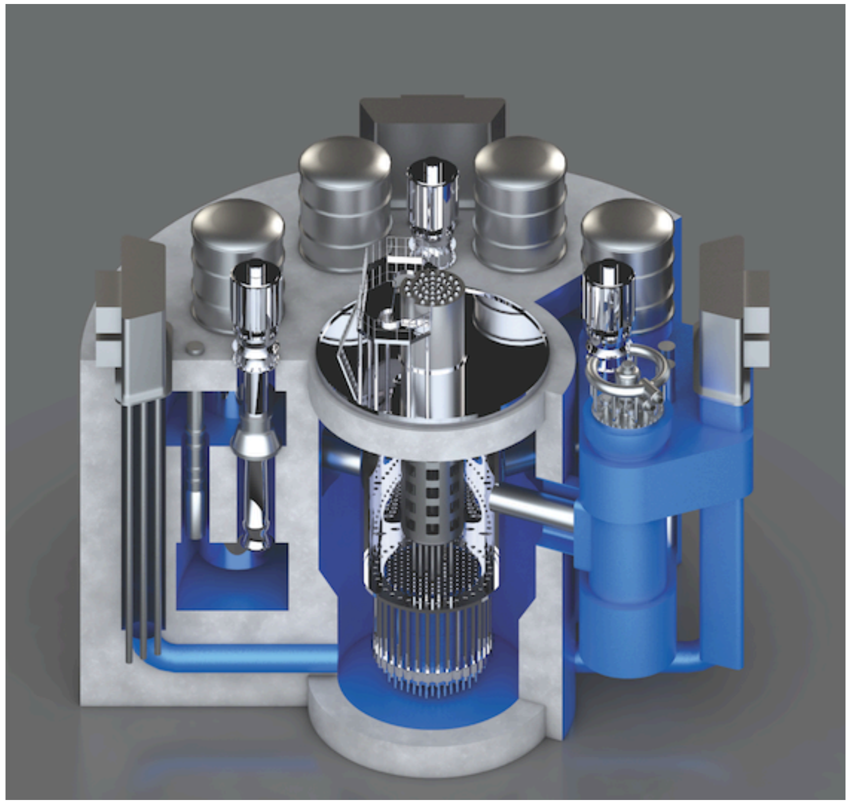
# Generation IV reactors



*A sustainable future for nuclear power*

Janne Wallenius & Alejandria Pérez

*Nuclear Engineering, KTH*

# Intended learning outcomes

Generation IV reactors are intended to:

**Increase fuel resources by a factor of 100**

**Reduce long term radiotoxic inventory of spent fuel by a factor of 100**

**Increase operational temperature, thus improving conversion factors**

After this course, you will be able to make design choices making Gen-IV reactors sustainable, safe and reasonably economical. The objective is achieved if you show you are able to

- **Assess breeding performance for potentials fuels and coolants**
- **Analyse reactor safety of fast neutron reactors with MA bearing fuels**
- **Select fuels and structural materials meeting design & safety criteria**

# Learning activities

- 14 course meetings:
- Presentations by teacher/facilitator (10 meetings) and students (4 meetings), followed by feedback
- Group discussions and exercises
- Learning material: Lecture notes,  Text book chapters
- Meeting evaluations
- 3 home assignments made groupwise, presented individually
- Conference paper with the title  “Safety of a fast neutron Generation IV reactor with coolant A, fuel B and cladding C“, written and presented together with co-authors.
- Individual interview on the intended learning outcomes (constitutes basis for grading)

# Generation IV objectives

- By the end of the last century major nuclear nations considered that a novel approach to developing the next generation of nuclear reactors, that would address public concerns related to
  - Sustainability
  - Economy
  - Safety
  - Non-proliferation
- **Generation IV International Forum** was created to define refined criteria for meeting the aforementioned concerns, to identify so called "Generation-IV reactors" that could meet such criteria, and to promote R&D and the eventual commercial implementation of the same

# Sustainability criteria

## 1) Resource utilisation

*Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilisation for worldwide energy production.*

## 2) Waste minimization and management

*Generation IV nuclear energy systems will minimise and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.*

# Economic criteria

## 3) Life cycle cost

*Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.*

## 4) Financial risk

*Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.*

# Safety criteria

## 5) Operational safety and reliability

*Generation IV nuclear energy systems operations will excel in safety and reliability.*

## 6) Core damage

*Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.*

## 7) Off-site emergency response

*Generation IV nuclear energy systems will eliminate the need for offsite emergency response.*

# Non-proliferation criterion

## 8) Proliferation resistance and physical protection

*Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.*

# Gen-IV systems

Six reactor types were selected by GIF as **having the potential** to meet the criteria for Generation-IV systems

1. Sodium-cooled fast reactors
2. Lead-cooled fast reactors
3. Gas-cooled fast reactors
4. Very high temperature reactors
5. Super-critical water reactors
6. Molten salt reactors

There is/was no Gen-IV reactor in operation!

# Sodium-cooled fast reactors

- 23 Na and NaK-cooled reactors have operated since 1951
- Total of 200 years of operational experience
- 6 sodium-cooled reactors are operating
- 2 are producing power on commercial basis (BN-600 & BN-800)
- 4 reactors are under construction (MBIR, PFBR & XIAPU I & II)

**Major issues observed:**

- Steam generator corrosion
- Sodium-water interaction
- Sodium fires
- Fuel reloading machine failures

# Under construction: XIAPU I & II

Sodium-cooled fast reactors, developed by CIAE.

- Model: CFR-600
- 640 MWe per unit
- Under construction in Xiapu, Chine
- Coolant temperature: 380 - 550°C
- Fuel form: $UO_2$
- Date for commissioning: 2023 & 2025

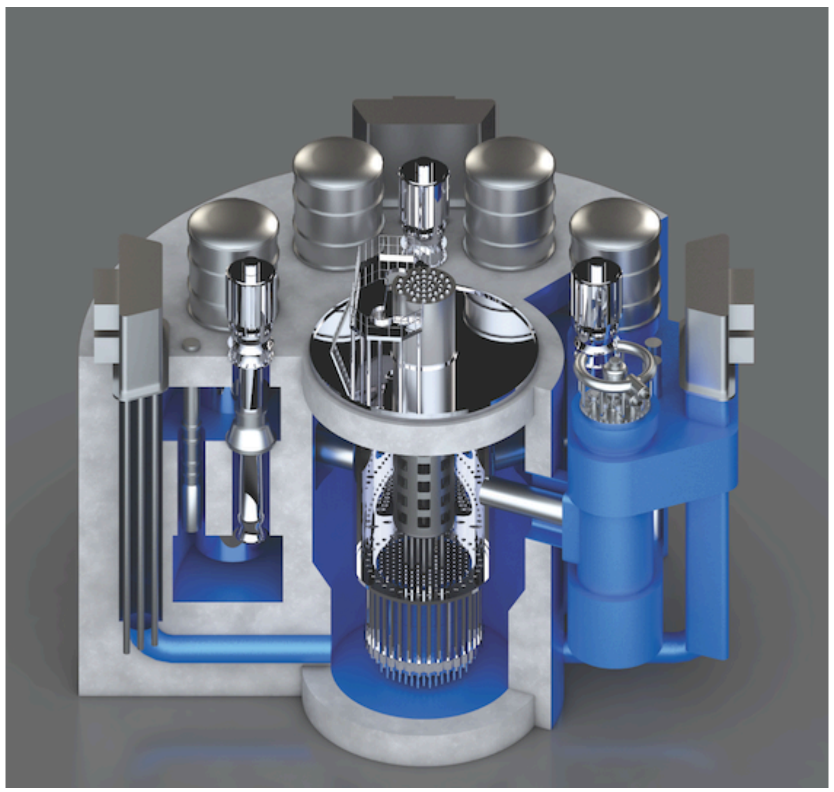
# Lead-cooled reactors

- Eleven PbBi-cooled reactors have operated since 1959
- Total of 80 years of operational experience (≈ 5 full power years)
- 1 reactor is under construction (BREST-300)

**Major issues to be addressed:**

- Formation of lead-oxide in the coolant
- Corrosion of stainless steel
- Erosion of pump impeller
- High temperature maintenance

# Under construction: BREST-300



Lead-cooled fast reactor, developed by NIKIET

- 300 MWe
- Under construction in Tomsk-region, Russia
- Coolant temperature: 420 - 650°C
- Fuel form: (U,Pu)N
- Recycle of minor actinides foreseen. First true Gen-IV system!
- Structural steel: EP-823 (Fe-12Cr-2Si)
- Date for commissioning: 2026

# Gas-cooled reactors

- No gas-cooled fast reactor has operated
- Nine He-cooled high-temperature reactors (HTRs) have operated
- Four He-cooled HTRs are in operation (HTTR, HTR-10, 2 x HTR-PM)

**Major issues to be addressed:**

- Costly fuel production
- Leakage of highly mobile and costly helium
- Mechanical properties of structural materials at high temperature
- Large size (and associated costs) of secondary system
- Activation of nitrogen impurities in graphite
- Recycle of fuel extremely difficult and costly

# In operation: HTR-PM

He-cooled high temperature reactor, developed by Tsinghua University

- 210 MWe (2 x 250 MWth)
- Built in Shidaowan, Shandong province
- Pressure vessel dimensions: 5.7 x 25 m
- Coolant temperature: 250 - 750°C
- Fuel form: TRISO coated $UO_2$ particle pebble bed
- Fuel enrichment: 8.5%
- Fuel residence time: 35 months
- Connected to grid in December 2021.

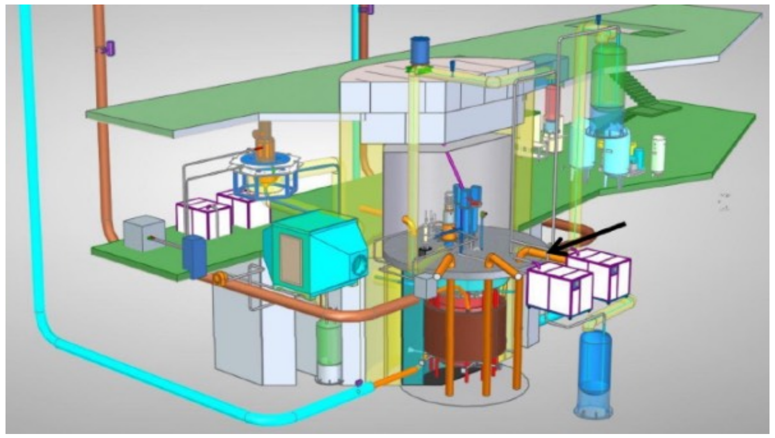
# Molten salt reactors

- Four molten salt reactors have operated (USA & China)
- One is under construction (TMSR-LF1)

**Major issues to be addressed:**

- Corrosion of structural materials
- Reduced number of boundaries for fission product release
- Shut-down margin
- Precipitation of actinides & fission products
- Delayed neutron source distribution

# Under construction: TMSR-LF1




Fluoride molten salt reactor, developed by SINAP.

- 2 MWth
- Under construction in Wuwei, China
- Fuel temperature: 630 - 660°C
- Fuel form: U-F-Li-Be (20% enriched in U-235)
- Date for commissioning: 2023