

Innovation in Nuclear Energy



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Delft University of Technology

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TU Delft Reactor Institute

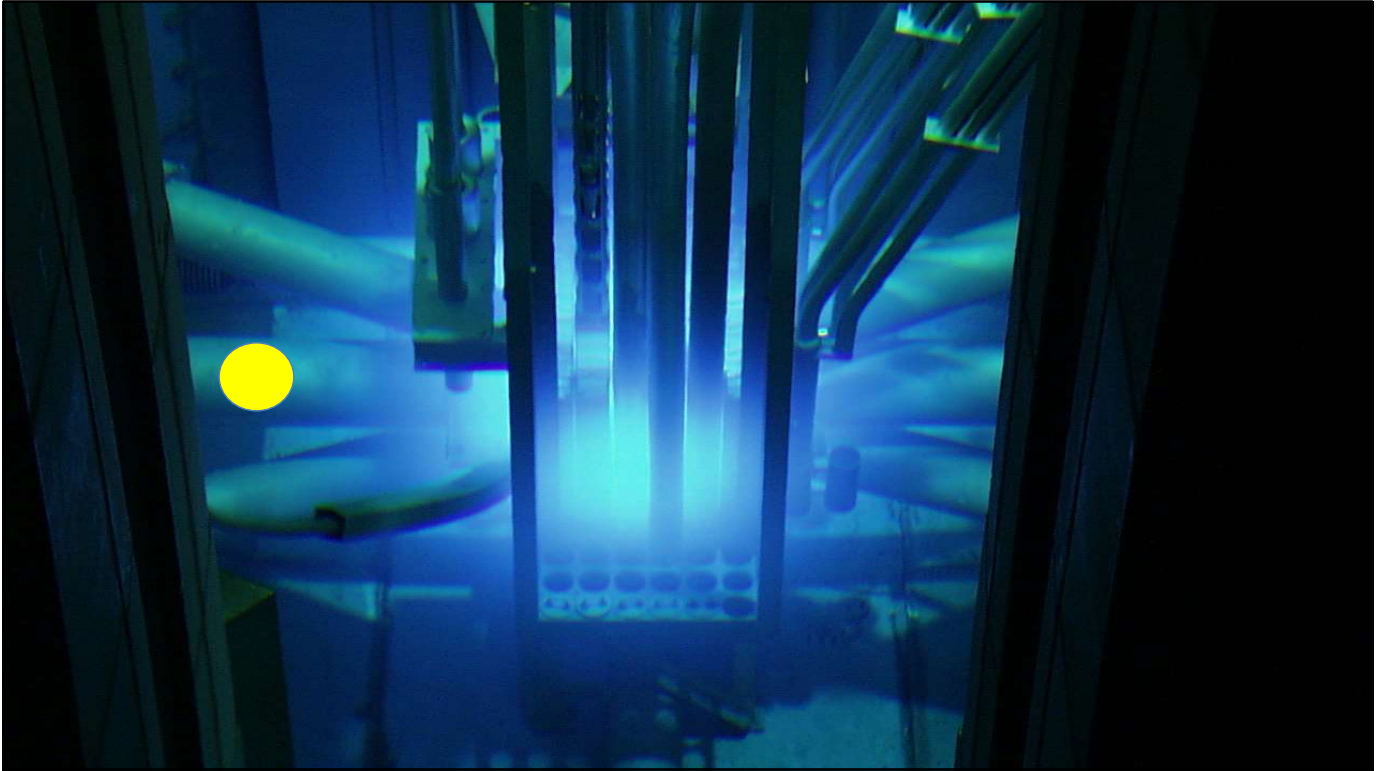
The TU Delft Reactor Institute is the Dutch Center of Excellence for Research using ionizing radiation, and for Education on radiation and its uses.

Het TU Delft Reactor Instituut is het Nederlands Kenniscentrum voor Onderzoek met ioniserende straling en voor Onderwijs over straling en het gebruik ervan.



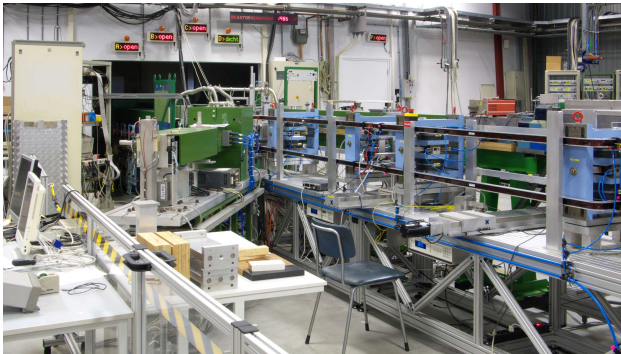
2

2



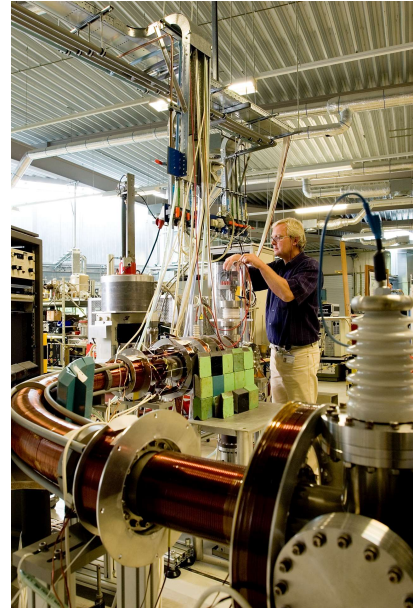
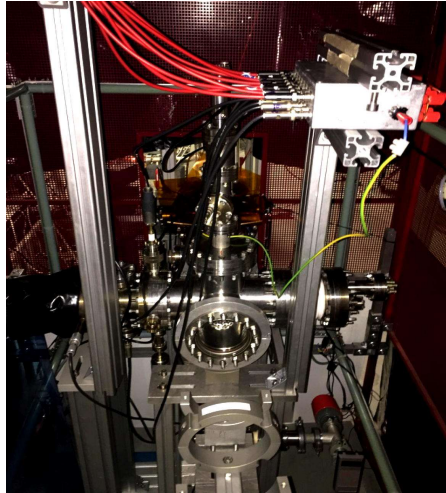
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Neutrons



4

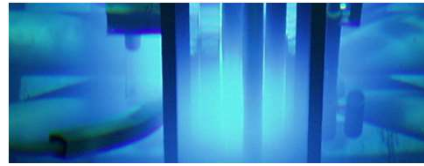
Positrons



Protons



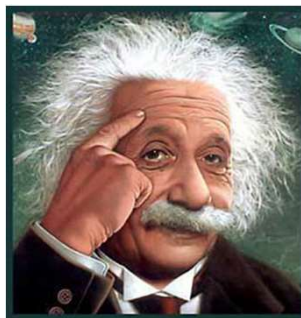
Activation of samples Production of radionuclides



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Nuclear fission

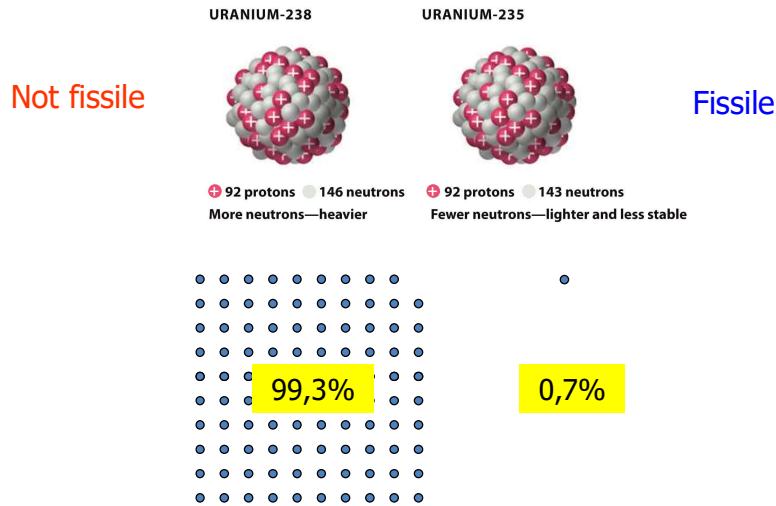


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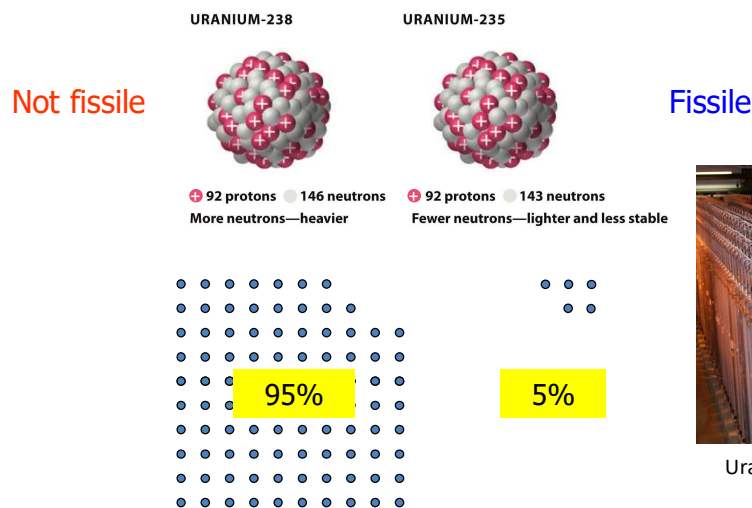
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Uranium isotopes



Infographic 23.1 part 2
Environmental Science for a Changing World
 © 2013 W. H. Freeman and Company

Uranium enrichment

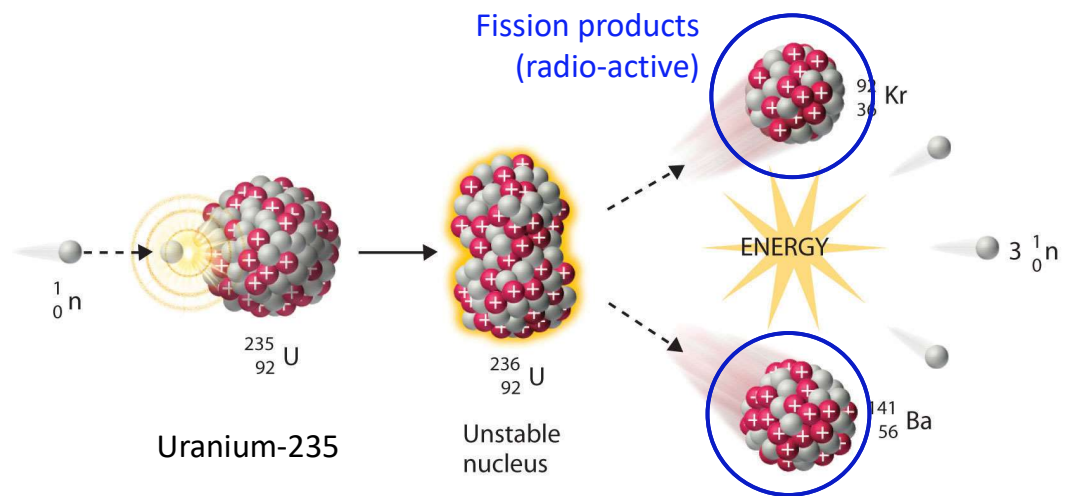


Uranium enrichment centrifuges (URENCO)



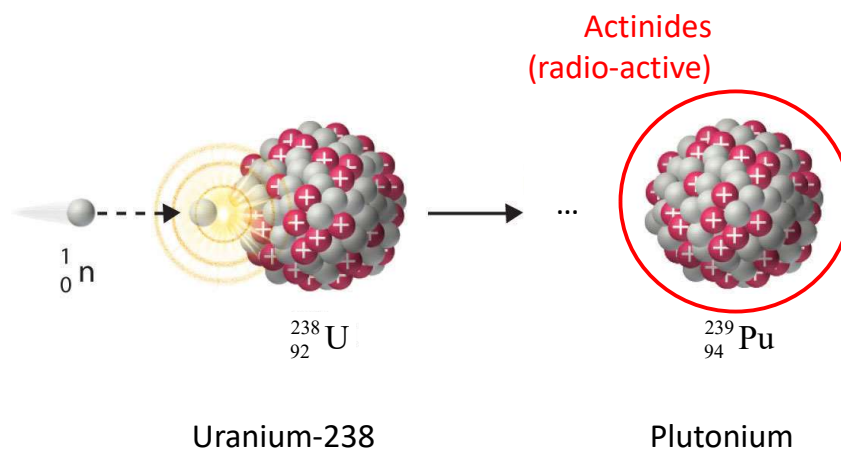
Infographic 23.1 part 2
Environmental Science for a Changing World
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Nuclear fission



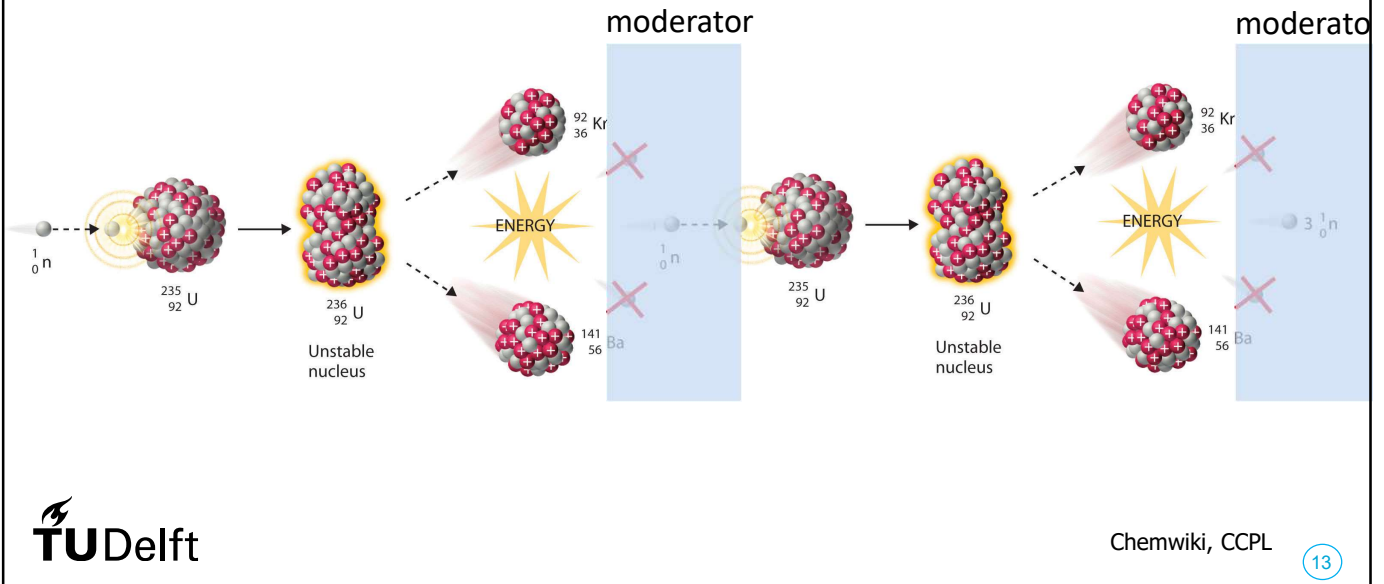
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Production of plutonium

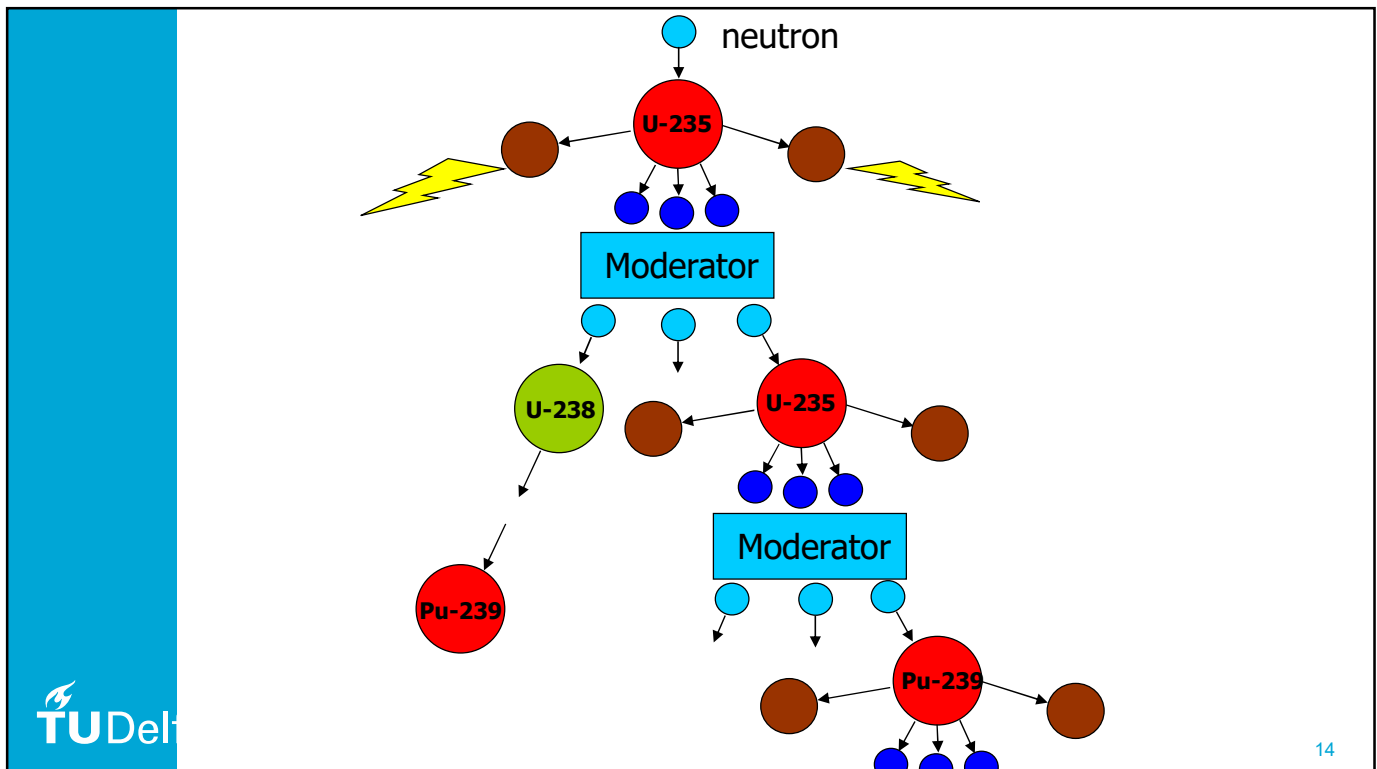


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Fission chain reaction



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Energy from 1 gram U-235

Gasoline



2500 liter

Coal

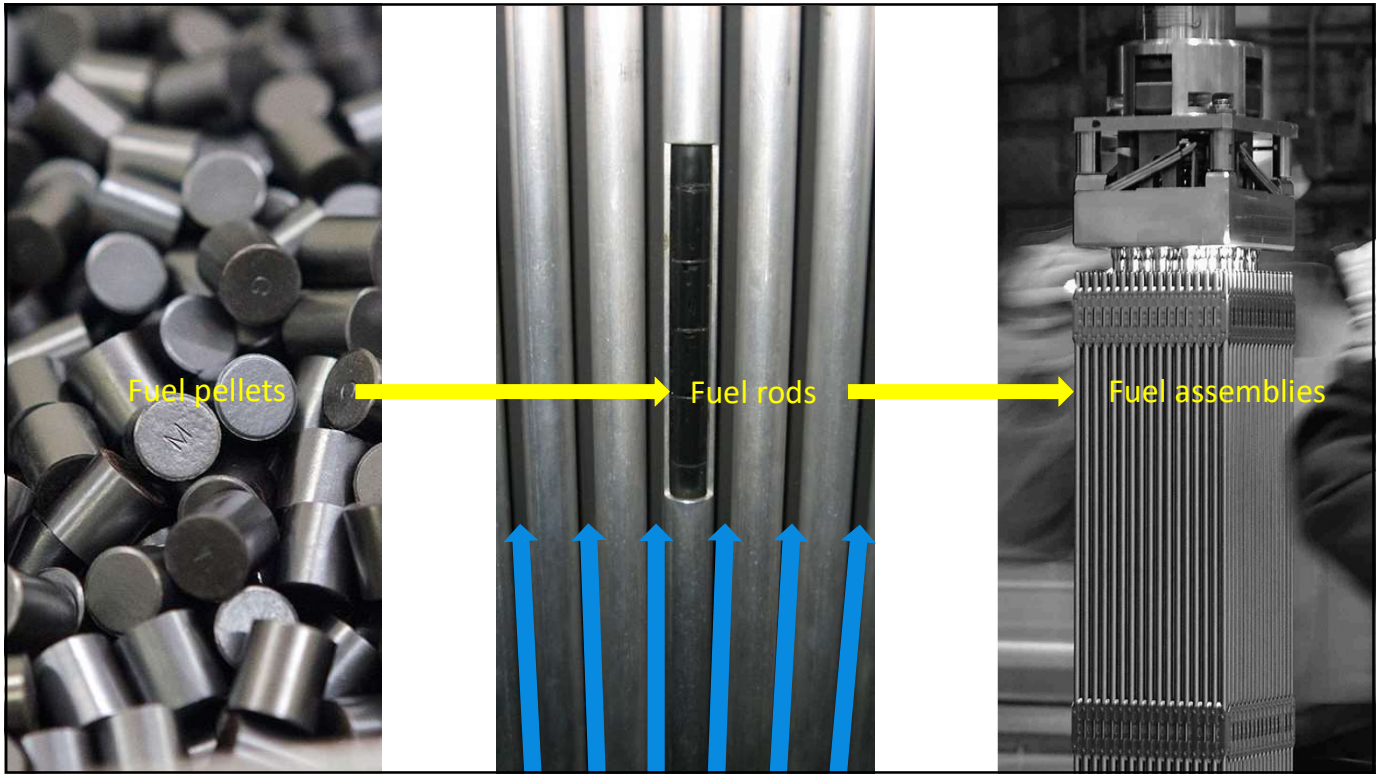


3000 kg

Nuclear power plants

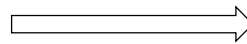
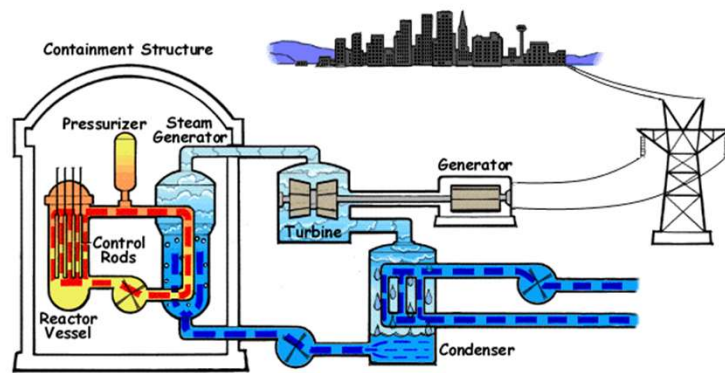


October 1939 issue of Amazing Stories
<https://www.pinterest.com/pin/540502392754920870/>



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Pressurized Water Reactor (PWR) Drukwaterreactoren



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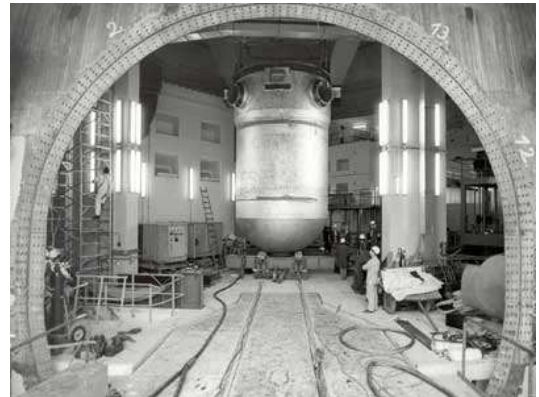
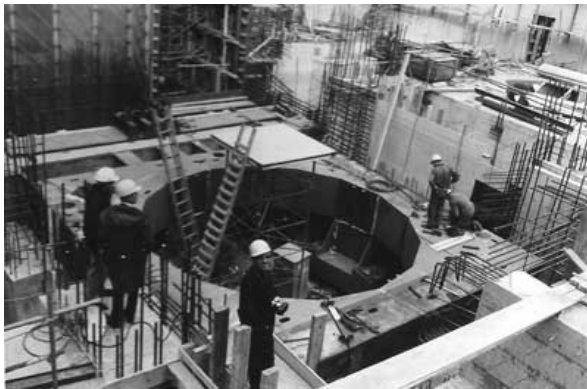
Kerncentrale Borssele



121 fuel assemblies, 38 tonnes of fuel

19

Kerncentrale Borssele

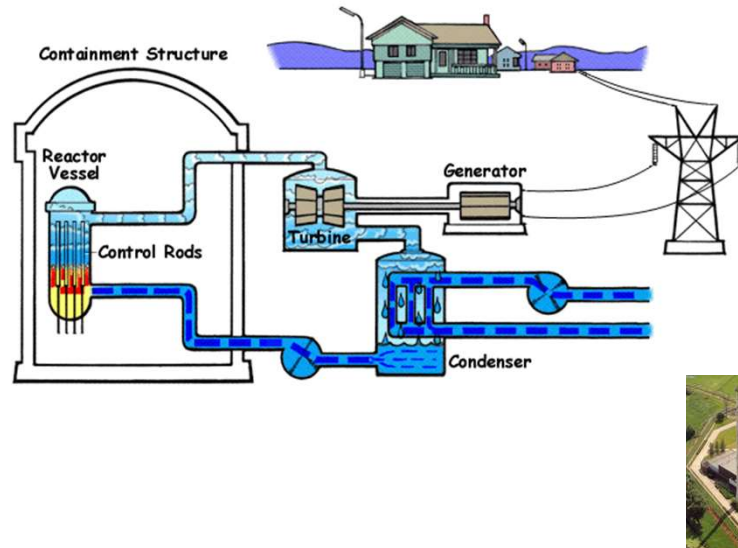


<http://www.euronuclear.org/e-news/e-news-22/Borssele%20.htm>

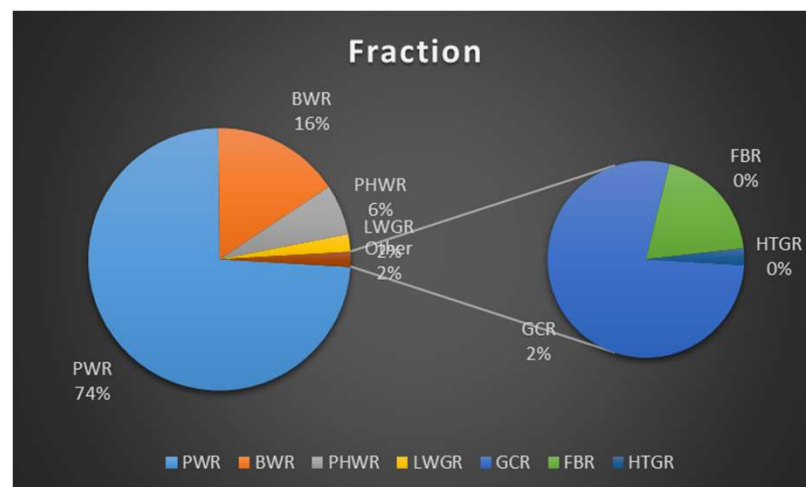
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Boiling Water Reactor (BWR)

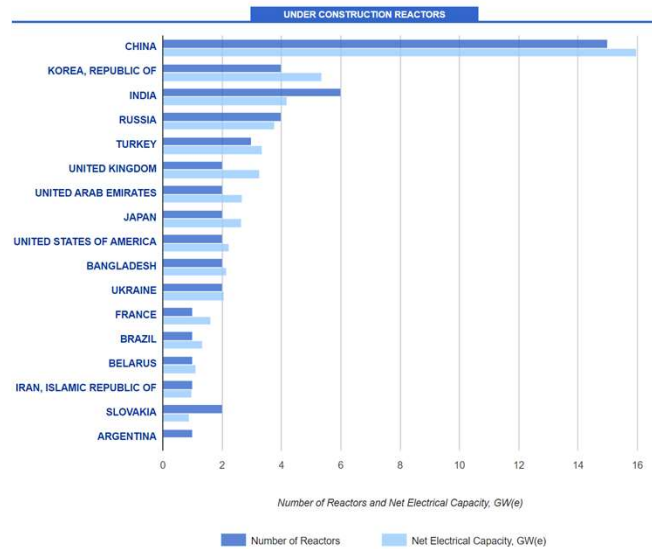
Kokendwaterreactoren



Fraction of reactor types



Reactors under construction (2022)



Origin	number
Russia	18
China	16
Korea	6
EU/France	3
US/Japan	2
Total	51

WANO (15-3-2022)

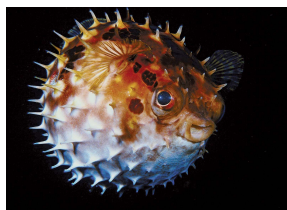
<https://pris.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx> consulted 15-3-2022

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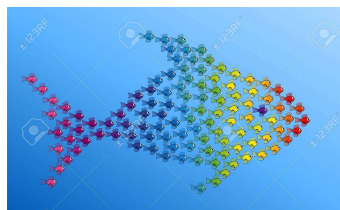
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Developments in Nuclear Energy

LWR



SMR



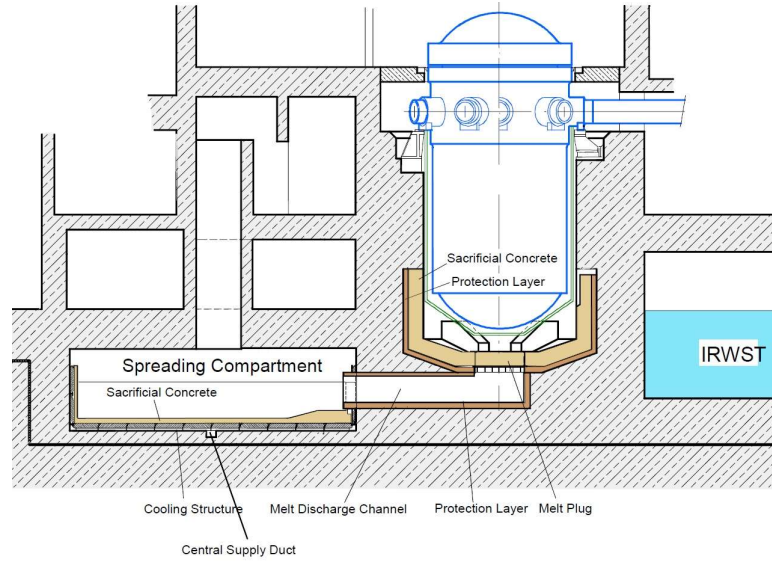
MSR



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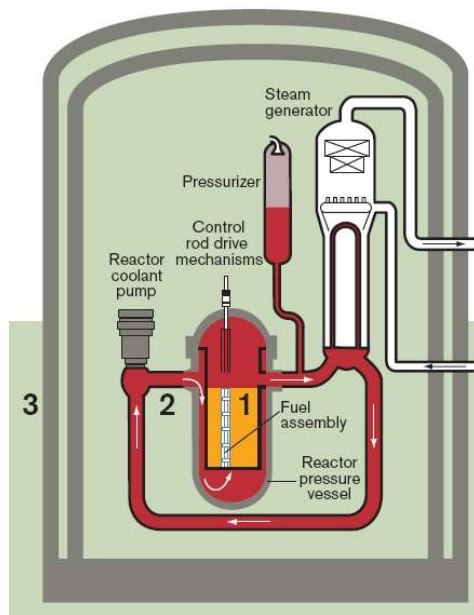
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Core catcher EPR



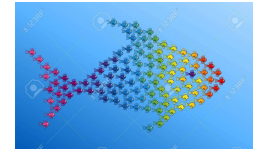
Safety of nuclear power plants

multiple barriers to keep radioactive nuclides inside



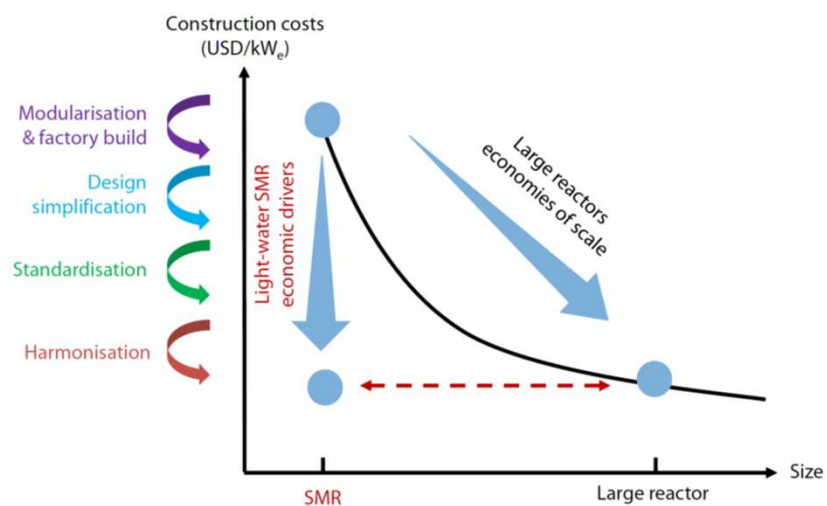
- 1 Fuel (pellet and cladding)
- 2 Primary system (steel)
- 3 Containments (2x concrete + steel)

Small Modular Reactors Kleine modulaire reactoren

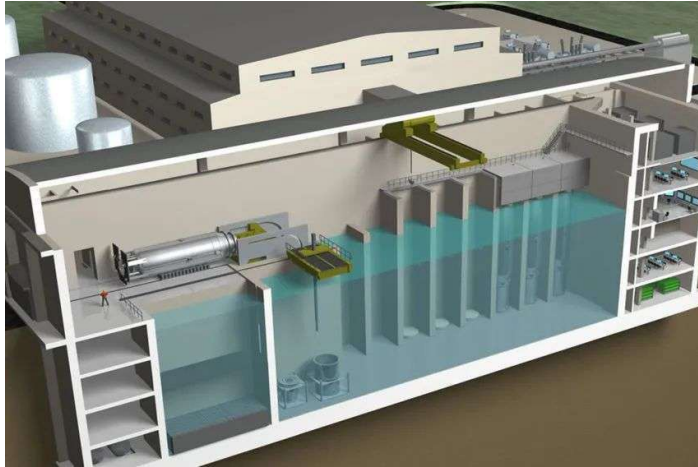


- Light Water Reactors (LWR)
- High Temperature Gas-cooled Reactors (HTGR)
- Liquid Metal-cooled Reactors (LMR)
- Molten Salt Reactors (MSR)

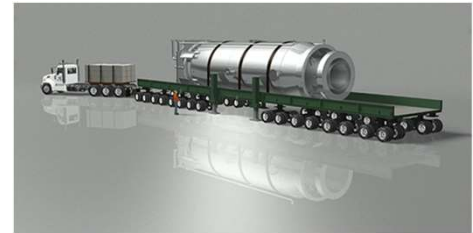
Cost reduction SMR



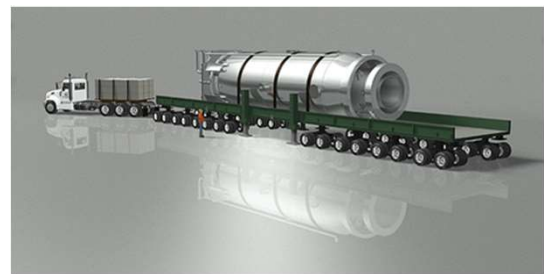
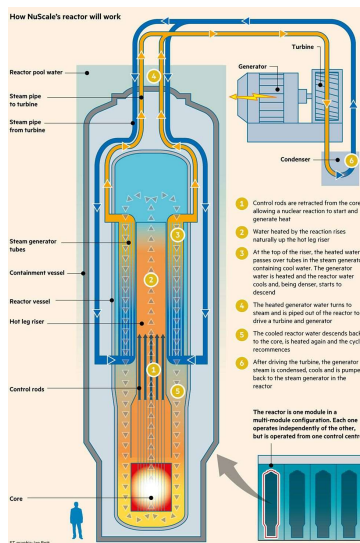
NuScale SMR VOYGR



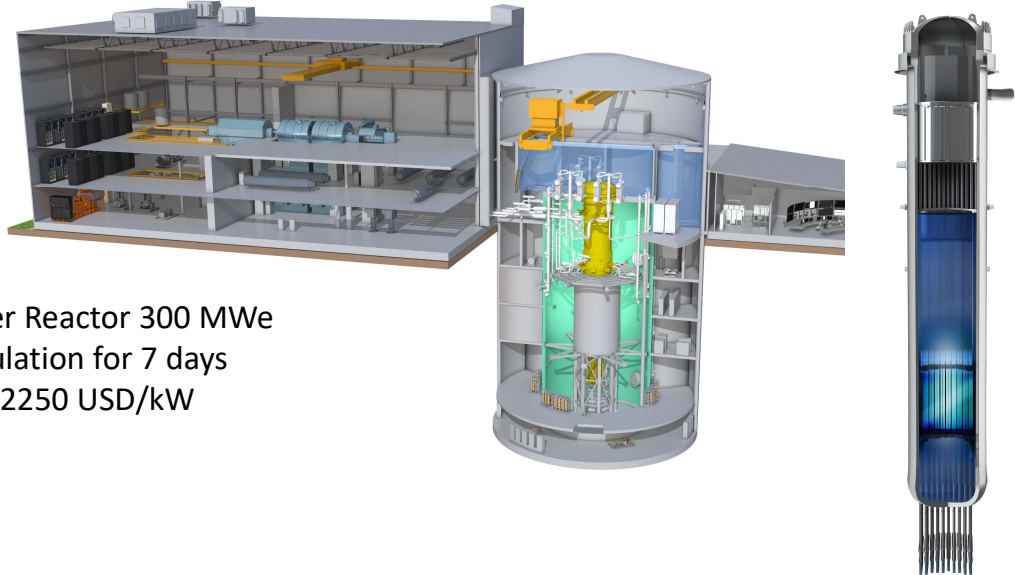
77 MWe per module
 1 module per 200.000 house holds
 4, 6 or 12 modules together
 Cost reduction 50% (claimed)
 Operational 2030



NuScale SMR VOYGR



General Electric BWRX-300 SMR

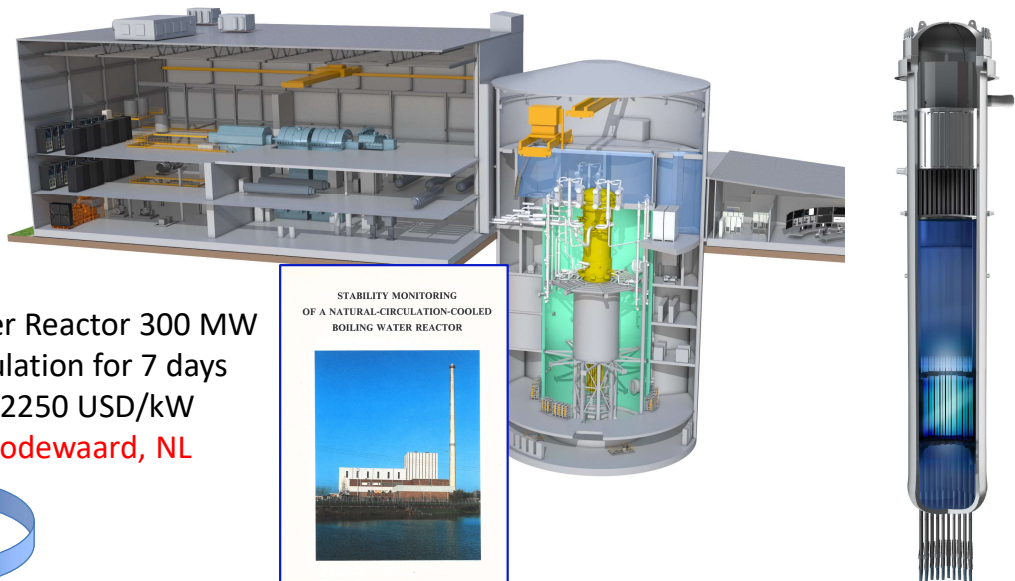


Boiling Water Reactor 300 MWe
 Natural circulation for 7 days
 Target price 2250 USD/kW
 Proven at:
 By:

 TU Delft

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General Electric BWRX-300 SMR



Boiling Water Reactor 300 MW
 Natural circulation for 7 days
 Target price 2250 USD/kW
 Proven at: **Dodewaard, NL**
 By:

 TU Delft



STABILITY MONITORING
 OF A NATURAL-CIRCULATION-COOLED
 BOILING WATER REACTOR



T.H.J.J. VAN DER HAGEN

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High Temperature Gas-cooled Reactor



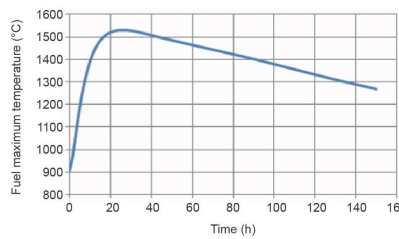
HTR-10 Beijing
First criticality Dec 2000



TU Delft



HTR-PM 2x250 MWt
Power 210 MWe
First criticality
Sep 2021

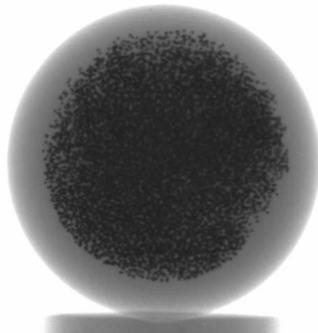


Temperatuur bij verlies aan koeling in HTR-PM

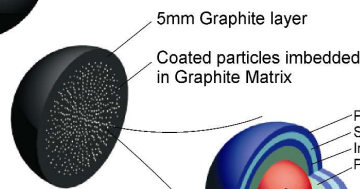
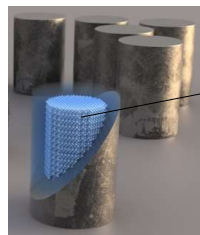


<https://world-nuclear-news.org/Articles/Chinas-HTR-PM-reactor-achieves-first-criticality>

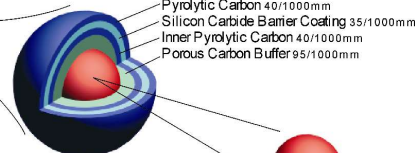
HTGR fuel



Dia. 60mm
Fuel Sphere



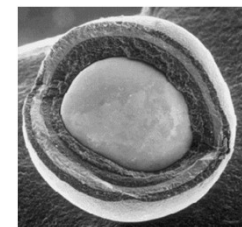
Section



Dia. 0,92mm
TRISO Coated Particle



Dia. 0,5mm
Uranium Dioxide
Fuel Kernel



- Pyrolytic Carbon 40/1000mm
- Silicon Carbide Barrier Coating 35/1000mm
- Inner Pyrolytic Carbon 40/1000mm
- Porous Carbon Buffer 95/1000mm

THORIUM

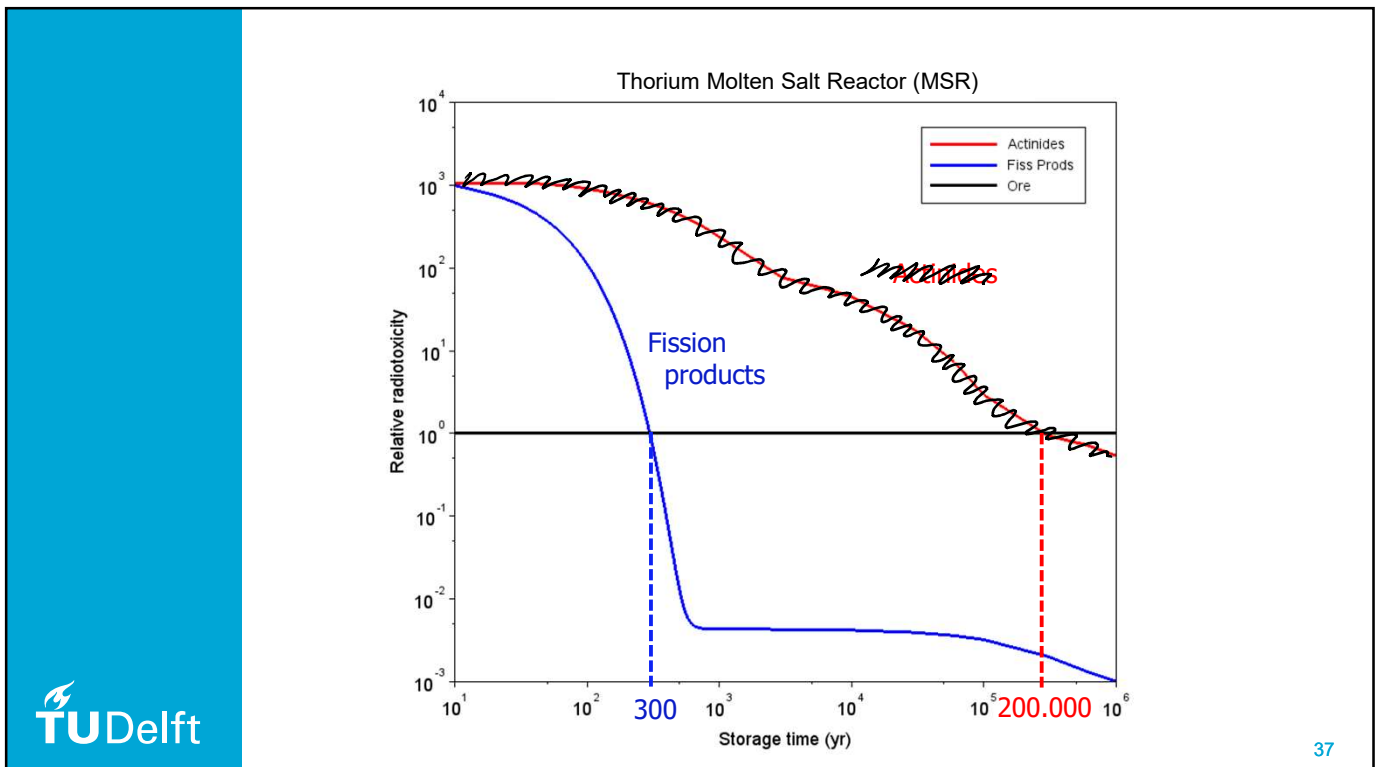
THE SMART ROCK.

PopAtomic.org

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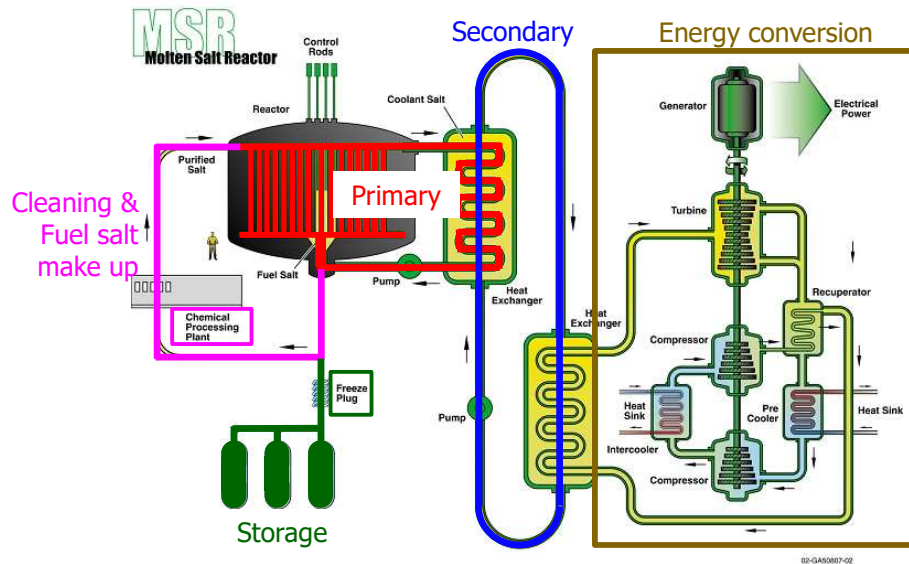
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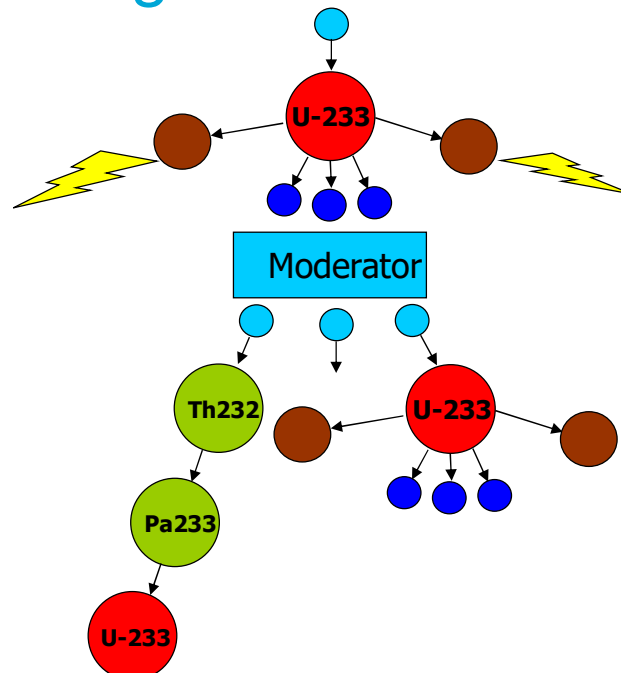


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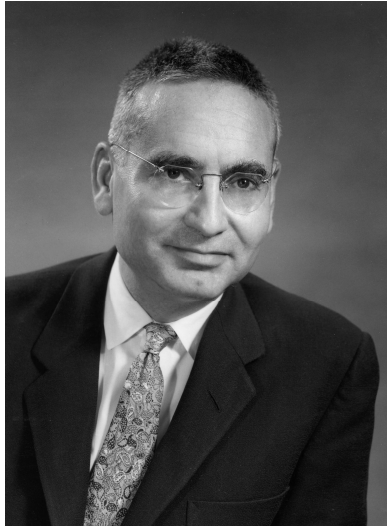
Molten Salt Reactor (MSR)



Breeding with thorium



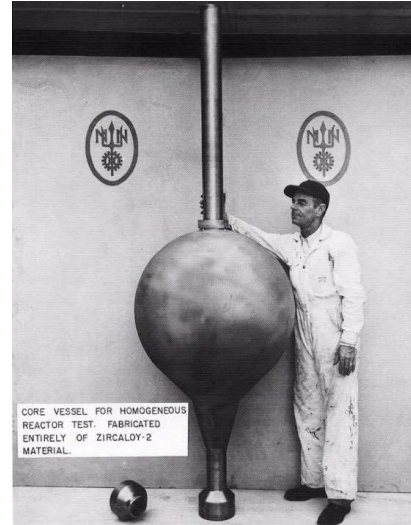
Alvin Weinberg 1915-2006



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

Alvin's 3P reactor 1952

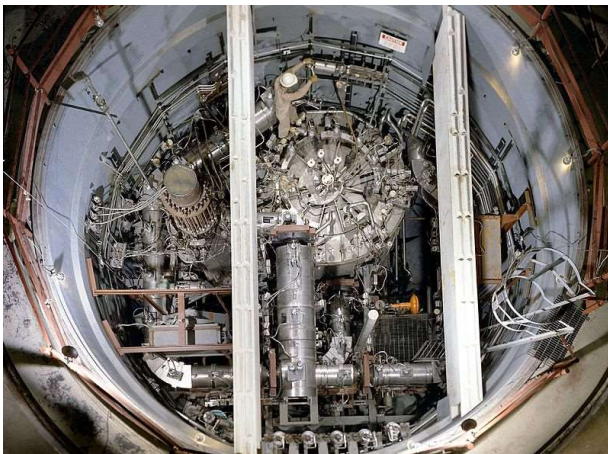


https://en.wikipedia.org/wiki/Aqueous_homogeneous_reactor

wikimedia commons, GNU 40

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Molten Salt Reactor Experiment 1965-1969



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

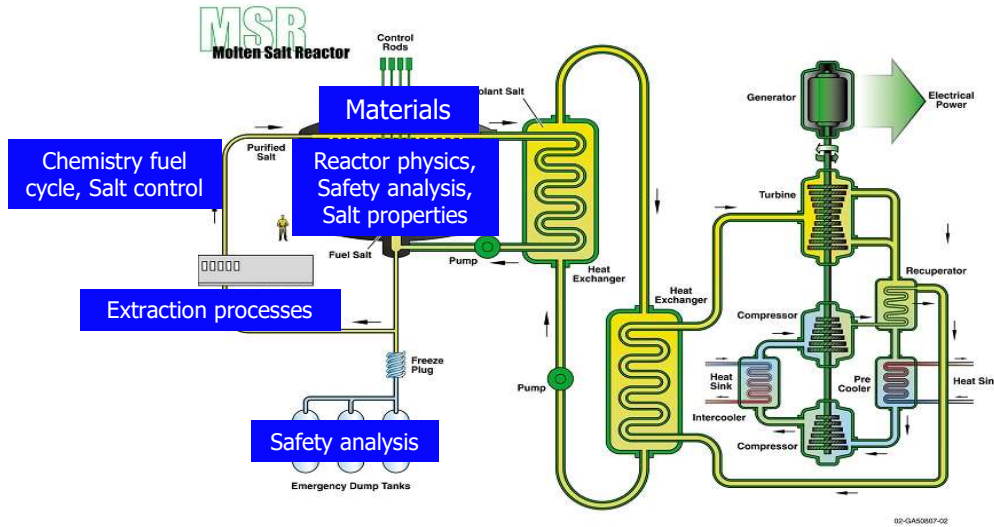
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See movie: <http://energyfromthorium.com/2016/10/16/ornl-msre-film/>

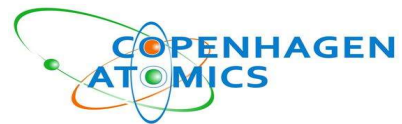
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MSR research themes



MSR Start ups

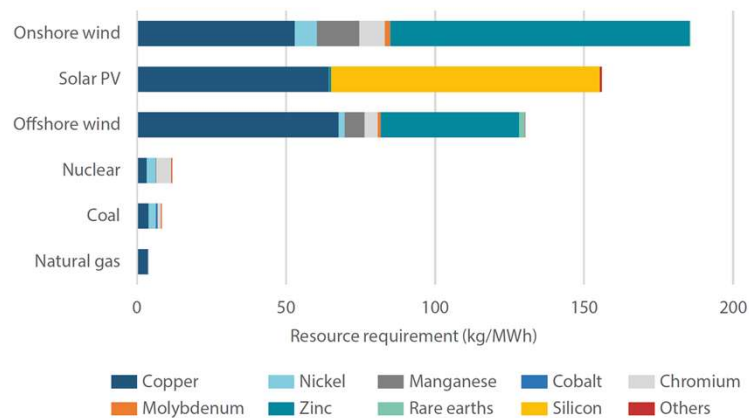


Conclusies

- 'Economy of scale' for large-scale electricity production
- New generation LWRs are very safe
- 'Economy of number' (SMR) upcoming
- Molten Salt Reactors (MSR)
 - Thorium-uranium, no production plutonium
 - Thorium-plutonium, destruction of plutonium
 - Uranium-plutonium, optional
- Metal-cooled Gen-IV reactors

Critical mineral needs

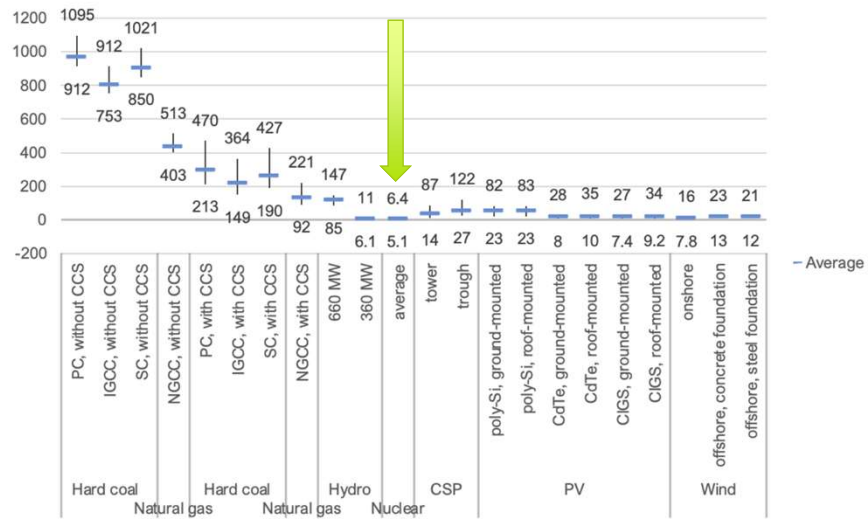
Figure 25. Critical minerals for different sources of electricity



Source: Analysis based on IEA (2021) data.

No CO2 emission

Lifecycle GHG emissions, in g CO₂ eq. per kWh, regional variation, 2020



Life cycle assesment of electricity generation options, United nations economic commission for Europe, 2021