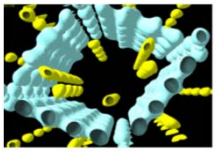
Research themes

Energy

- solar cells
- batteries
- hydrogen storage
- magneto caloric
- nuclear reactors

Materials research



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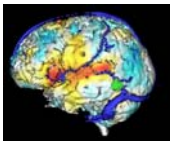
Research themes

Health

- radiation and radionuclides for diagnostics and therapy
- pre-clinical imaging methods and systems
- (new) production routes for (new) radionuclides
- nuclear reactors and facilities for isotope production
- robust and adaptive proton therapy (HollandPTC)



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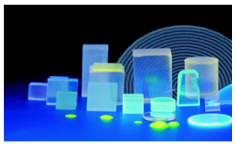
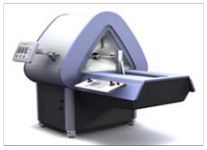
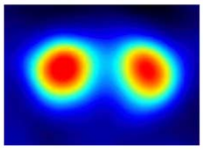
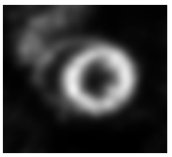
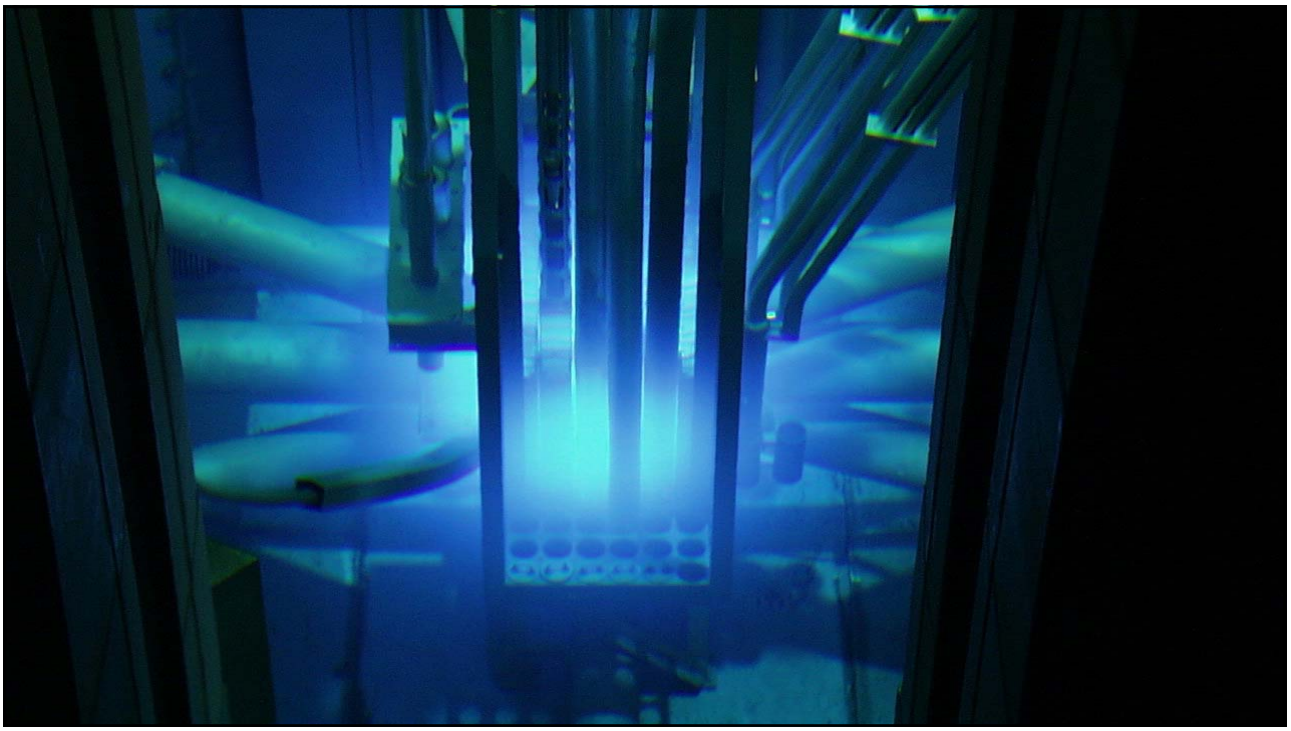








3




A> open
B> open
C> open
D> dicht

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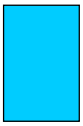
Electricity consumption in the Netherlands



energieinNederland.nl

Households 23 TWh/a

Total 106 TWh/a

(1 TWh = 1 billion kWh)

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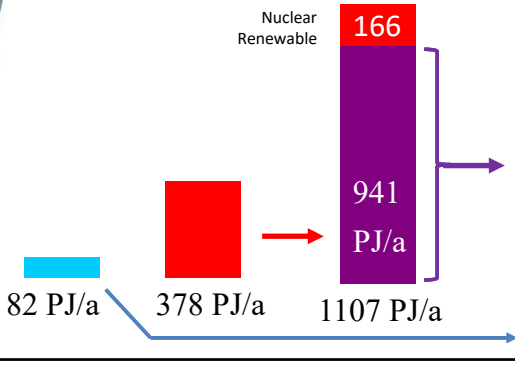
Energy consumption in the Netherlands

Fossil energy consumption 2928 PJ/a oil 39%, gas 40%, coal 14%



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World population and electricity use

Country	Population (million)	Electricity (kWh/cap)	CO2 emission (ton/cap)
World	7429	3110	4.35
OECD	1284	8048	9.02
China	1386	4290	6.57
Asia	2470	1040	1.61
Africa	1225	576	0.95

IEA, Key world energy statistics, 2018
data from 2016

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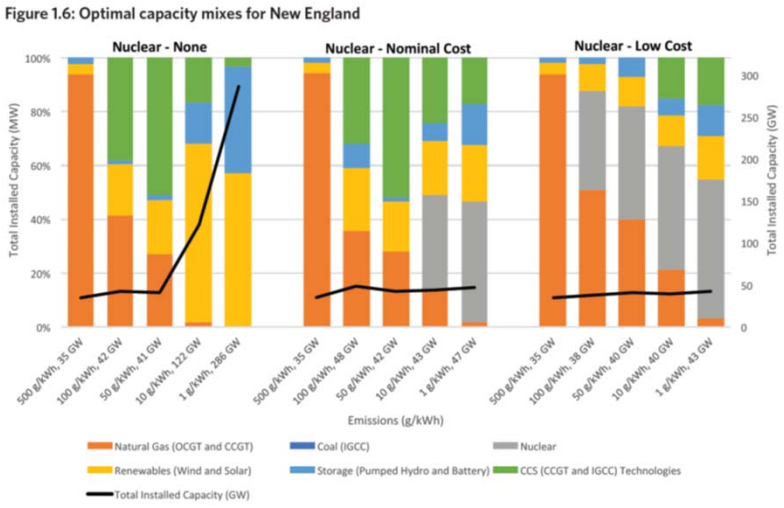
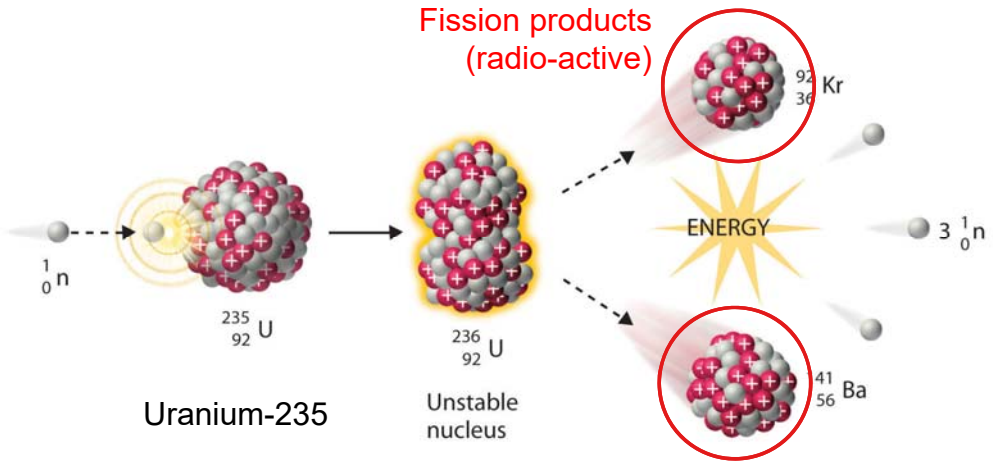
System mix electricity generation



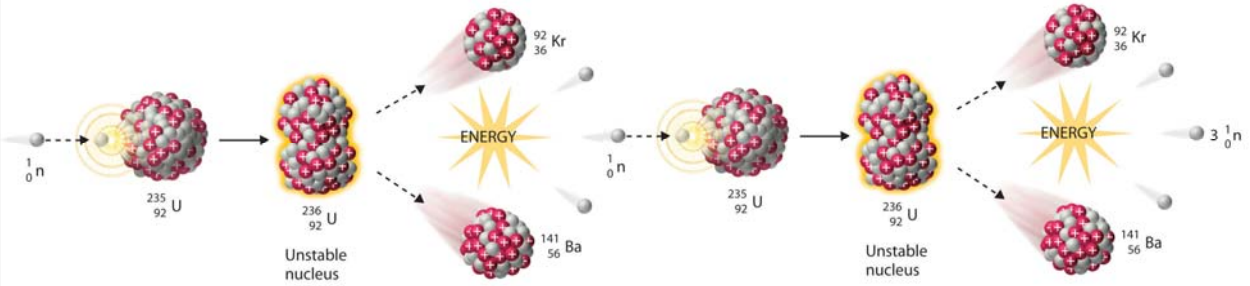
MIT, The Future of Nuclear Energy in a Carbon-Constrained World, 2018

Nuclear fission



Chemwiki, CCPL

Fission chain reaction



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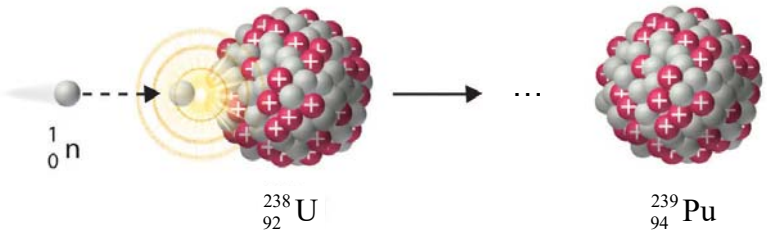
Chemwiki, CCPL

Production of plutonium



Uranium-238 Plutonium-239

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Energy from 1 gram U-235

Gasoline

2500 liter

Coal

3000 kg

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From neutrons to fission

James Chadwick

Discovery of neutron 1932

Otto Hahn and Fritz Strassman

Discovery of nuclear fission 1938

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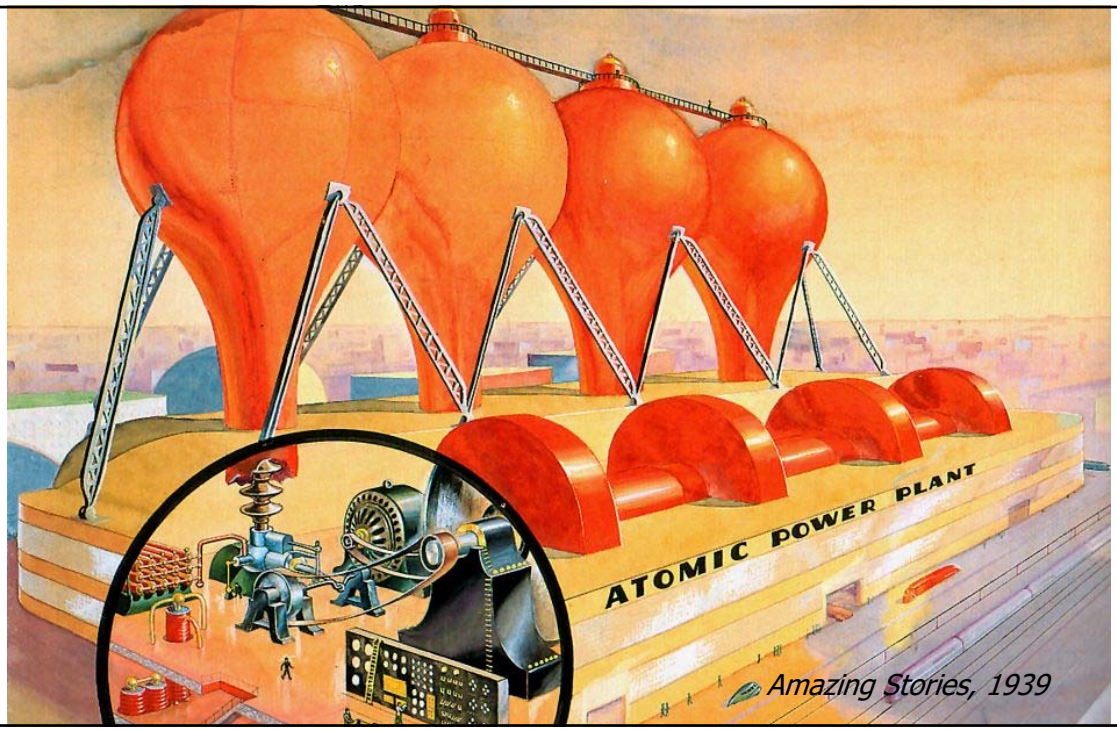
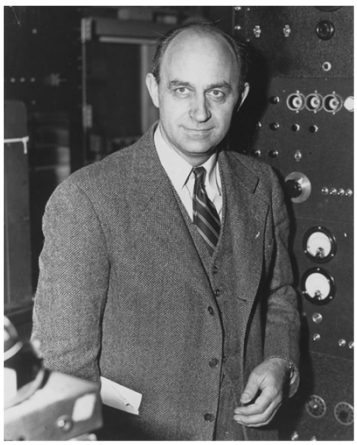


Amazing Stories, 1939

18

Enrico Fermi
1901-1954

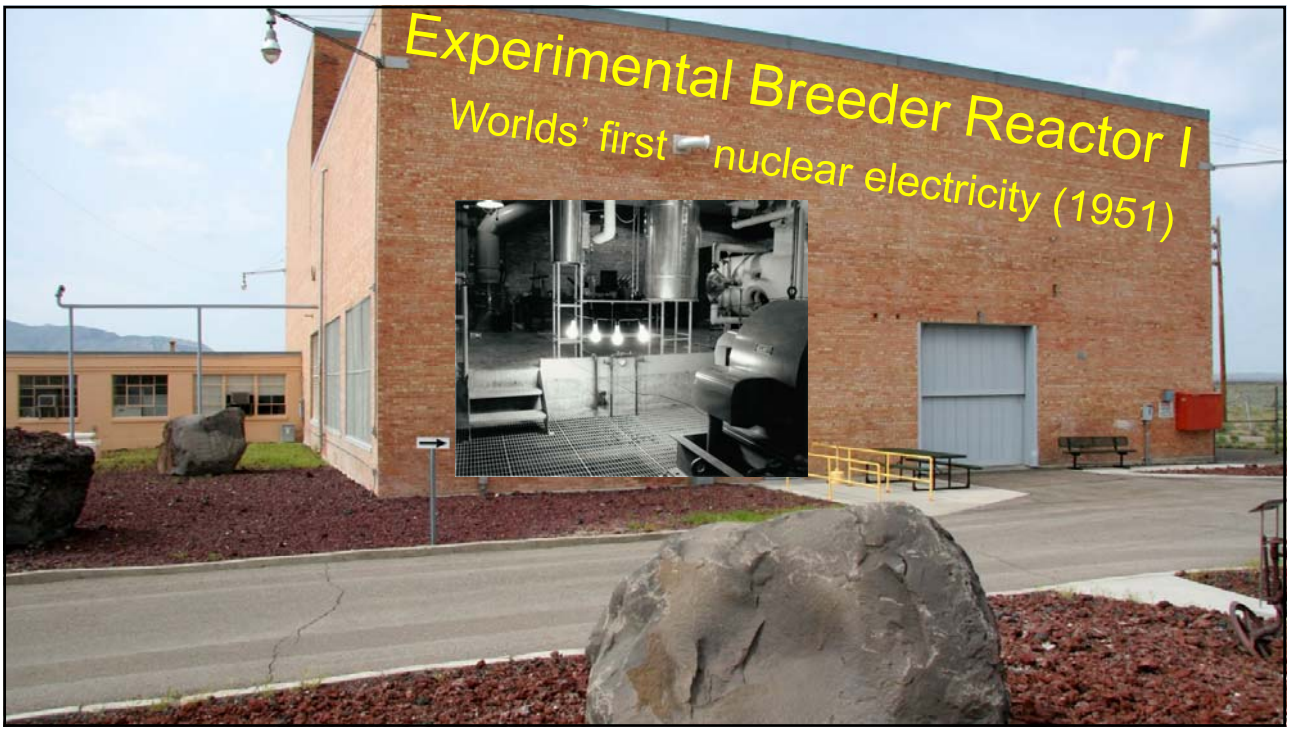


Chicago Pile 1
Worlds' first man-made nuclear fission reactor (1942)

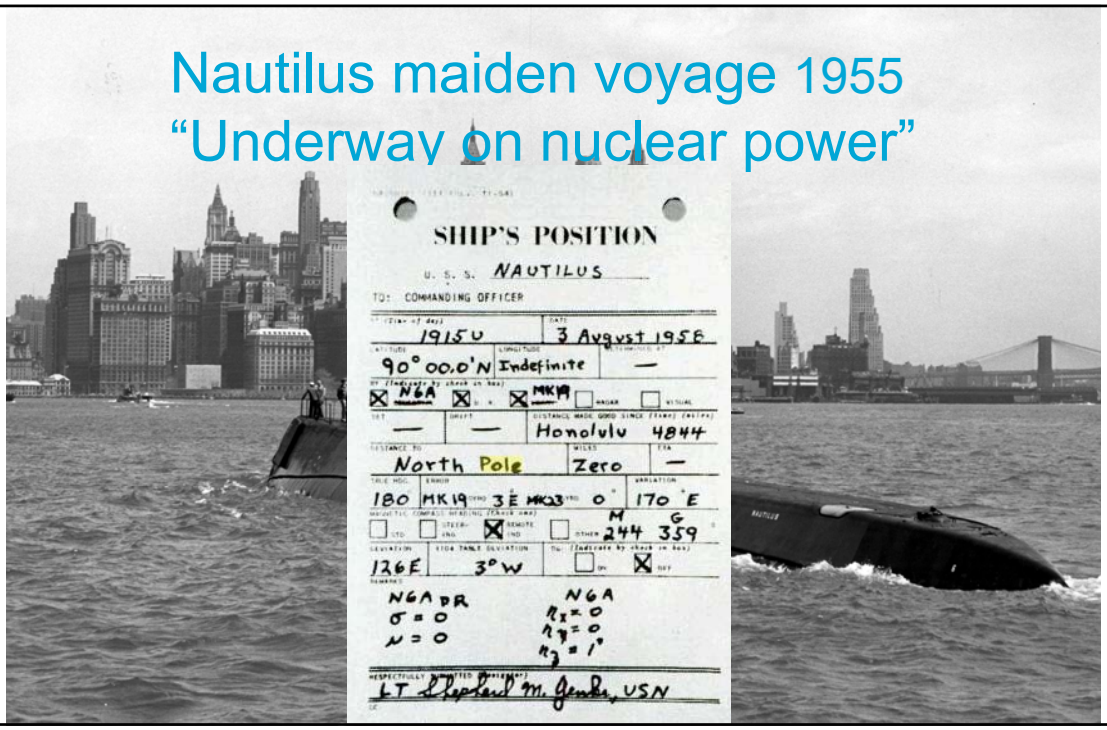
Painting Gary Sheehan

TU Delft

wikimedia commons, GNU 19



Nautilus maiden voyage 1955
"Underway on nuclear power"



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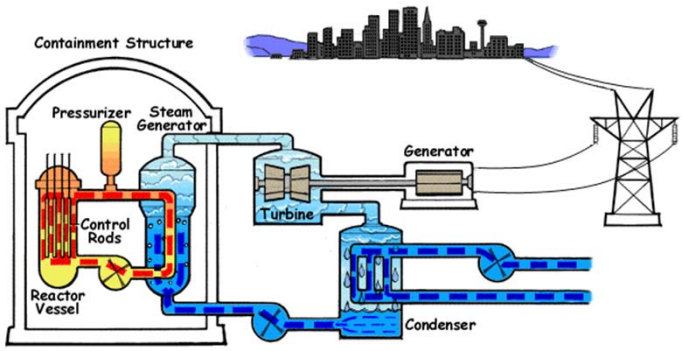
Pressurized Water Reactors



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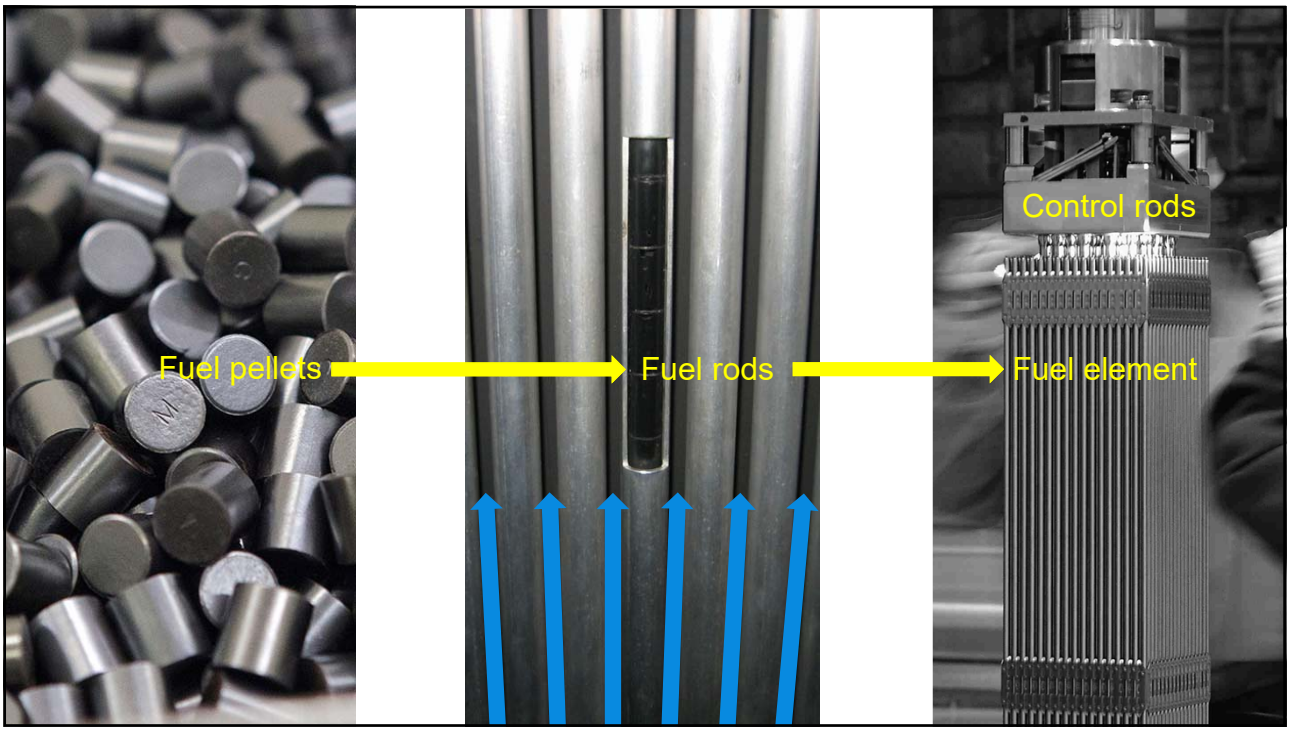
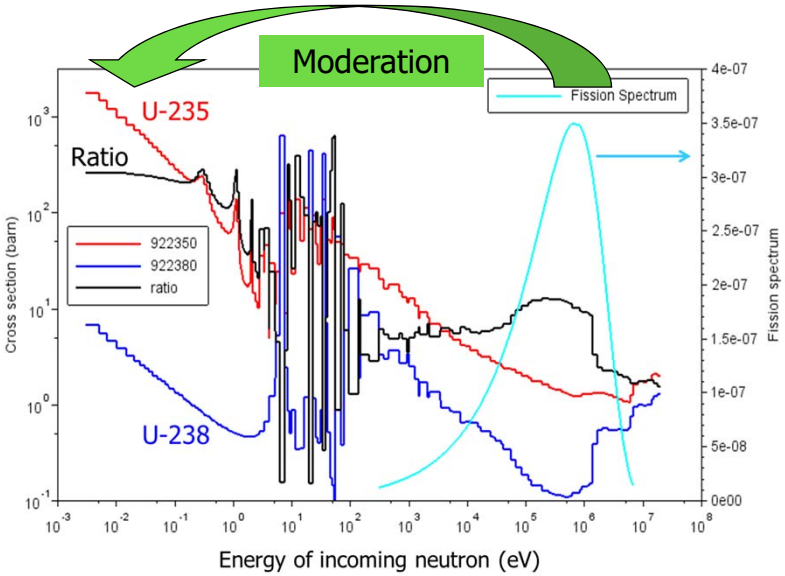


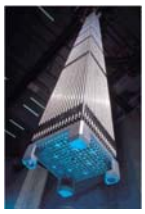
Moderation of neutrons



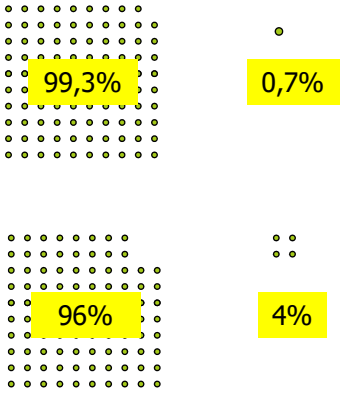
25

Fuel enrichment

Natural uranium



4% enriched uranium
in nuclear fuel



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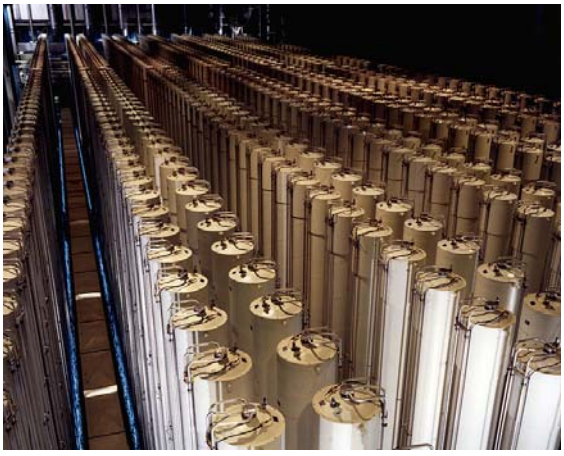
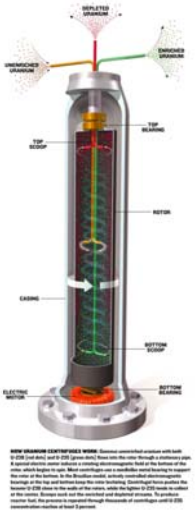
Ultra centrifuge technology





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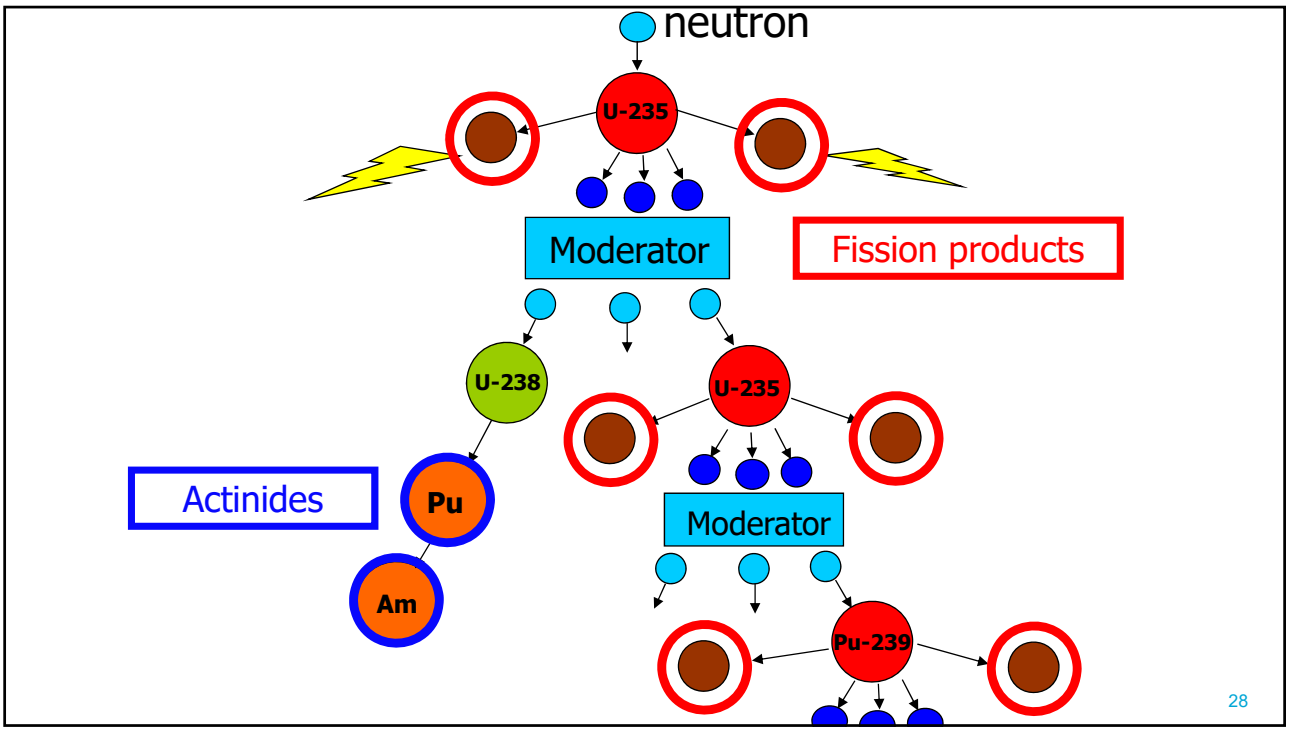
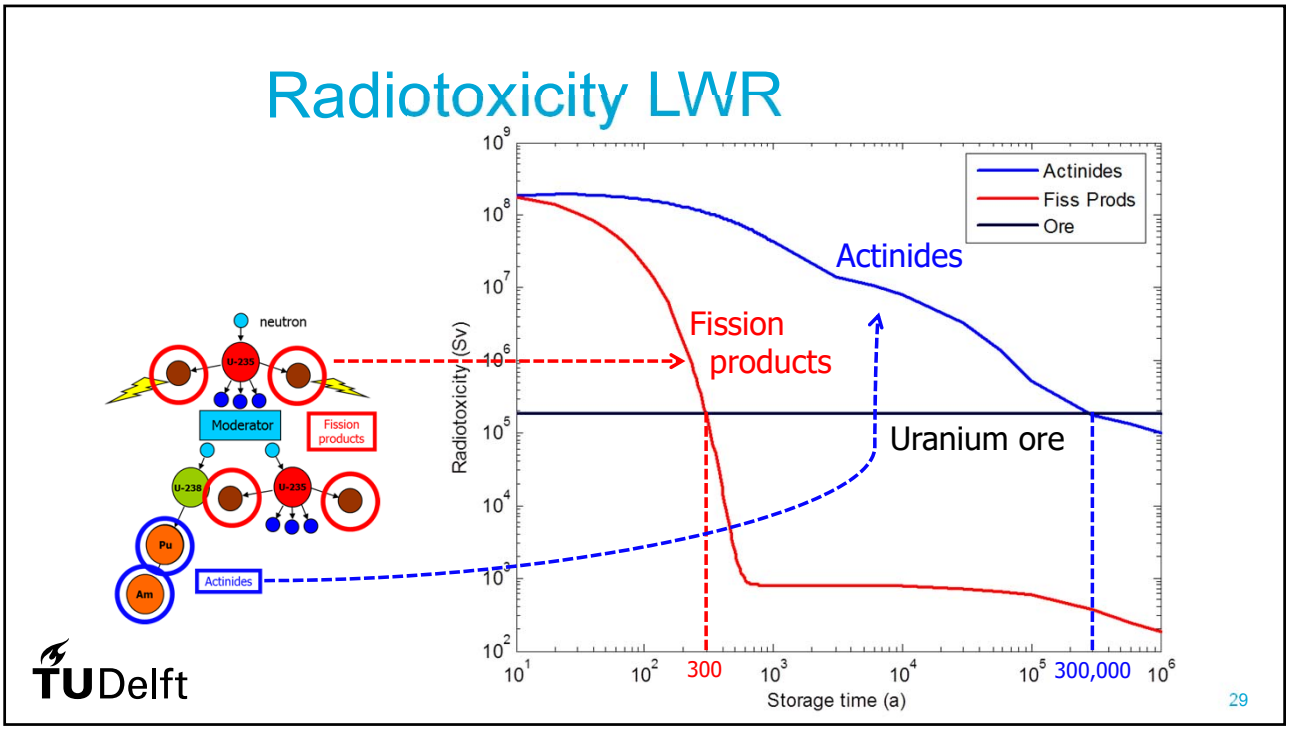

neutron
U-235
Moderator
Fission products
U-238
U-235
Actinides
Pu
Moderator
Am
Pu-239
28


Radiotoxicity LWR
neutron
U-235
Moderator
Fission products
U-238
U-235
Pu
Am
Actinides
Actinides
Fiss Prods
Ore
Actinides
Fission products
Uranium ore
Radiotoxicity (Sv)
300
300,000
Storage time (a)
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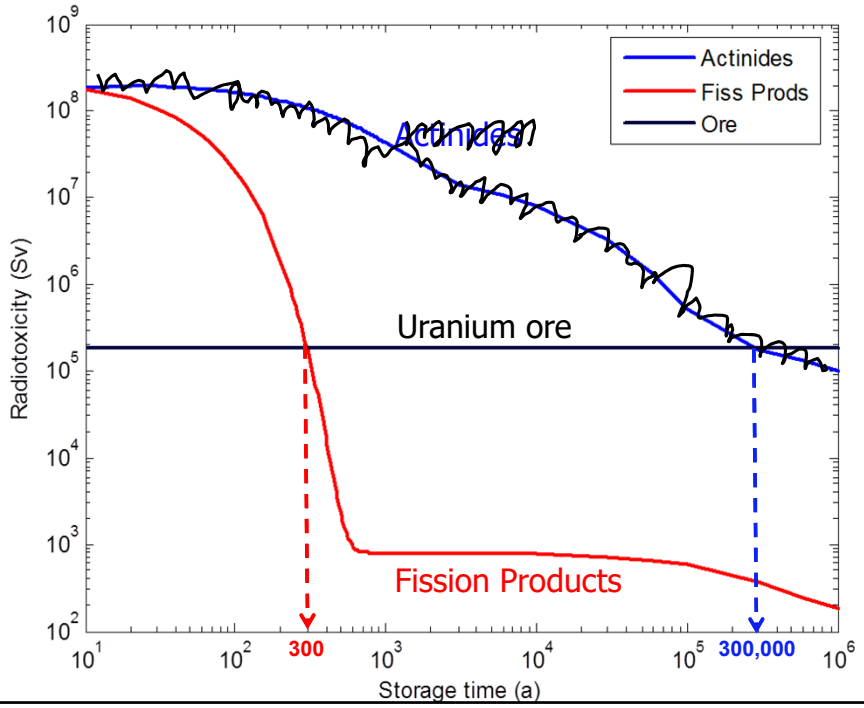
29



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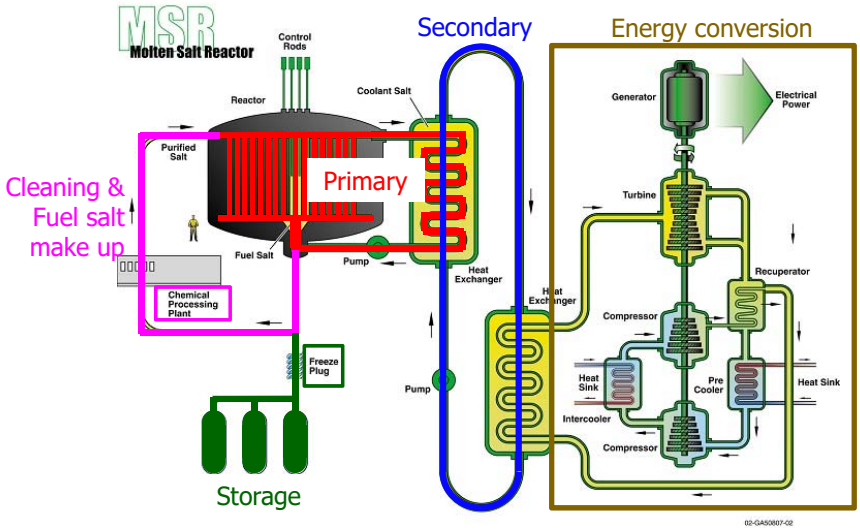
Molten Salt Reactor (MSR)



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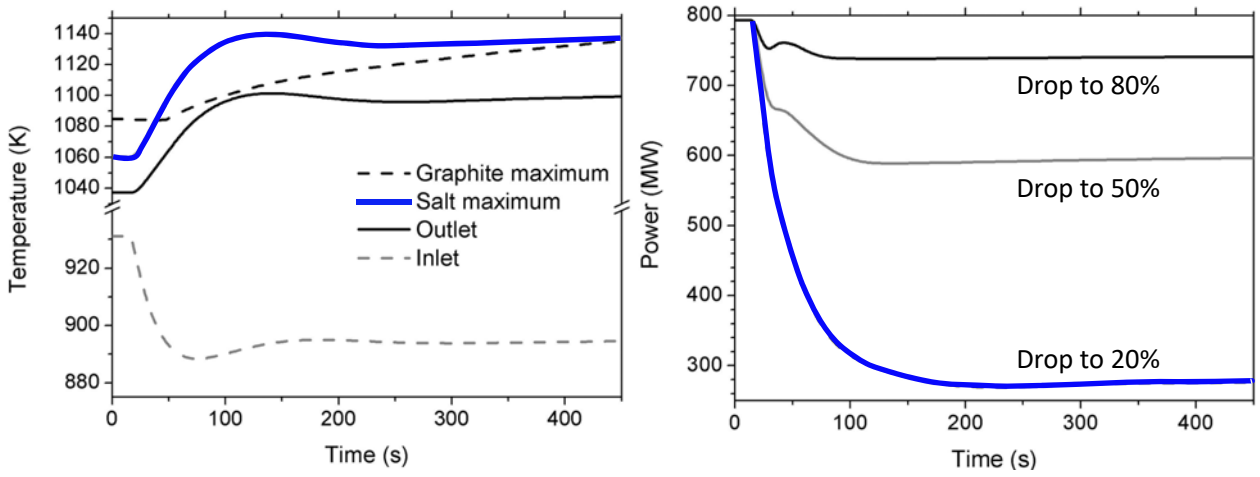
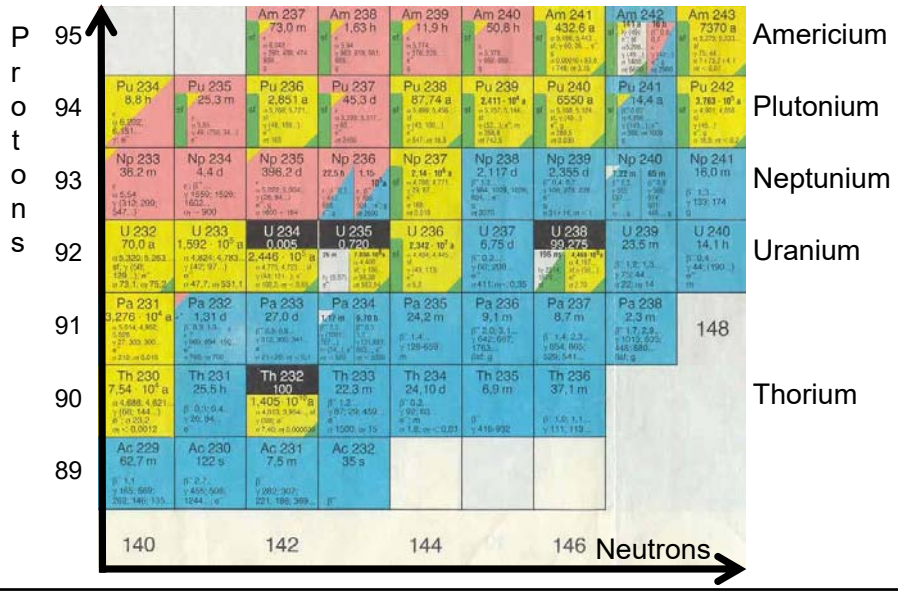
MSR Pump coast down

Pump coast-down to 20%





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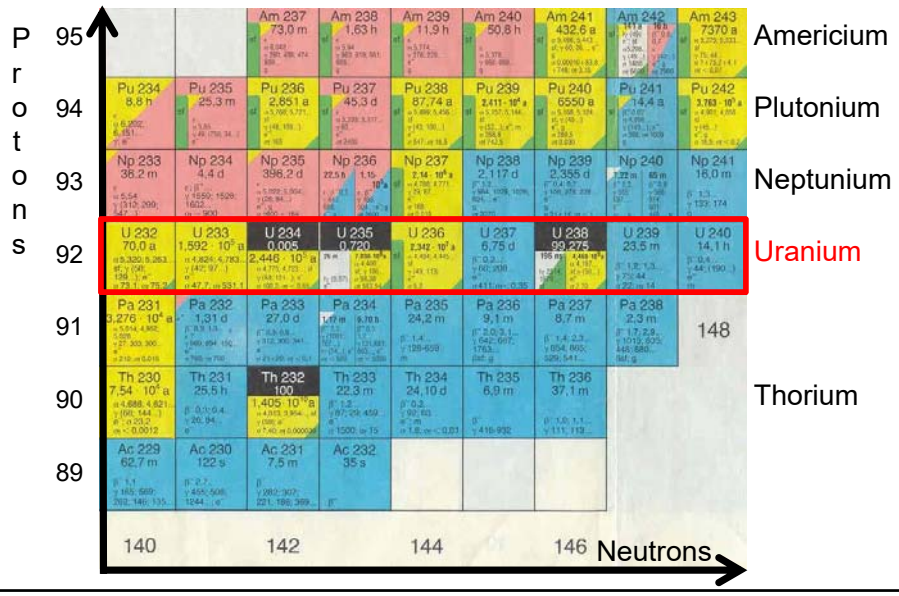

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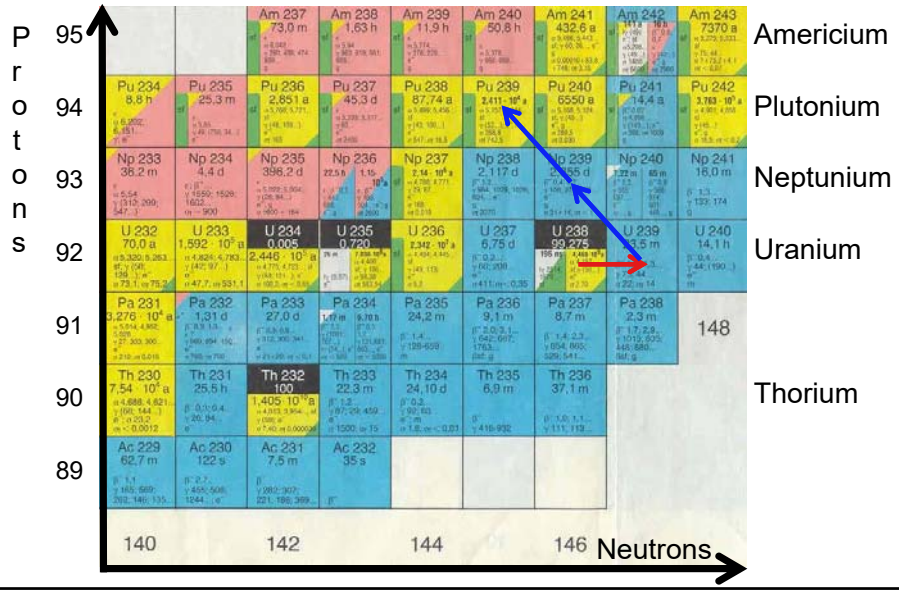
From uranium to plutonium



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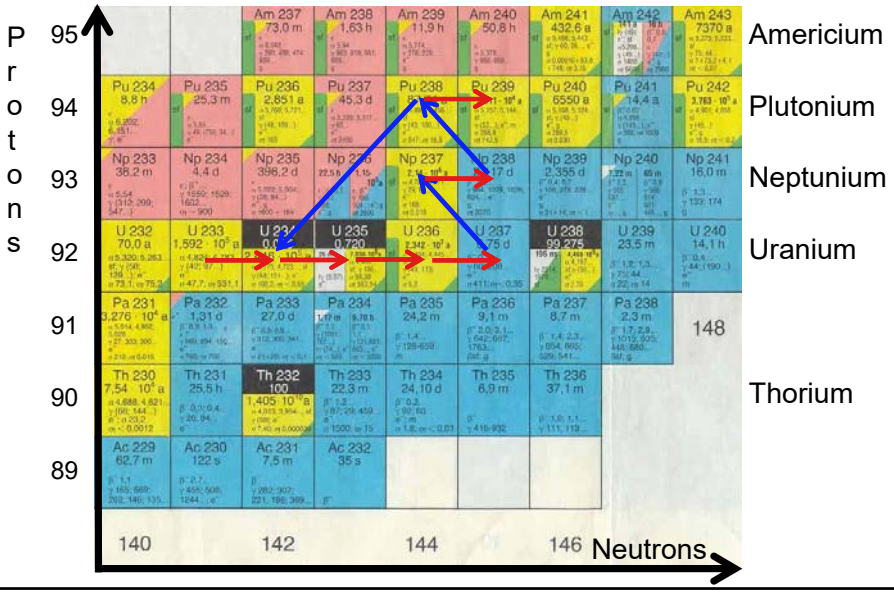
From thorium to uranium-233

37

From uranium-233 to plutonium



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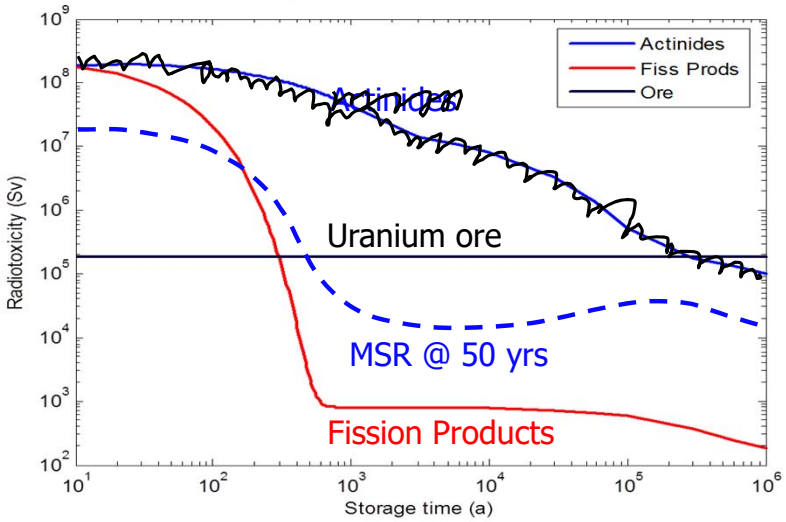
Radiotoxicity thorium-MSR



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Heat Transfer Reactor Experiments (1956)

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Alvin Weinberg
1915-2006

https://www.ornl.gov/content/alvin-m-weinberg-fellowship

Alvin's 3P reactor
1952

https://en.wikipedia.org/wiki/Aqueous_homogeneous_reactor

wikimedia commons, GNU

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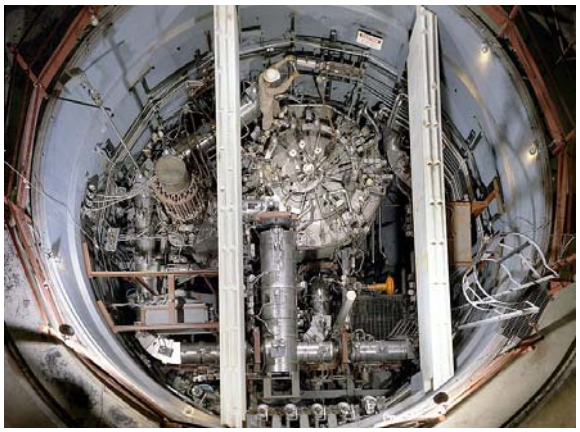
Molten Salt Reactor Experiment
1965-1969



https://en.wikipedia.org/wiki/Molten-Salt_Reactor_Experiment

See movie: http://energyfromthorium.com/2016/10/16/ornl-msre-film/

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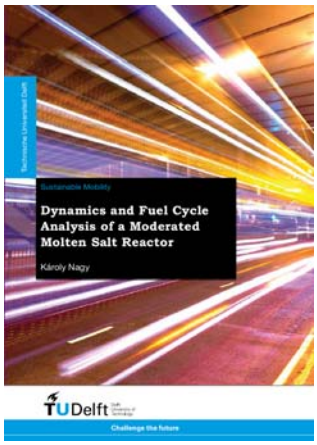
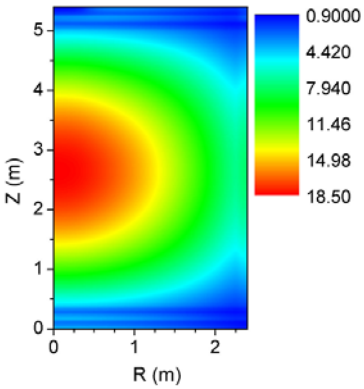
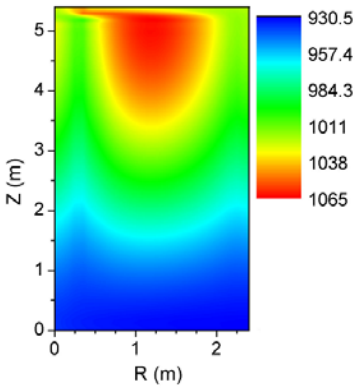
TUD Molten Salt Breeder Reactor





Power density [MW/m^3]



Salt temperature [K]

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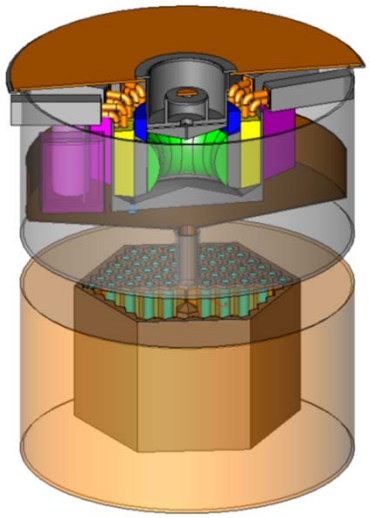
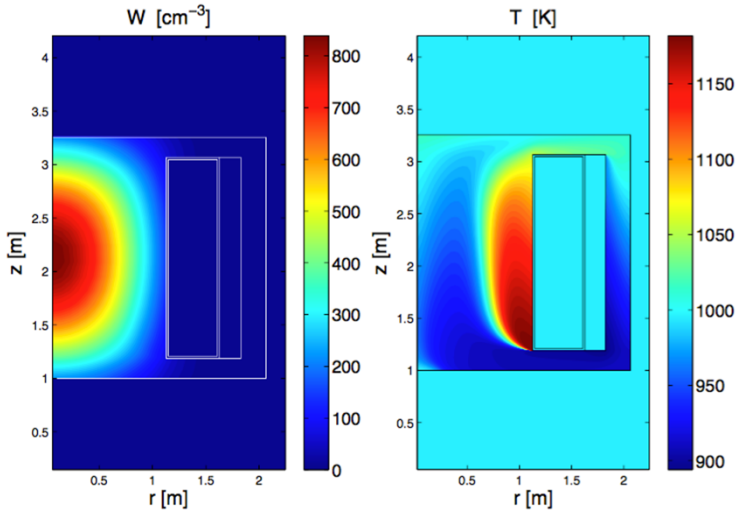
European SAMOFAR project

Safety analysis of the Molten Salt Fast Reactor

cnrs TUDelft EDF Cinvestav Unidad Saltillo cea SAMOFAR IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE KIT Karlsruher Institut für Technologie PAUL SCHERRER INSTITUT PSI European Commission AREVA

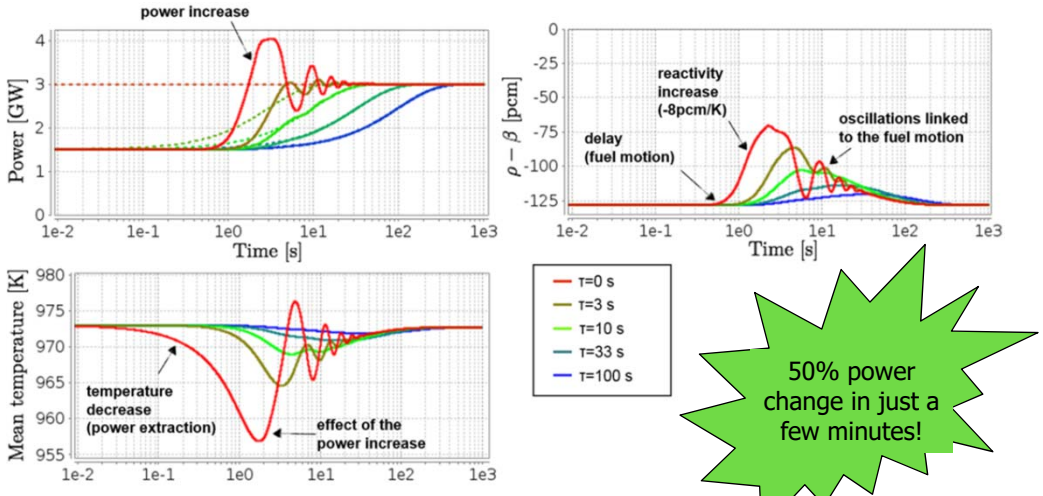
Molten Salt Fast Reactor





45

MSFR Load follow operation



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Elsa Merle-Lucotte *et al*, CNRS, France

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Thorium by-product mining

Summary of Cumulative By-Product Thorium Availability from Multiple Sources

Primary Commodity	Potential Associated Thorium Yield (tonnes/yr Th)
Titanium	79 800
Uranium	9000
REEs ("Direct")	780
Tin	760
Iron	330
Total	90 700

40 years of global electricity production!

Ault *et al.,* Nuclear Technology, **189**:152-162, 2015

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Abundancy of thorium

On some beaches the energy contents of one kilogram of sand corresponds to thousands of litres of gasoline

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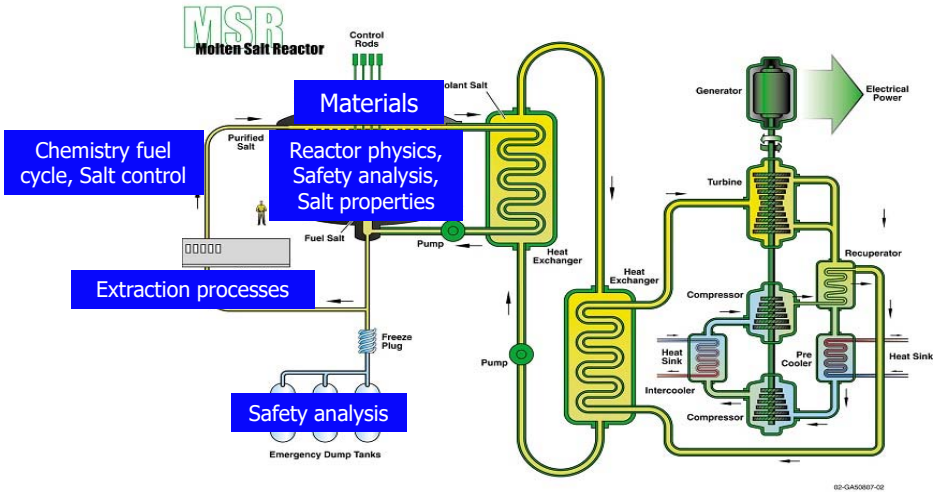
MSR research themes



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Conclusions

- Thorium-MSR power plant:
  - Is safe and sustainable
  - Produces much less long-lived nuclear waste
  - Consumes thorium or existing nuclear waste
- Research areas:
  - Fuel salt (properties, chemistry, extraction, (re)processing)
  - Structural materials (radiation, temperature, corrosion)
  - Numerical simulation (design, safety analysis, licensing)
  - Experimental validation (freeze plugs, salt flow, freezing, components testing, …)

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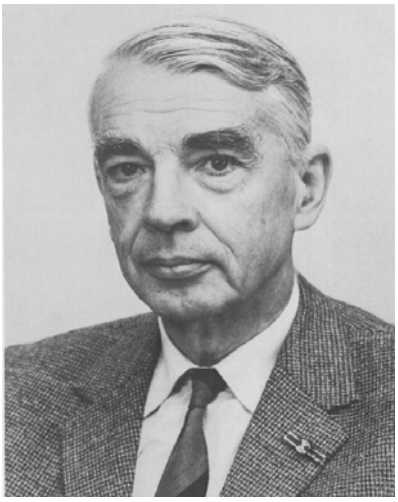
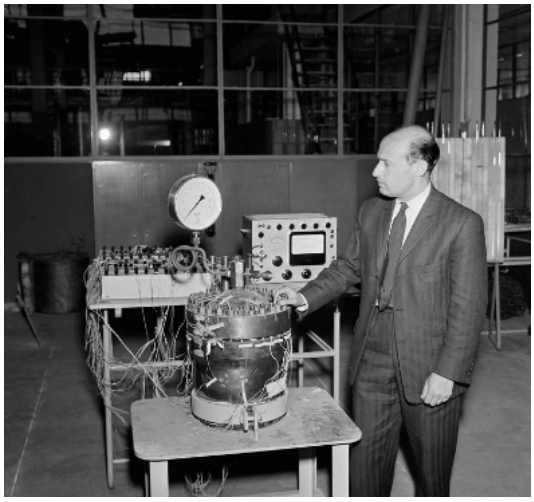
Historical research at TU Delft



Prof J.J. Went
(1907-1986)



Prof D.G.H. Latzko
(1924-)

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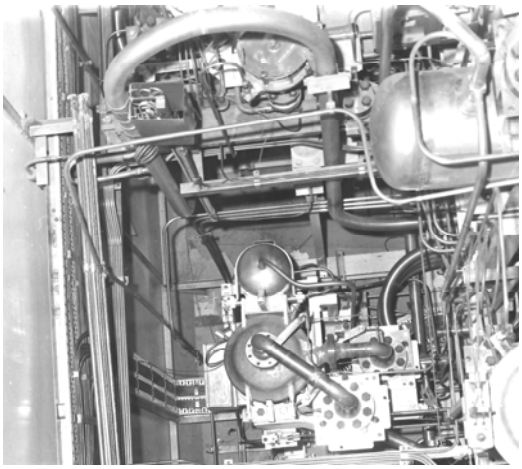
KEMA Suspension Test Reactor 1974-1977



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