Developing Lead-Cooled Small Modular Reactors - SUNRISE

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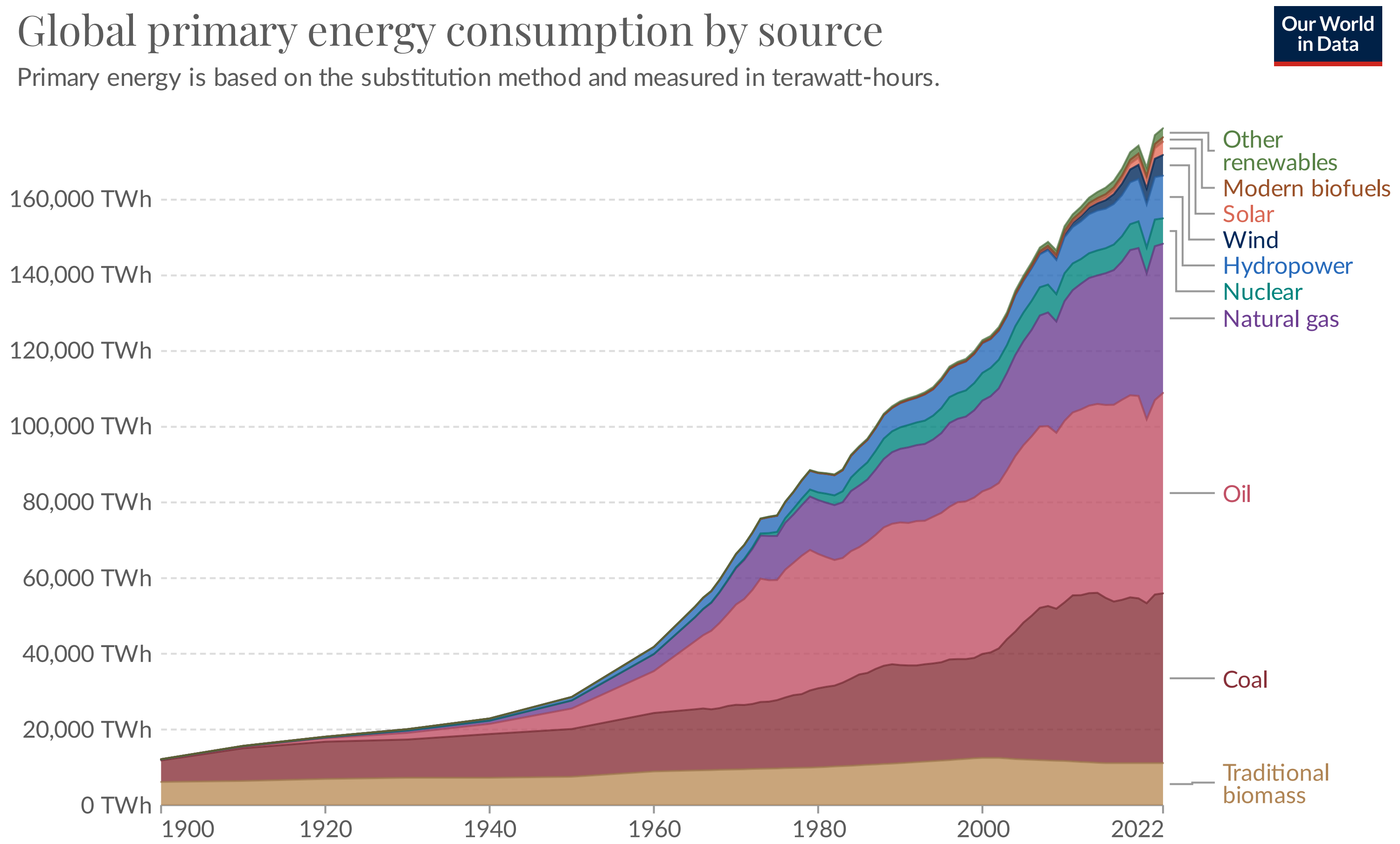
Global Energy Consumption

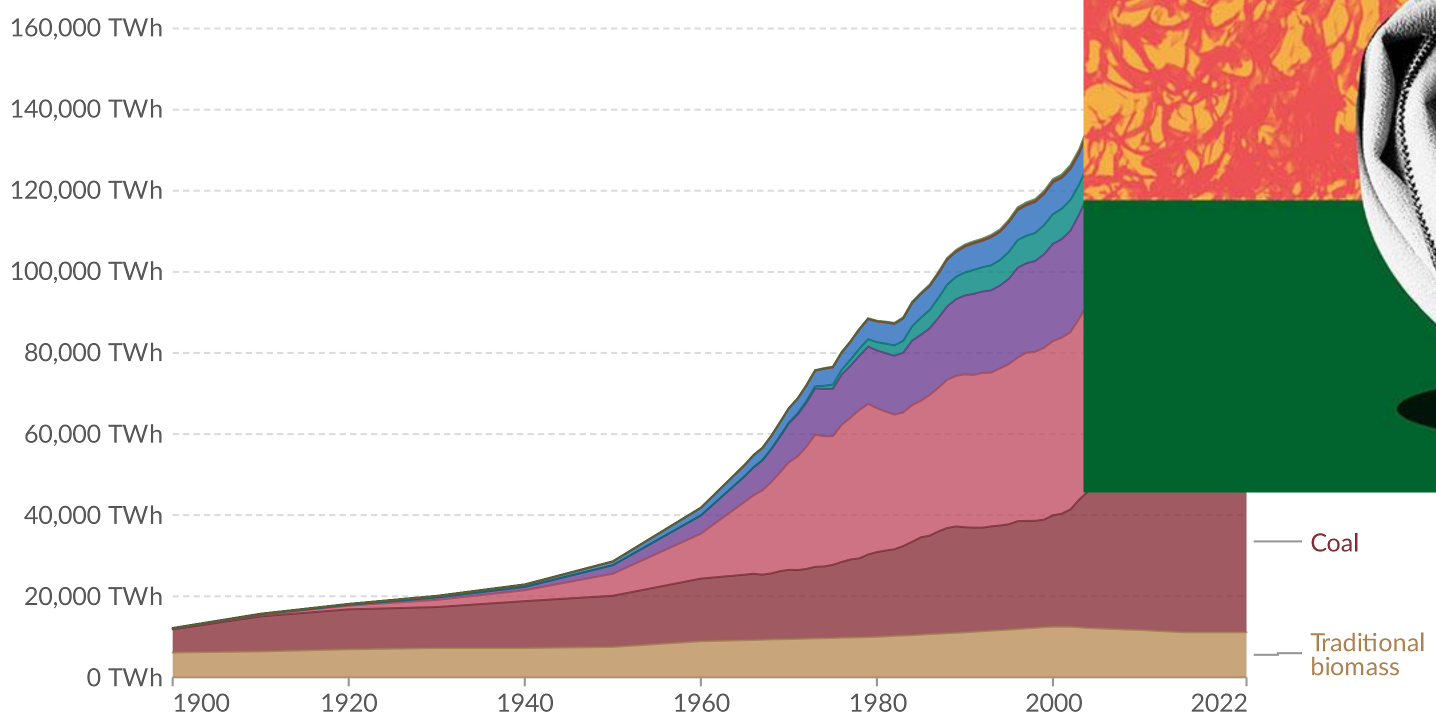


Data source: Energy Institute - Statistical Review of World Energy (2023); Smil (2017)
Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

Global Energy Consumption

Global primary energy consumption by source

Primary energy is based on the substitution method and measured in terawatt-hours.



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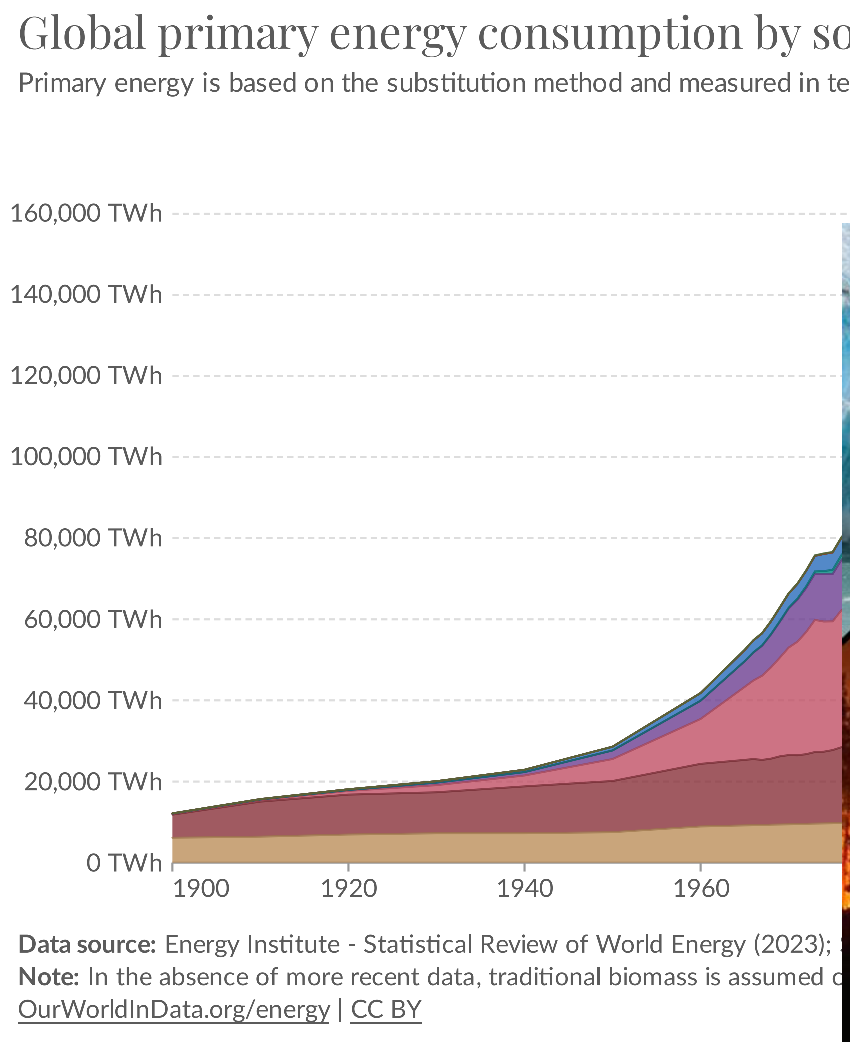
Global Energy Consumption



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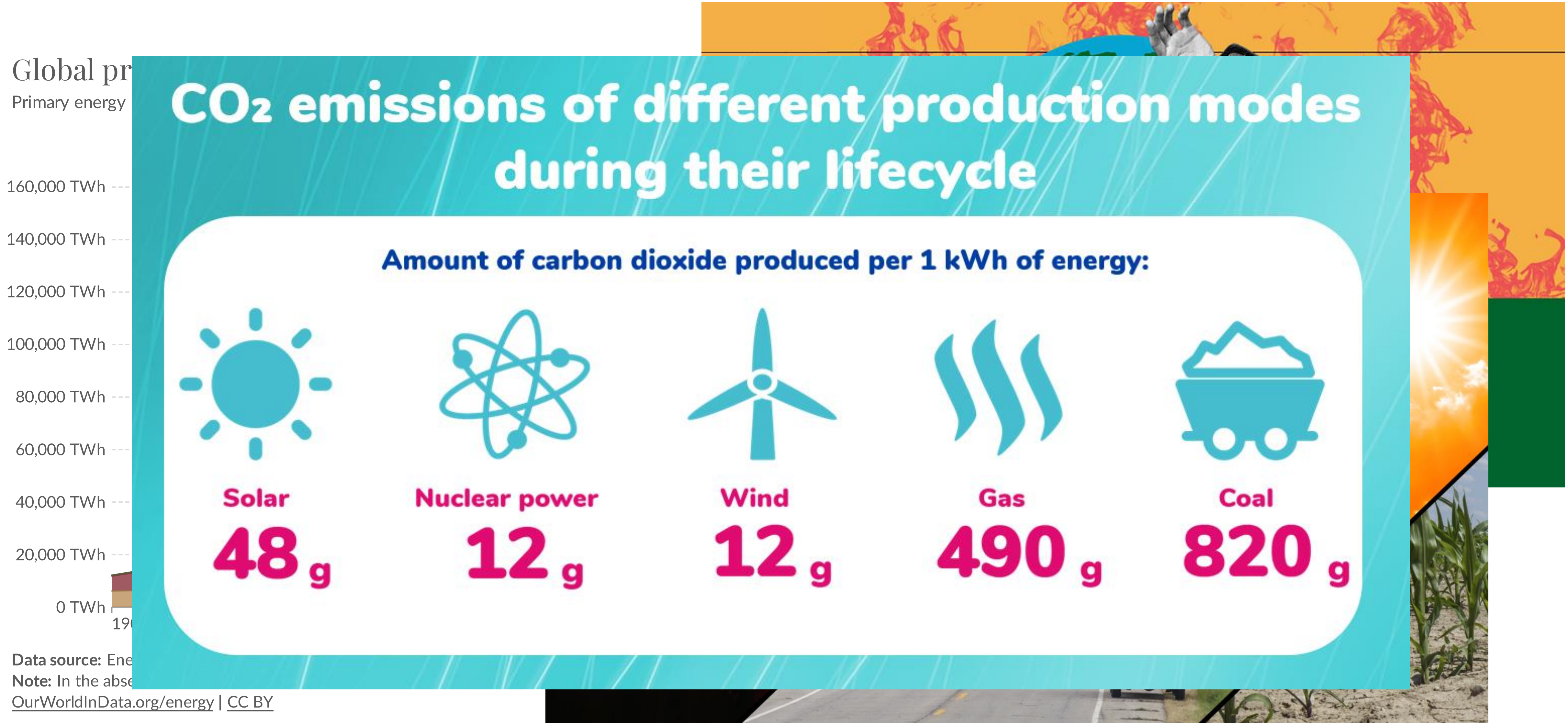

Nuclear Energy

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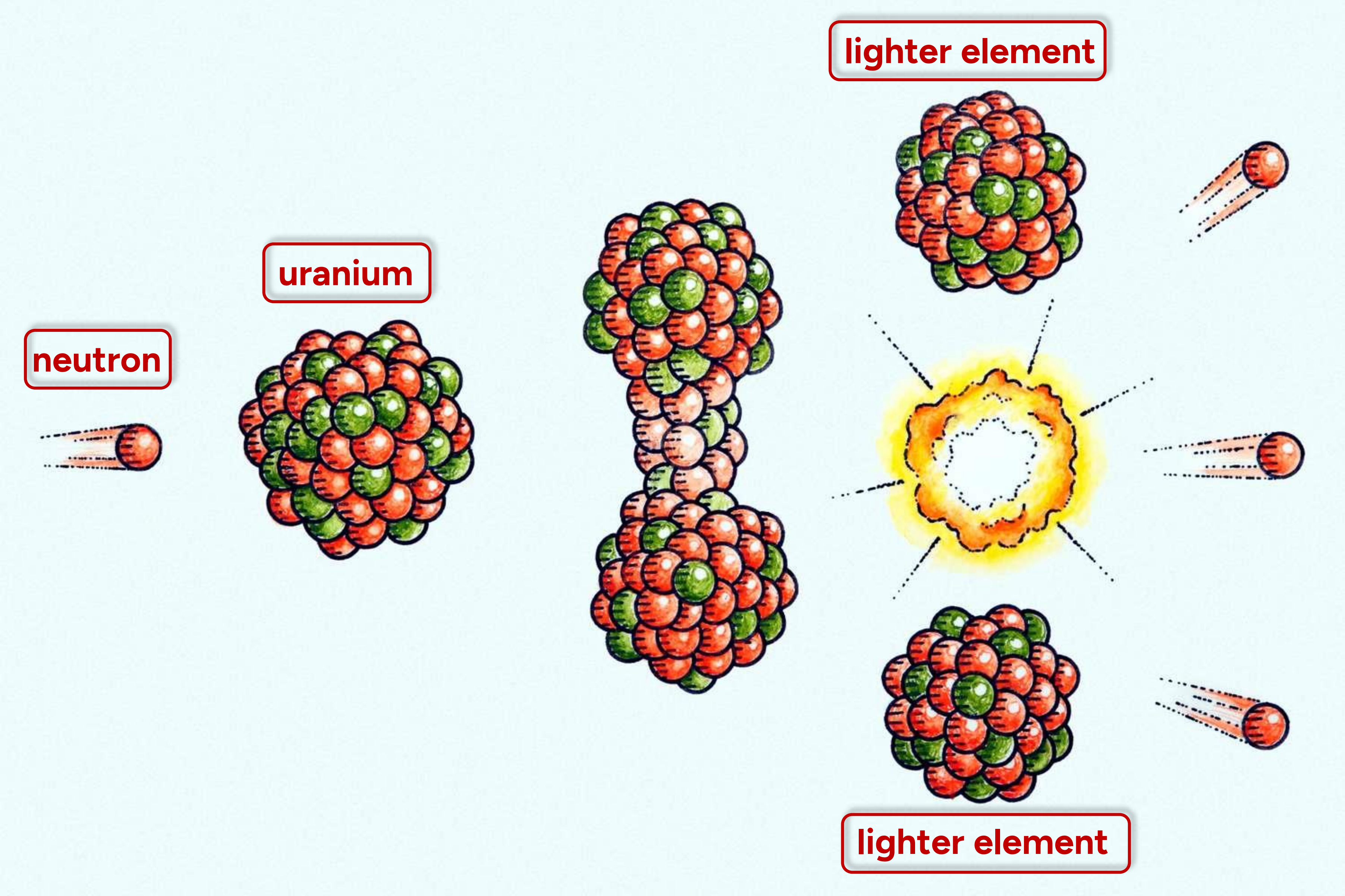
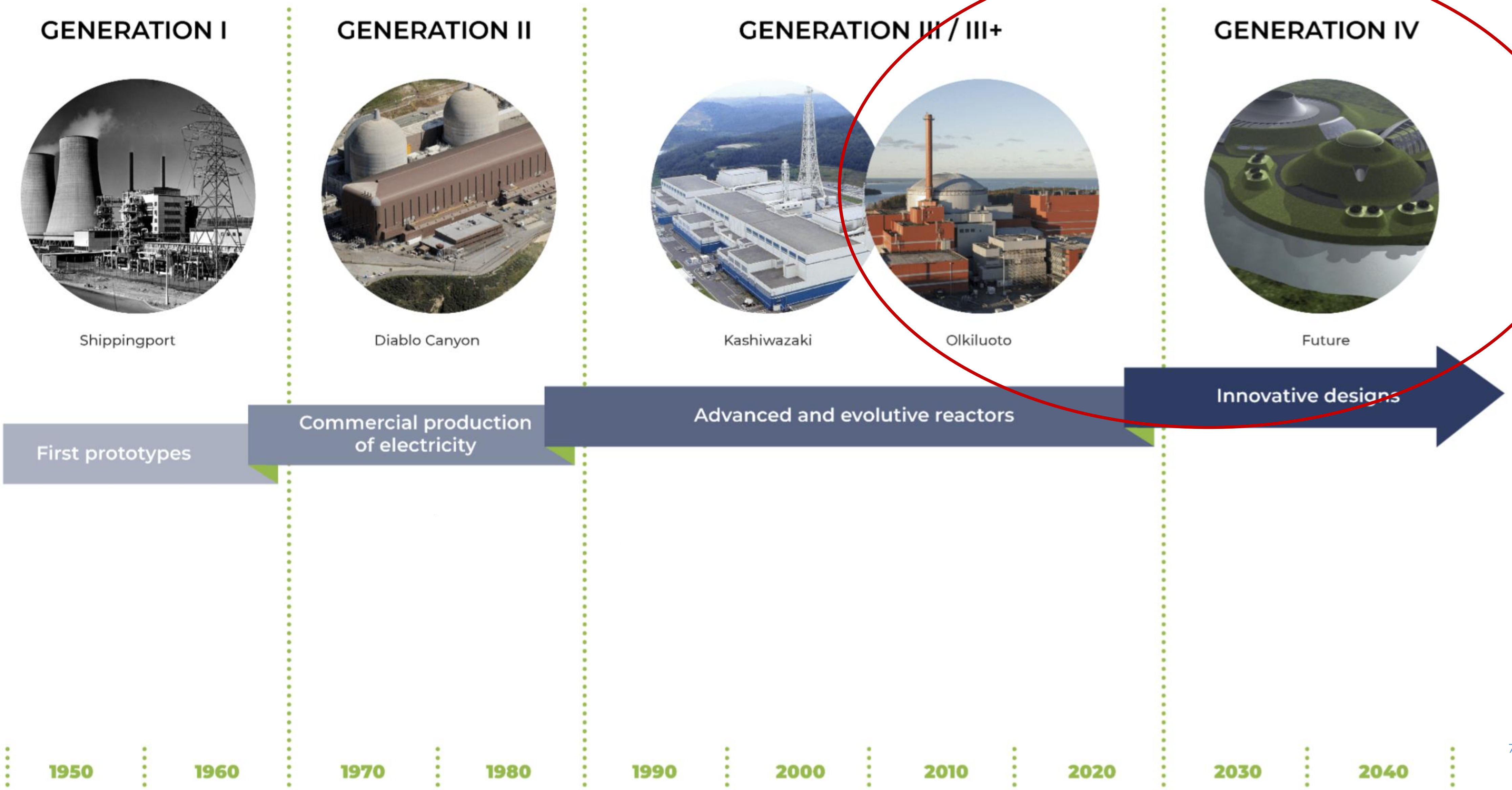


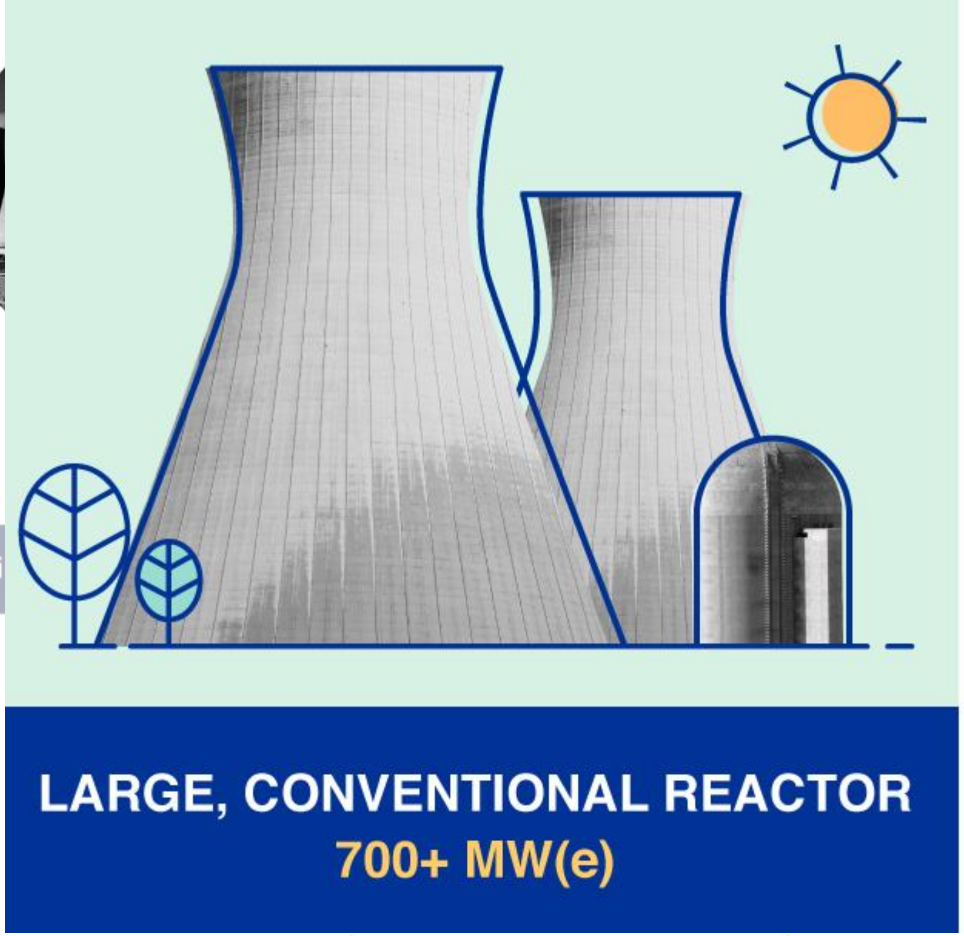
- Uranium is a naturally occurring element
- **Fission reaction:** Splitting a heavy nucleus, e.g. **uranium**, with the help of a **neutron** into two smaller elements, releasing energy
- Many neutrons and U atoms can sustain a **fission chain reaction** inside a nuclear reactor core

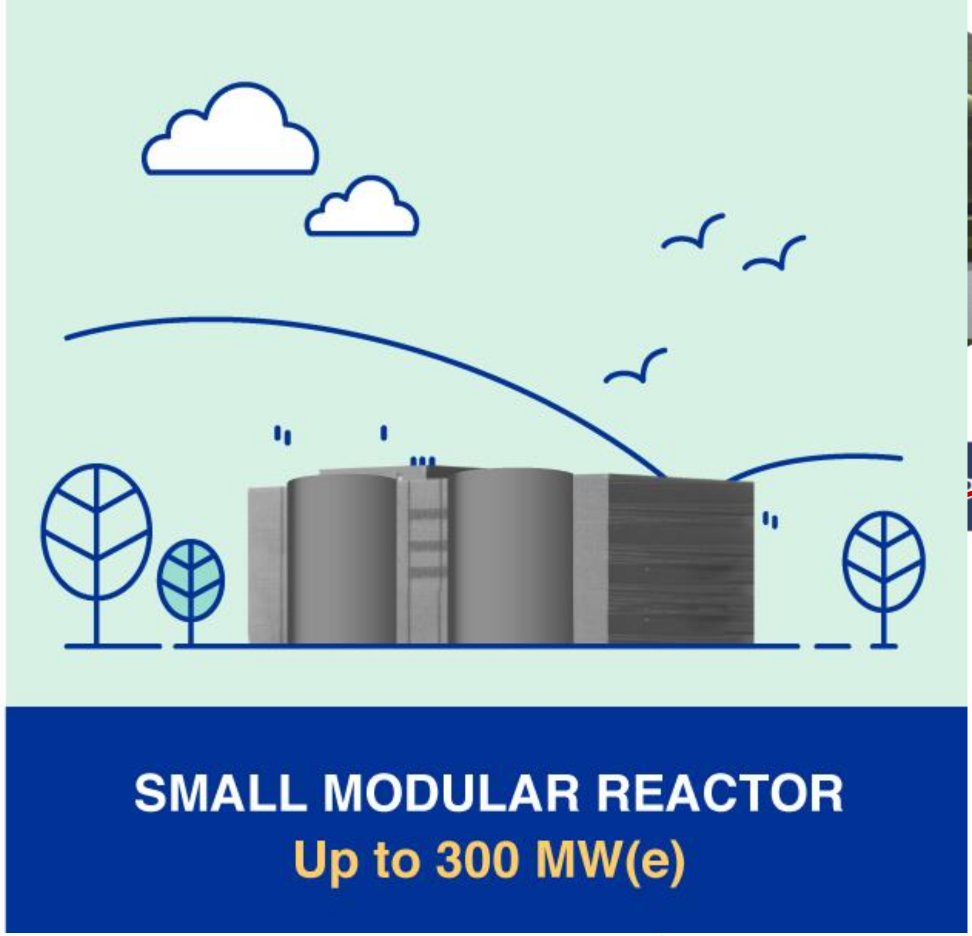
Generations of Nuclear Energy



Generations of Nuclear Energy

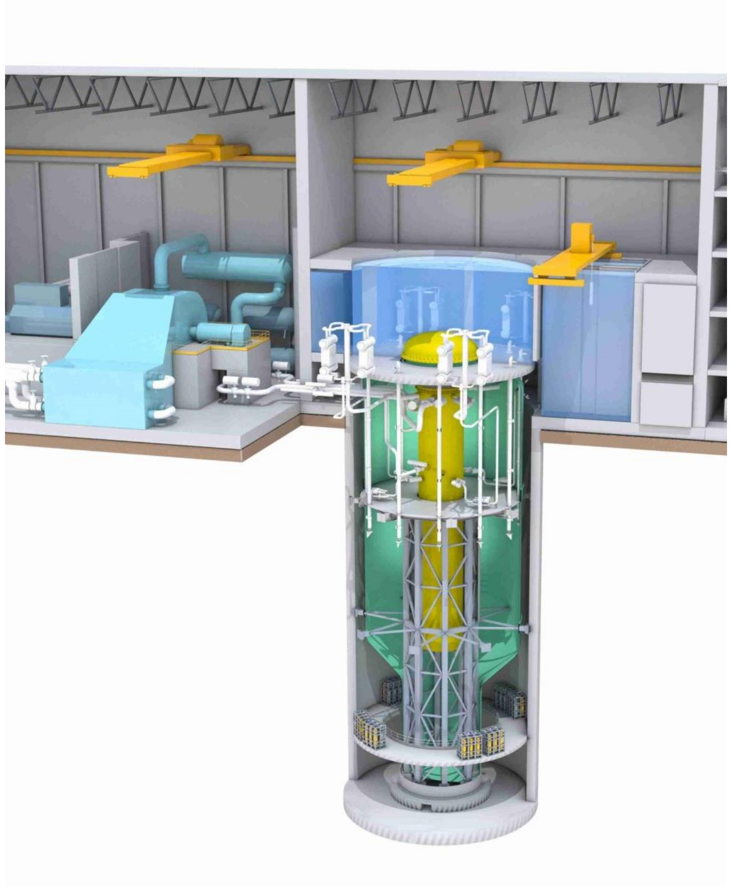
GENERATION I | GENERATION II | GENERATION III / III+ | GENERATION IV





1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 | 2040

Small Modular Reactors (SMRs)



BWRX-300,
300 MWe, LWR

SEALER-55,
55 MWe, LFR

- **Small –** a fraction of the size of a conventional nuclear reactor
- **Modular –** factory-assembled components and transported on site
- **Reactors –** harnessing of nuclear fission

What is Generation IV?

GEN IV International Forum
Expertise | Collaboration | Excellence

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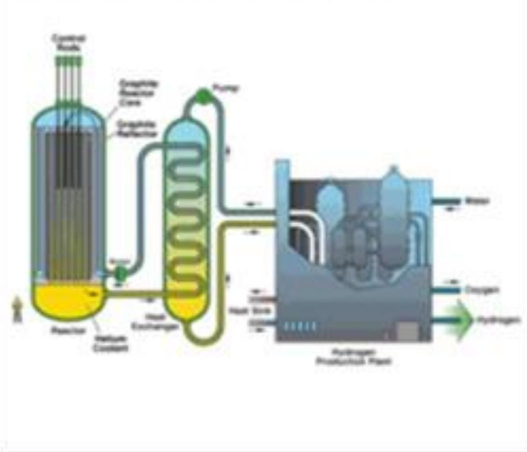
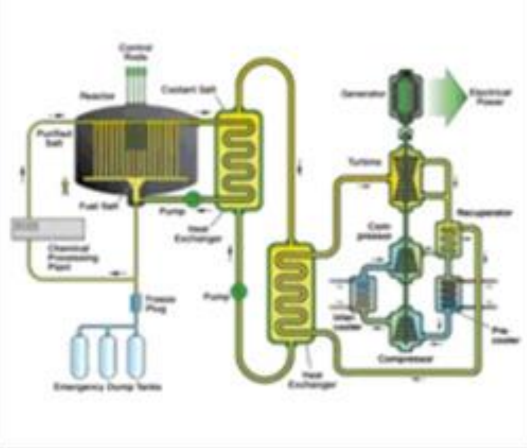
Generation IV goals:
1. Sustainability
2. Economy
3. Safety & reliability
4. Non-proliferation

- Can be either small or large
- Liquid metal, gas, water coolants
- Fast or thermal neutrons
- Various fuel types

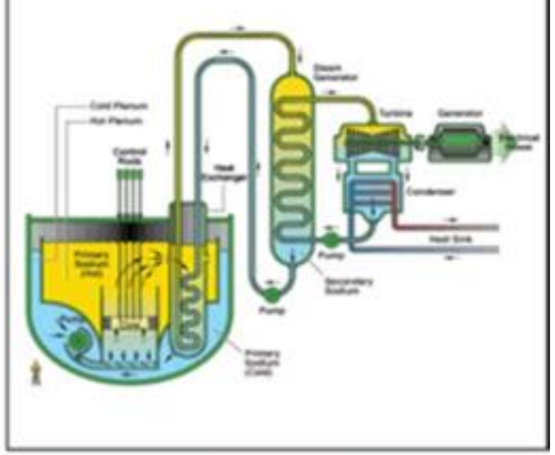
Very-high-temprature reactor



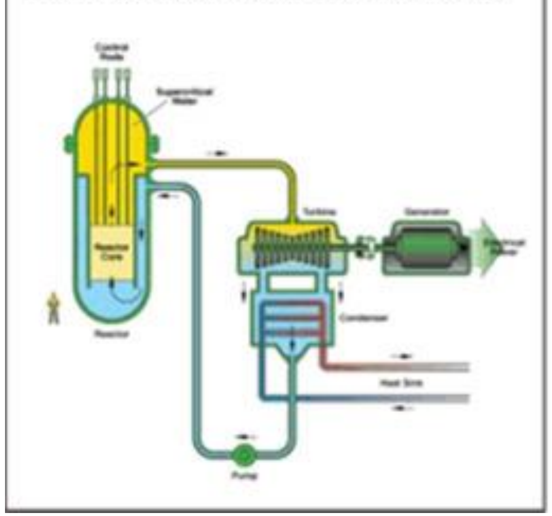
Molten salt reactor



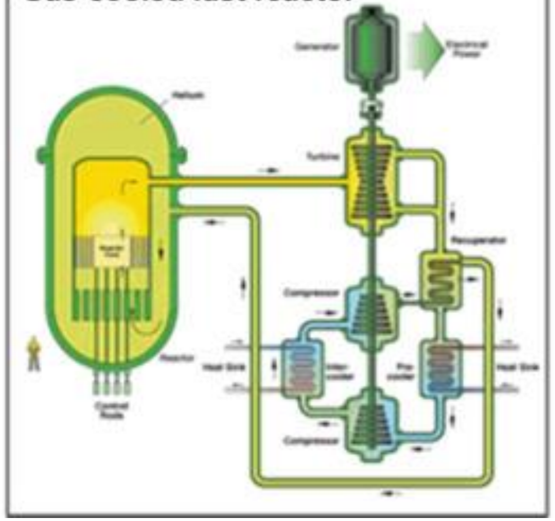
Sodium-cooled-fasr reactor



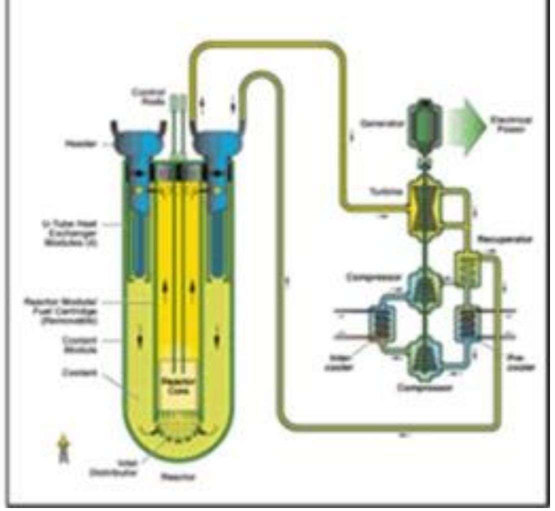
Supercritical-water-cooled reactor



Gas-cooled fast reactor



Lead-cooled fast reactor



What is Generation IV?

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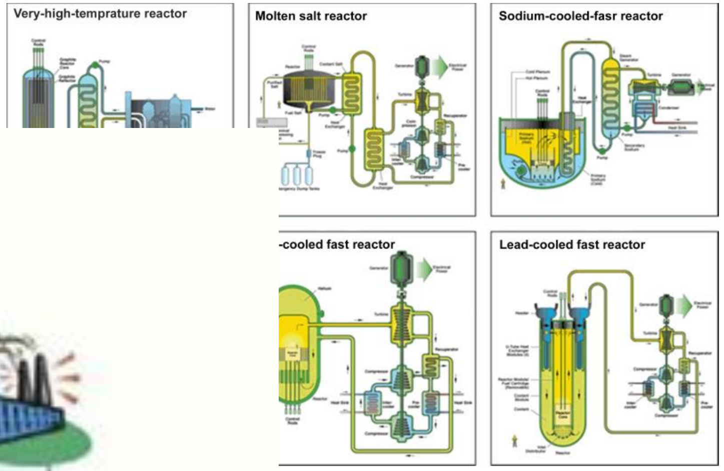

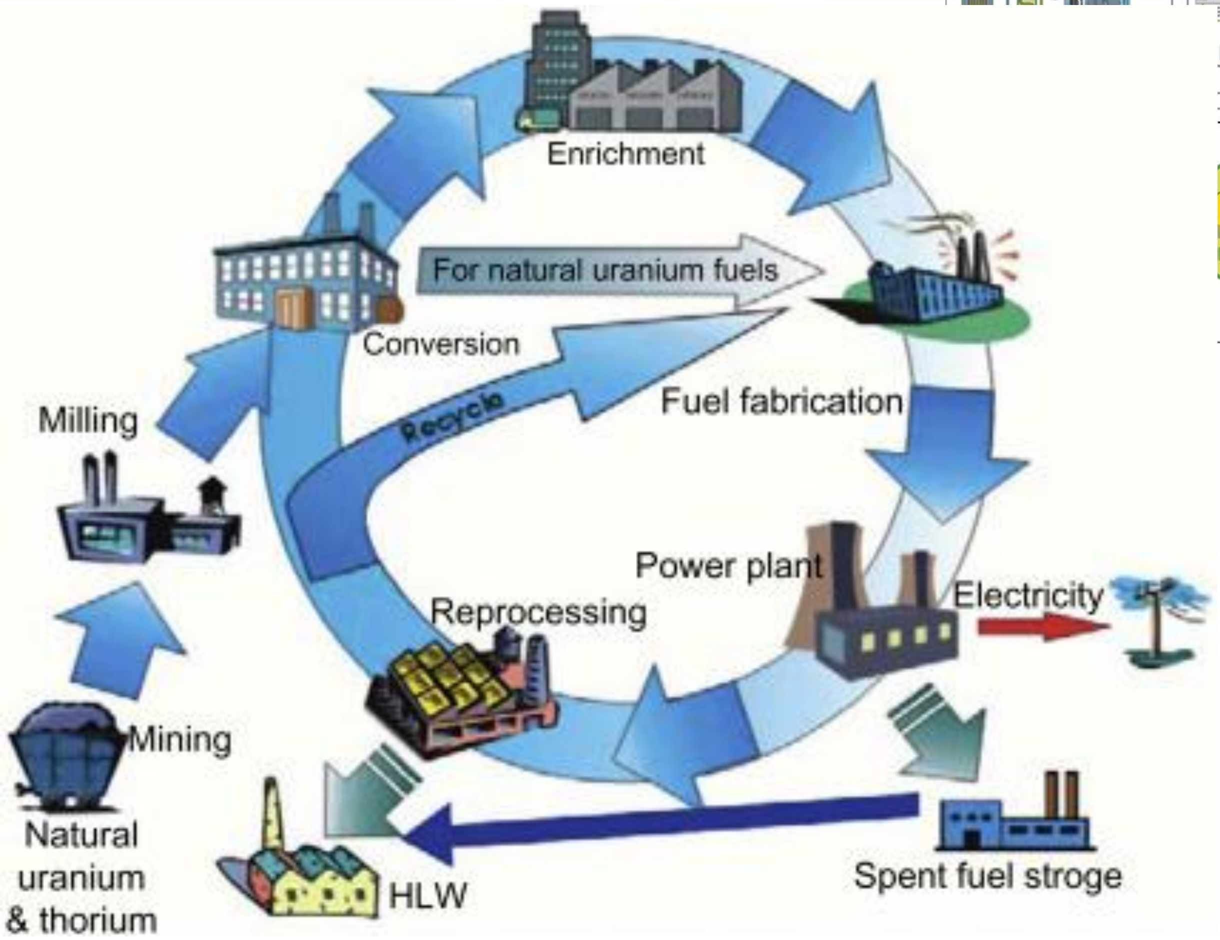

Some Gen-IV reactors can:
- Transform long-life heavy elements into non-radioactive elements
- Increase 10 times uranium availability.

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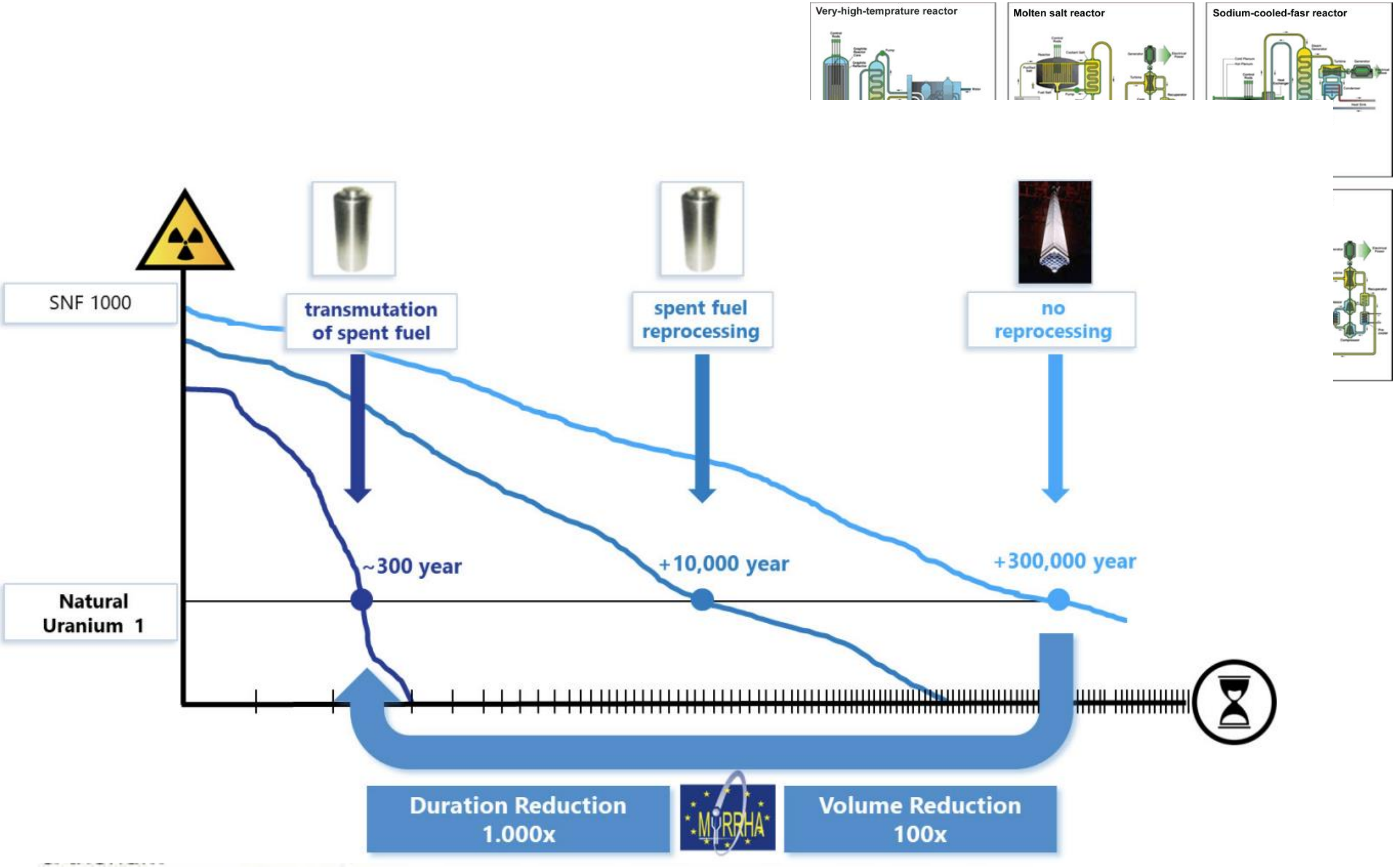

Sustainable Nuclear Energy Research in Sweden (SUNRISE)

- SUNRISE was formed by KTH, UU and LTU together with large parts of the Swedish nuclear and steel industry (and global partners).

- **Goals:**
  - Design a lead-cooled research reactor to be ready by 2030.

- **Stages:**
  - *Stage 1*: Research and development to license the research reactor
  - *Stage 2*: Build an electrically heated prototype and conduct experiments
  - *Stage 3*: Build and operate the SUNRISE reactor

- International academic partners, Industry stakeholders, Societal stakeholders

SUNRISE

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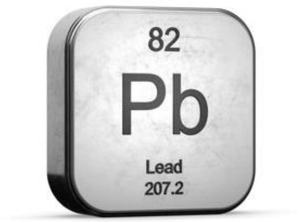
Motivation for SUNRISE

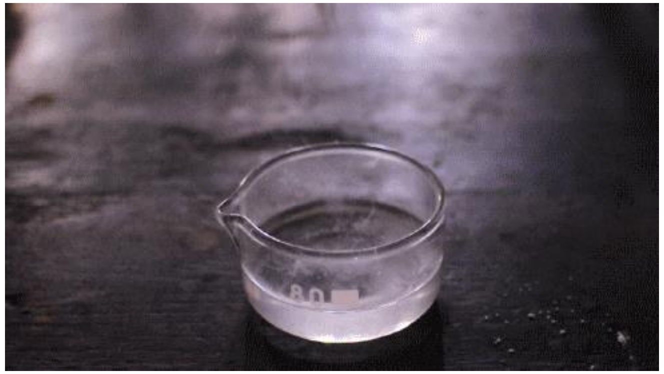
- Nuclear power is the only carbon neutral and long-term, sustainable source of **base load** electricity
  - Can be scaled up sufficiently to meet the requirements of the green transition
  - Can be paired and increase the efficiency of renewable sources towards the clean energy transition
- The use of lead coolant implies that passive safety can be achieved in the most compact format

Five Work Packages within SUNRISE

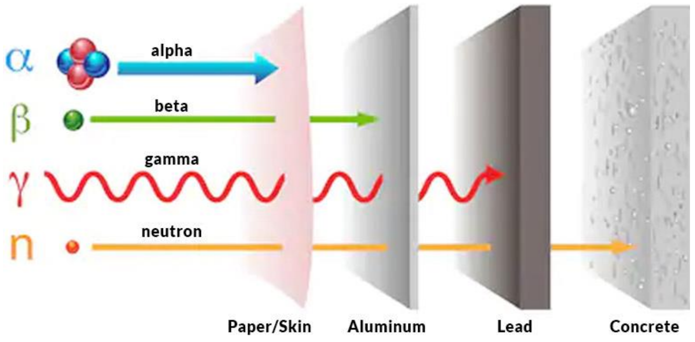
- **WP1**: Design and safety analysis of research reactor (LFR)
- **WP2**: Steel performance and testing
- **WP3**: Manufacturing methods and testing on reactor components
- **WP4**: Nuclear Fuel Development
- **WP5**: Erosion-corrosion test facility

Benefits of using liquid lead as a coolant





Sodium in water



- High boiling point (1749 °C)
- Operation in atmospheric pressure
  - ➢ Thinner reactor vessel → cheaper and simpler manufacturing
- No violent exothermic reaction in contact with water
- Passive safety through natural circulation is achievable
- Fast neutrons can be used
- In case of fuel rod damage, iodine and cesium will form compounds with lead, reducing their release to environment
- Efficient shielding from gamma-radiation

Challenges with liquid lead

- Opaque – visual inspections impossible. New methods must be developed
- High melting point (327 °C)
  - Maintenance at high temperatures.
  - Risk of freezing issues. Design must mitigate risks with ”overcooling”
- Nickel requires an oxide layer for protection
  - Erosion of the oxide layer must be avoided
- High density – many components float

SOLUTIONS ARE NEEDED..

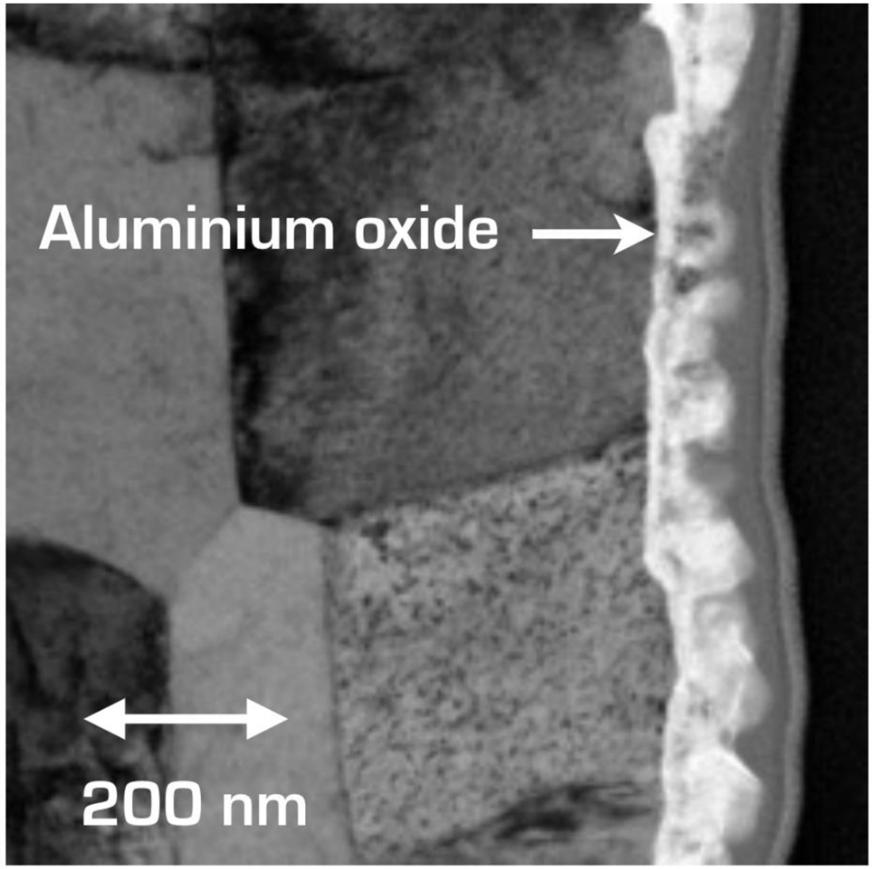
NEW ADVANCED MATERIALS AND PROCESSES!

Anvil floating in mercury

Steel Performance at KTH

Development of a lead-compatible steel

- **FeCrAl** steel form thin, self-healing and protecting, layers of alumina oxide on the surface.
- Reactive elements have been added to ensure a stable oxide layer of a high quality.
- **FeCrAl** alloys developed at KTH have demonstrated exceptional performance in high-temperature lead.
  - **2 years at 550 °C**
  - **10 weeks at 850 °C**
- Laser welding of FeCrAl on bulk 15-15Ti
  - Process development ongoing at LTU
- Development ongoing of other alumina forming steels for other applications (AFA)



Nuclear Fuel Development at KTH – Uranium Nitride UN

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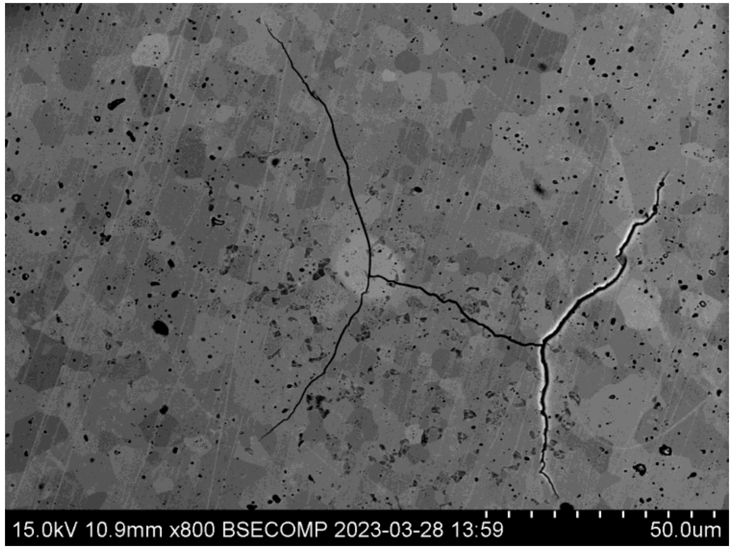
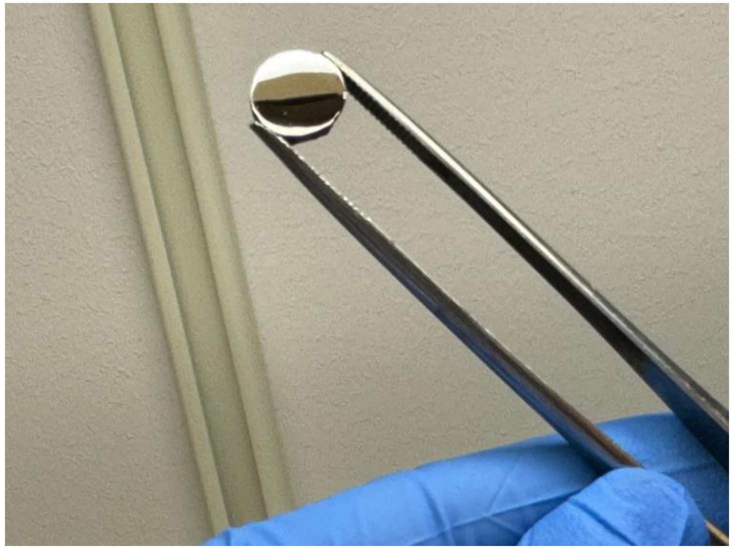
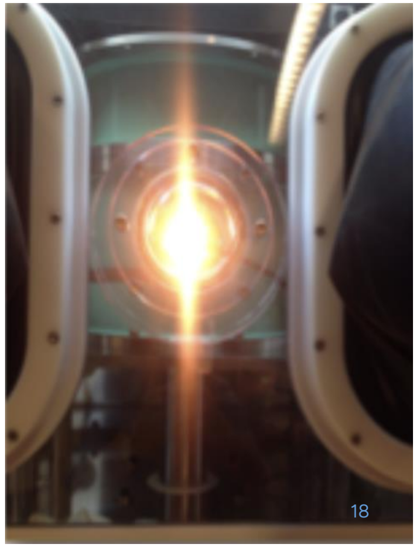
+ Higher uranium density (40 % compared to UO_2)
  - Allows 20 years of operation in a SMRs
+ Higher ability to conduct heat compared with UO_2
+ High melting temperature (2850 °C)
+ Sintering fuel in a few minutes
+ Study of the simulated fuel

– ^{15}N enrichment required, as a reaction of ^{14}N with neutrons produces radioactive ^{14}C

– Low operational experience – additional time to qualify







Optimal Timeline for Commercialization

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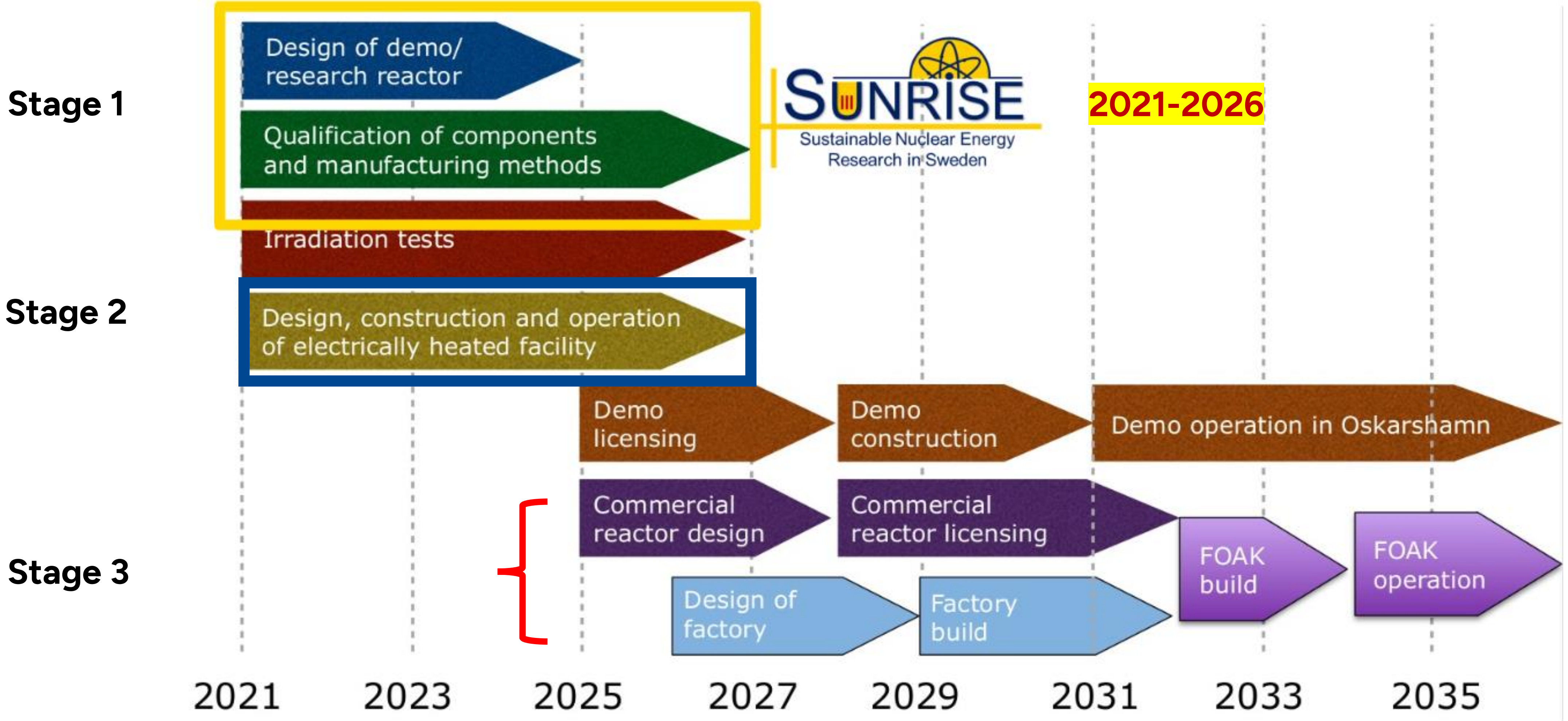

KTH VETENSKAP OCH KONST

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Thank you for your attention!

Questions?