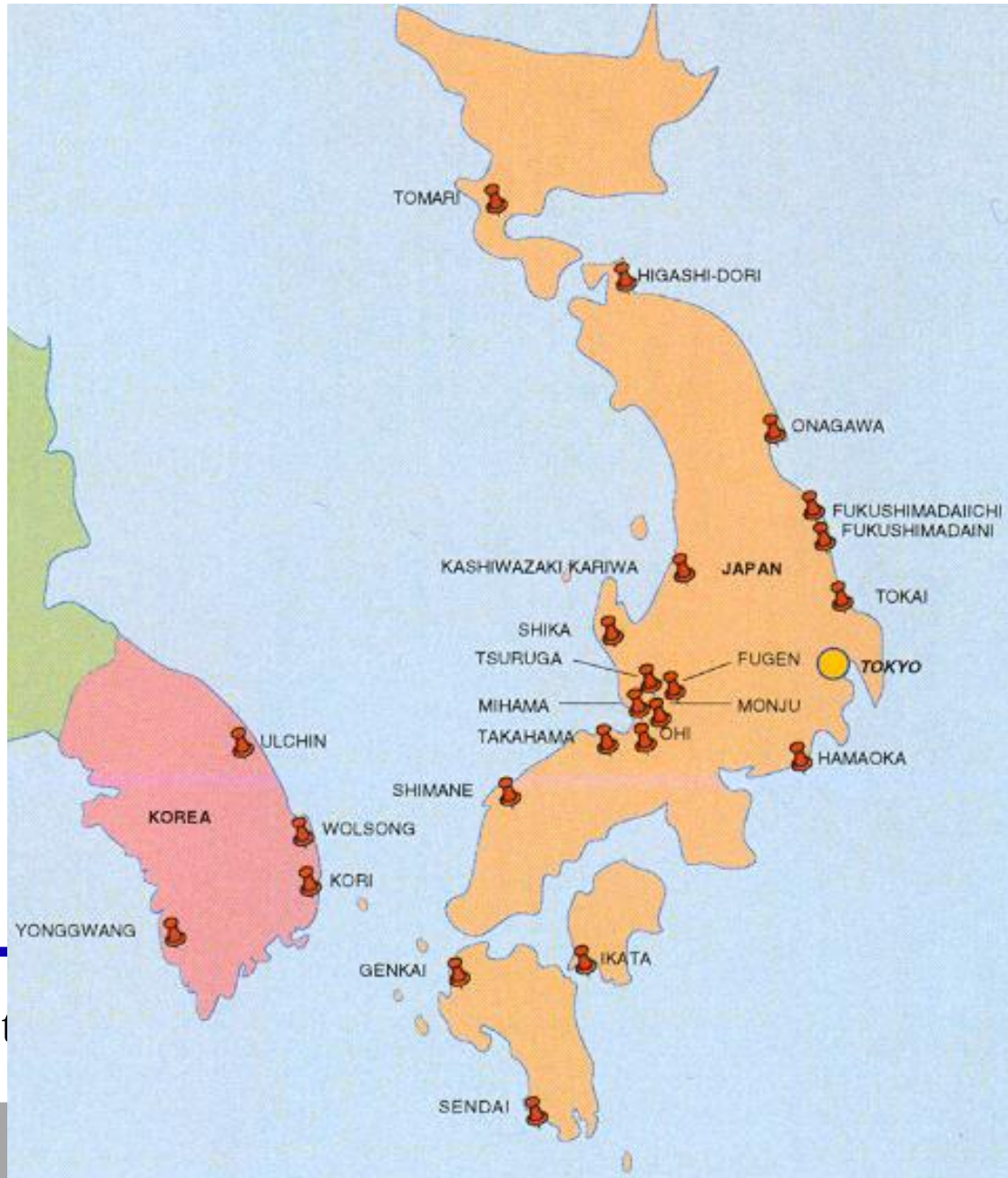


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# ...and in the rest of the World


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# Some interesting examples (1)

**The Doel nuclear plant in northern Belgium (near Antwerpen) is located in a historical background and in a very densely populated area.**

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# Some interesting examples (2)

All nuclear reactors in Japan (nearly 50 units) were shut down after the Fukushima earthquake in 2011.

The Sendai plant, situated on the southernmost island (see slide 20 above), was restarted in 2015.

The **Kashiwazaki-Kariwa plant** on the west coast *(**pictured here**)* is the largest in the world, featuring 7 reactors with a total installed capacity >7000 $MW_{el}$, which had already survived another strong earthquake beyond its design limit, in 2007. It has also been recently approved for restart.

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# Some interesting examples (3)

***Most notable new developments in Europe:***

**a)** The third unit of the Olkiluoto nuclear plant site (TVO) in Finland – shown here under construction (left) and as an artist's impression when completed (right) – featuring the first modern European Pressurized Water Reactor (EPR) of 1600 $MW_{el}$ capacity. The reactor was supposed to enter operation in 2010. However, it is not finished yet and has become quite notorious due to the multiple problems and delays that have demanded almost double the investment.

# Some interesting examples (4)

***Most notable new developments in Europe:***

**b)** Another unit of EPR design is being built in France, at the Flamanville site. It has also been delayed and will not be completed anytime soon. Recently, the focus is primarily on the UK where two super-modern EPR units (3200 $MW_{el}$) have been proposed for the **Hinkley Point** site in southwest England ***(pictured here)***, under fierce discussions and critique by anti-nuclear lobbyists for several years. The ”Hinkley Point C” project was finally approved and contracts signed in Sept-Oct 2016, at a very high cost. A major investor is the Chinese CGN group.

**c)** In the meantime, without too much media hype, Belarus is building its first-ever nuclear power plant of the new Russian (Rosatom) AES design – two PWR units of 1200 $MW_{el}$ each, based on the classic VVER-1000 type from the Soviet era. While everybody else suffers from delays, the Belarus reactors would probably be the first troublefree new construction in Europe to enter commercial operation as planned, by 2018 - 2020.

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# Some interesting examples (5)

**In the USA**: Four notable modern constructions are taking place – namely two new units at the Vogtle plant in Georgia, and two other at the Summer plant in South Carolina. All of them would feature the Westinghouse Advanced Pressurized Water Reactor design **(AP1000)** of 1100 $MW_{el}$, and again all of them suffer from serious delays and added costs.

Bankruptcy and closure of Westinghouse in 2017 left Vogtle struggling to complete the project, while Summer will be abandoned.

*The progress at the **Vogtle plant** is shown in photos here:*



# Some interesting examples (6)

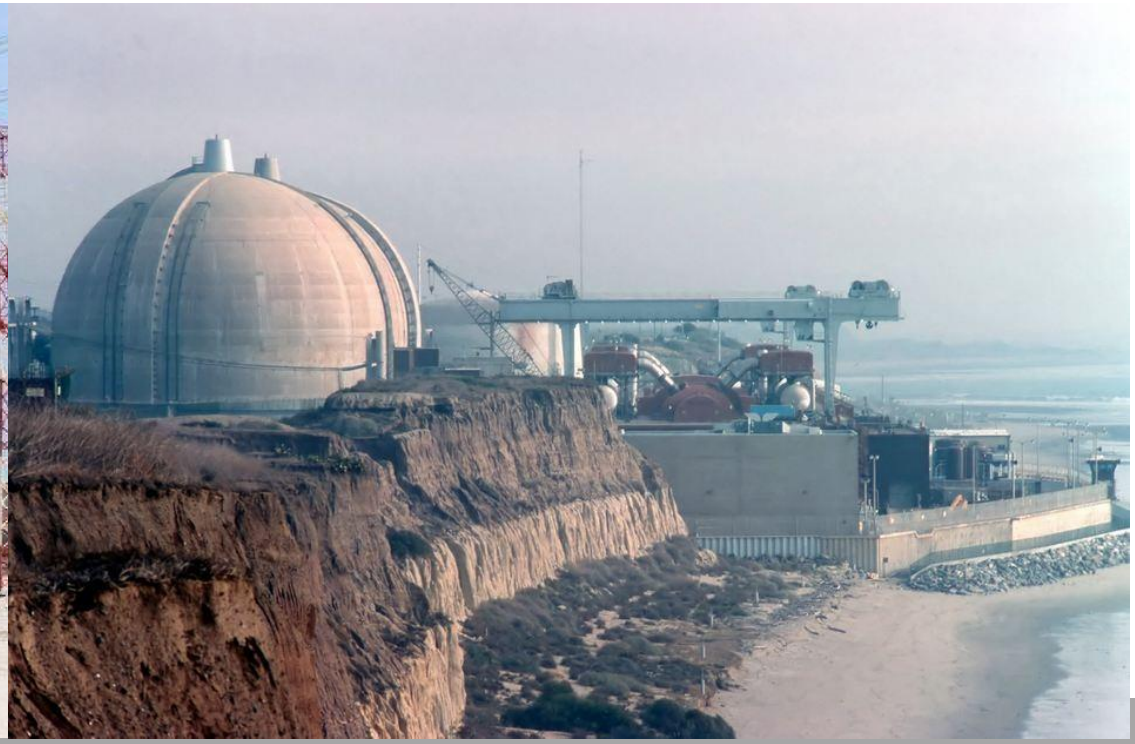
**In Asia –** several countries are building new reactors. Most notably:

a) **China** proceeds with the construction of multiple new reactors (>20 units!) of all available modern types, and will also add very soon a new home-made Chinese designed reactor.

b) **South Korea** is building several new reactors of own design – namely KEPCO's APR-1400 type – adding them at two sites to already existing Korean nuclear power stations.

c) **Turkey** wanted to build a nuclear plant since long time. A contract was finally signed in 2015 with Rosatom for 2 reactors by 2022 (+2 more later), under Russian financing, at the Akkuyu site on the Mediterranean coast in south Turkey.

d) The **Unated Arab Emirates (UAE)** is building its first nuclear plant at the **Barakah site in Abu Dhabi**, of APR-1400 design and delivered entirely by Korean suppliers. The first two units (***pictured here***) will supply power to a monster-large water desalination plant!



# Some interesting examples (7)

**Old mothballed reactors under revival:**

Towards the end of last century, several countries abandoned the construction of nearly-complete reactors. Some of these reactors have recently been (or might be in the future) considered for completion.

A good example is the **Watts Bar plant** in Tennessee, the USA. It was planned to have two reactors. Construction started in the 1980's and stopped when the site was 80% complete. The first reactor was fully completed in 1996 – so it became the last reactor to be built in the USA for the last 20 years.

The second reactor at Watts Bar was very recently reopened and finalized, reaching its rated power for the first time in July 2016 (1150 MW). Thus, it became the first reactor to be added to the grid since 1996!

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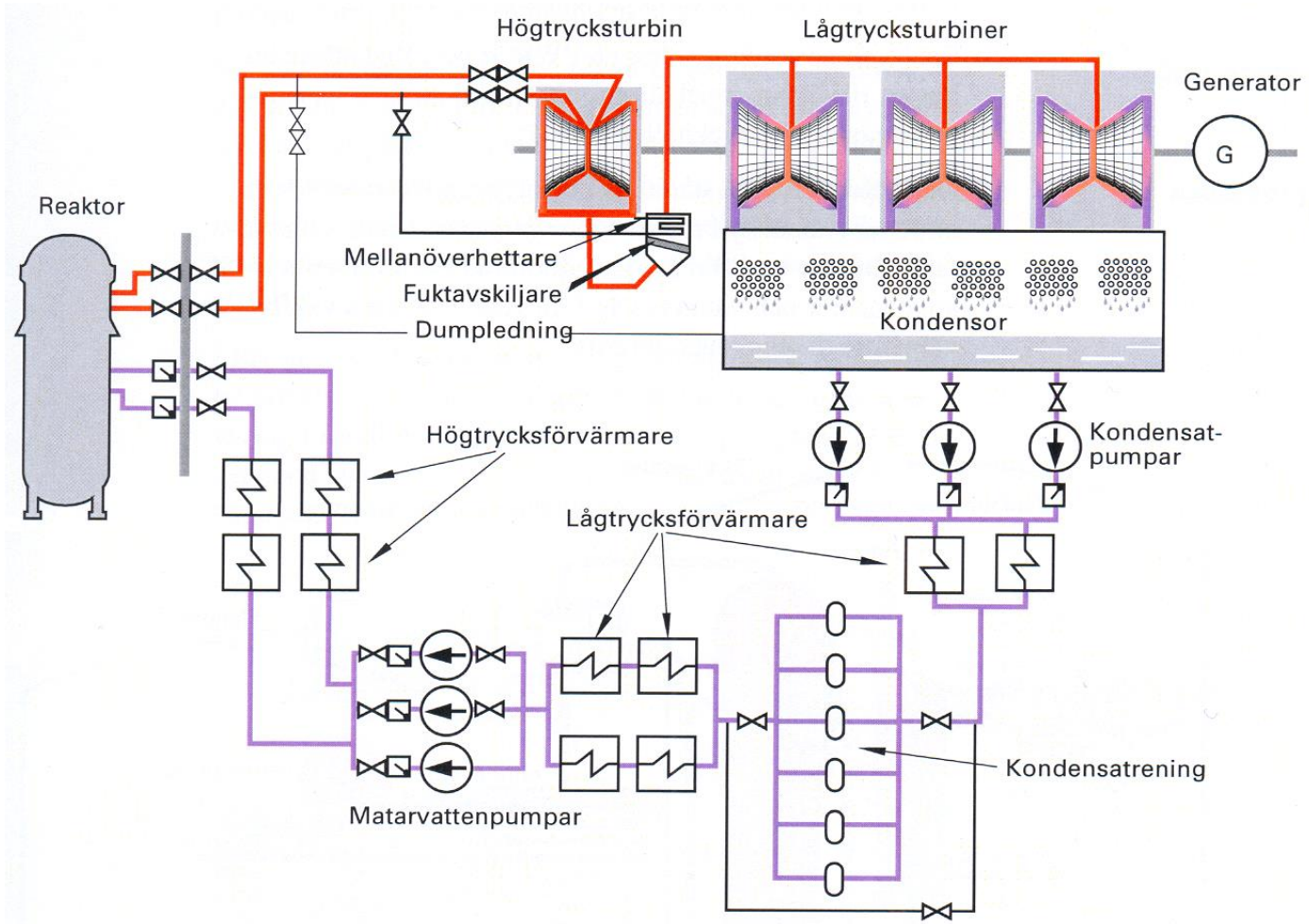
# Again a Steam Cycle is employed!

Regardless of how advanced the nuclear process is, it again involves the conversion of heat into power!

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# Summary of Nuclear Reactors Worldwide

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**Check the website of the World Nuclear Association:**
**www.world-nuclear.org**
Tons of information on technology fundamentals, and
a database of nuclear power reactors - country by country!

***World nuclear statistics as of year 2016:***
~440 existing reactors worldwide, in 30 countries;
~50 new reactors under construction (20 of them in China);
174 being planned, other 300 considered or proposed...

China will soon have 50+ GW installed nuclear capacity in a fleet of 56 reactors