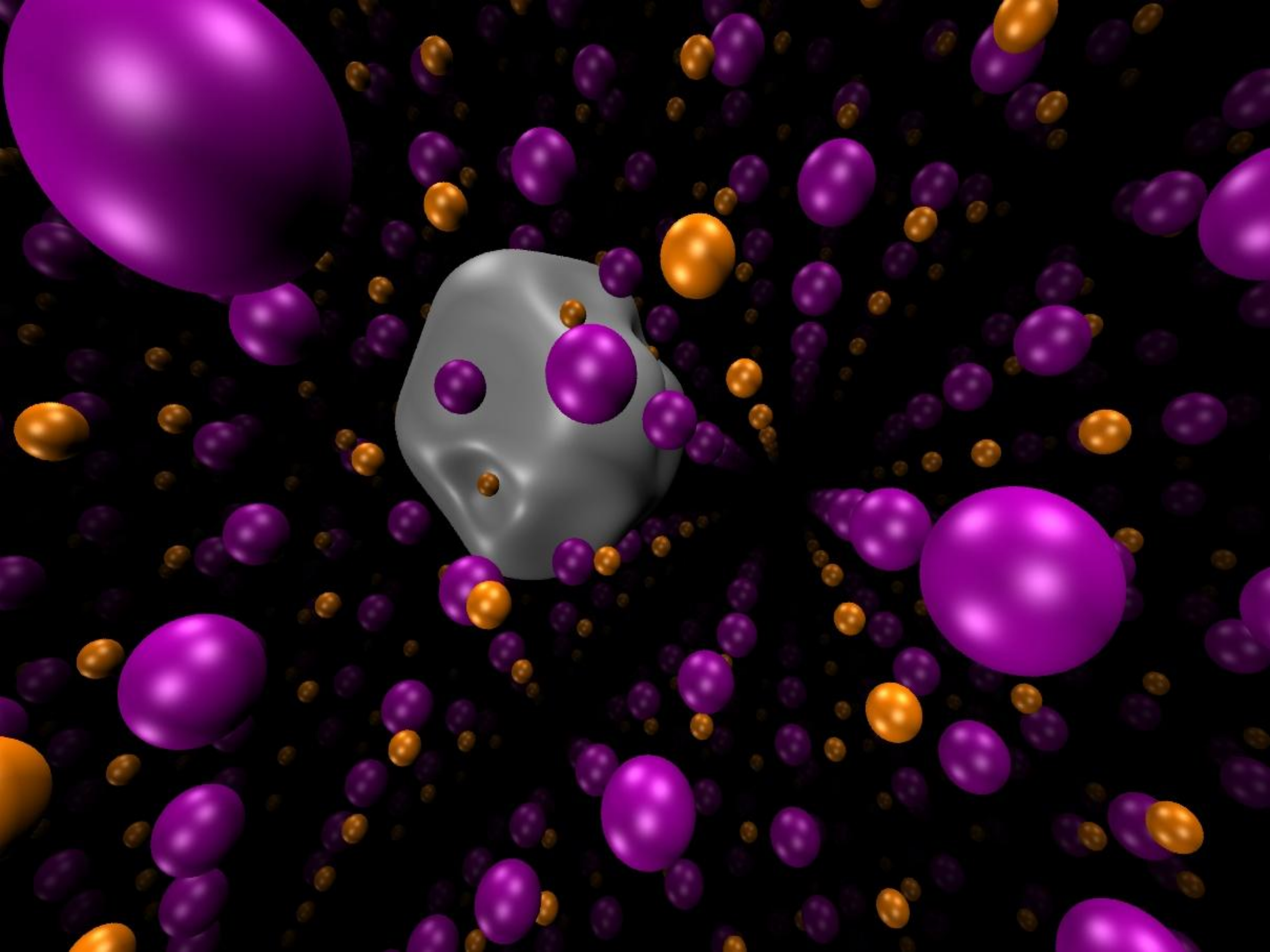

Future nuclear power production: generation IV

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Future nuclear power production: challenges in generation IV

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Future nuclear power production: technological challenges in generation IV

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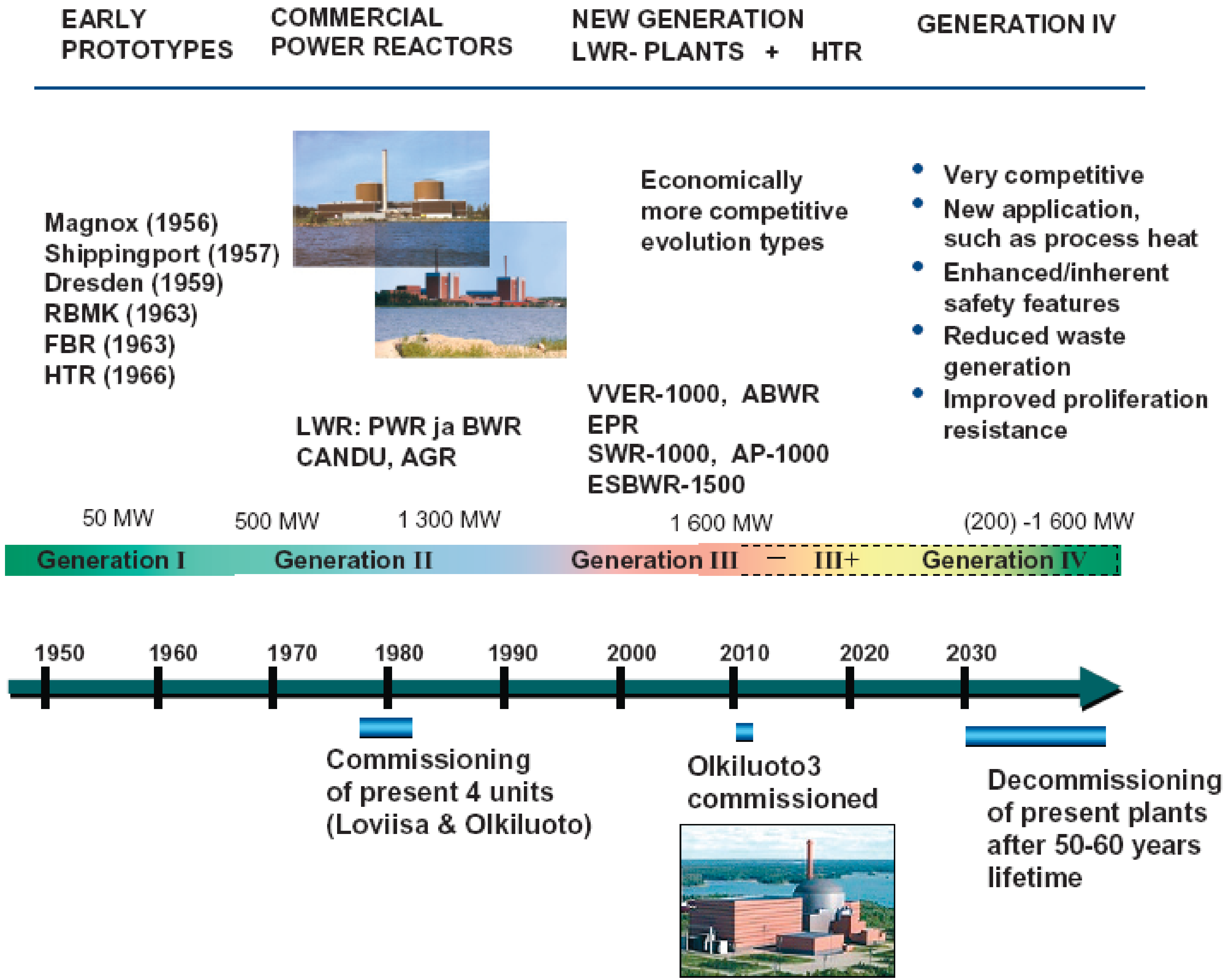

EARLY PROTOTYPES
COMMERCIAL POWER REACTORS
NEW GENERATION LWR- PLANTS + HTR
GENERATION IV
Magnox (1956)
Shippingport (1957)
Dresden (1959)
RBMK (1963)
FBR (1963)
HTR (1966)
LWR: PWR ja BWR
CANDU, AGR
Economically more competitive evolution types
VVER-1000, ABWR
EPR
SWR-1000, AP-1000
ESBWR-1500
Very competitive
New application, such as process heat
Enhanced/inherent safety features
Reduced waste generation
Improved proliferation resistance
50 MW
500 MW
1 300 MW
1 600 MW
(200) -1 600 MW
Generation I
Generation II
Generation III
III+
Generation IV
1950
1960
1970
1980
1990
2000
2010
2020
2030
Commissioning of present 4 units (Loviisa & Olkiluoto)
Olkiluoto3 commissioned
Decommissioning of present plants after 50-60 years lifetime

Objectives of GenIV

- Sustainable nuclear energy
  - fuel recycling, U-238 conversion, less and shorter-lived waste
- Competitive nuclear energy
  - fuel and plant cycle efficiency, economic life-cycle, less financial risk
- Safe and reliable systems
  - inherent , robust and transparent safety features, public confidence
- Proliferation resistance and physical protection
  - improved design, robust facilities

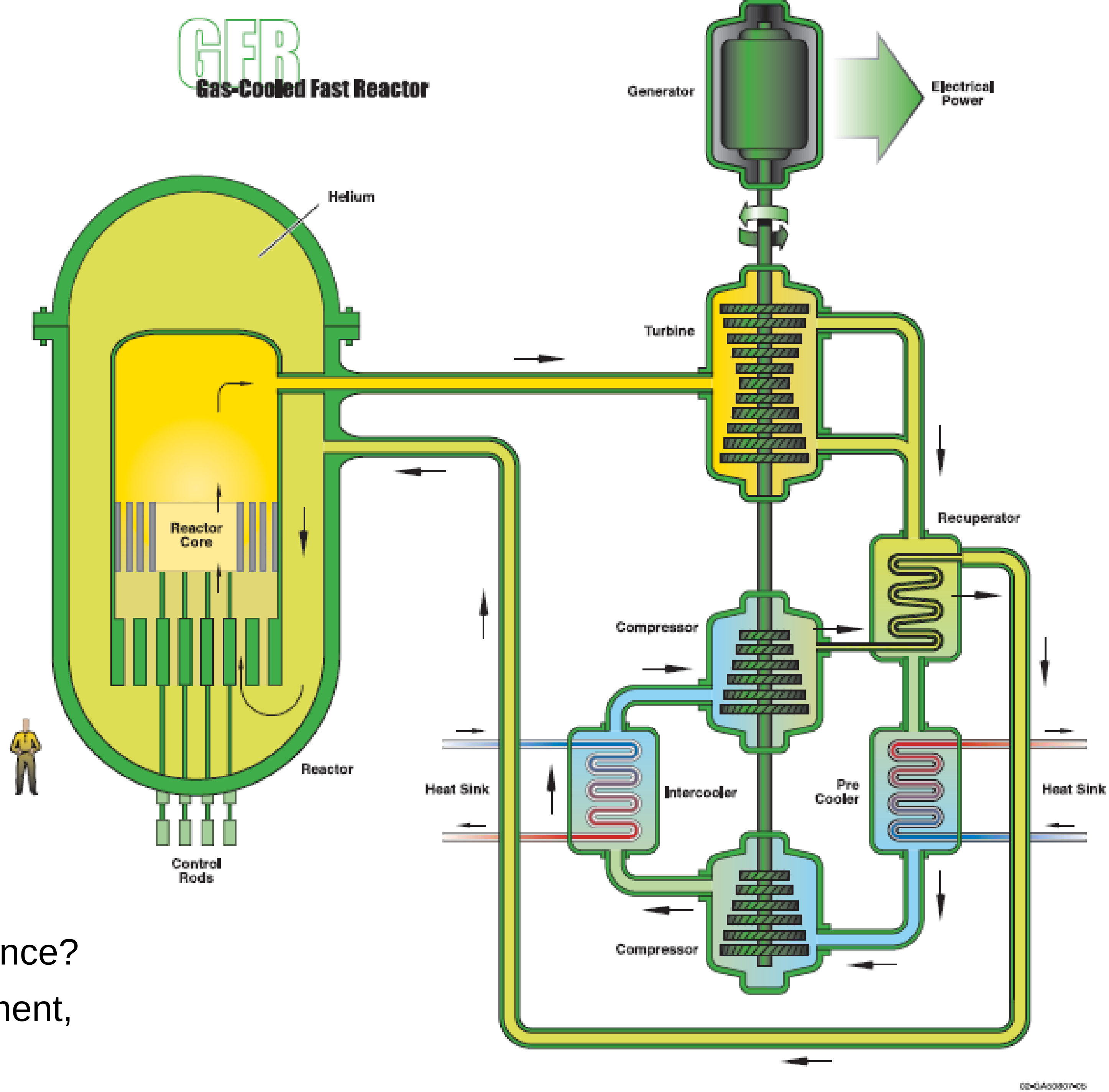
GenIV roadmap from 2002: 6 systems

Generation IV International Forum (GIF): http://www.gen-4.org

- Gas-cooled Fast Reactor (GFR)
- Lead-cooled Fast Reactor (LFR)
- Molten Salt Reactor (MSR)
- Sodium-cooled Fast Reactor (SFR)
- Super-Critical-Water Cooled Reactor (SCWR)
- Very-High-Temperature Reactor (VHTR)

GFR

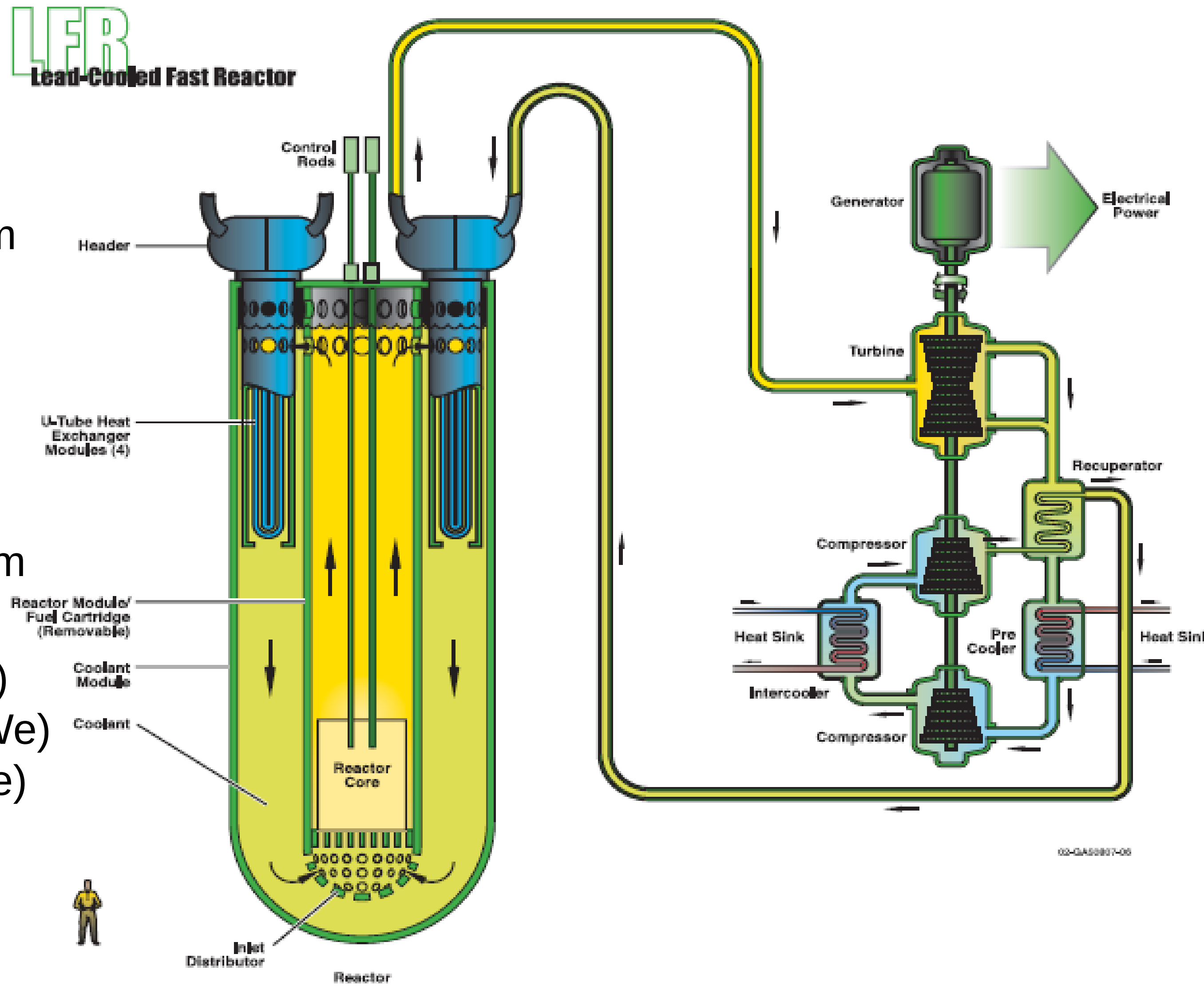
- Fast neutron spectrum
- Helium-cooled
- Outlet 850°C
- Electricity through gas turbine
- High efficiency
- Closed fuel cycle
- Burn actinides, thorium as fuel



Challenges

- Materials resistance?
- Spent fuel treatment, refabrication

LFR



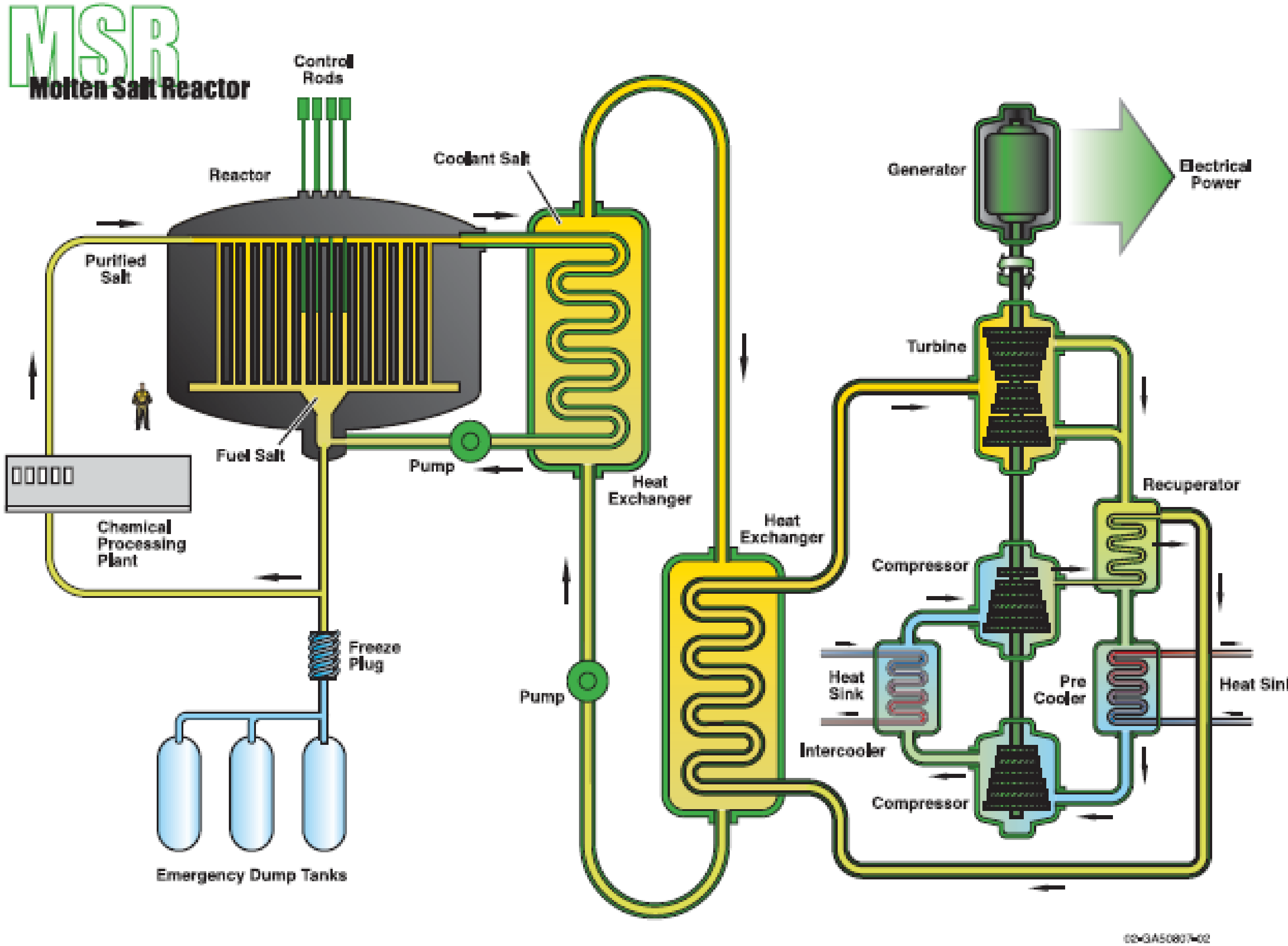
- Fast neutron spectrum
- Pb / Pb-Bi cooled
- Outlet 550-800°C
- Electricity production
- Closed fuel cycle
- Burn actinides, thorium as fuel
- Battery (50-150 MWe)
  Modular (300-600 MWe)
  Monolithic (1200 MWe)

Challenges

- Steel corrosion by lead?
- Pump resistance

MSR

- Fuel and coolant a molten fluoride mixture (U, Pu, Th, Na, Zr)
- Flexible fuel composition
- Outlet 700+°C
- Low vapor pressure in vessel
- Closed fuel cycle
- Burn actinides, produce electricity

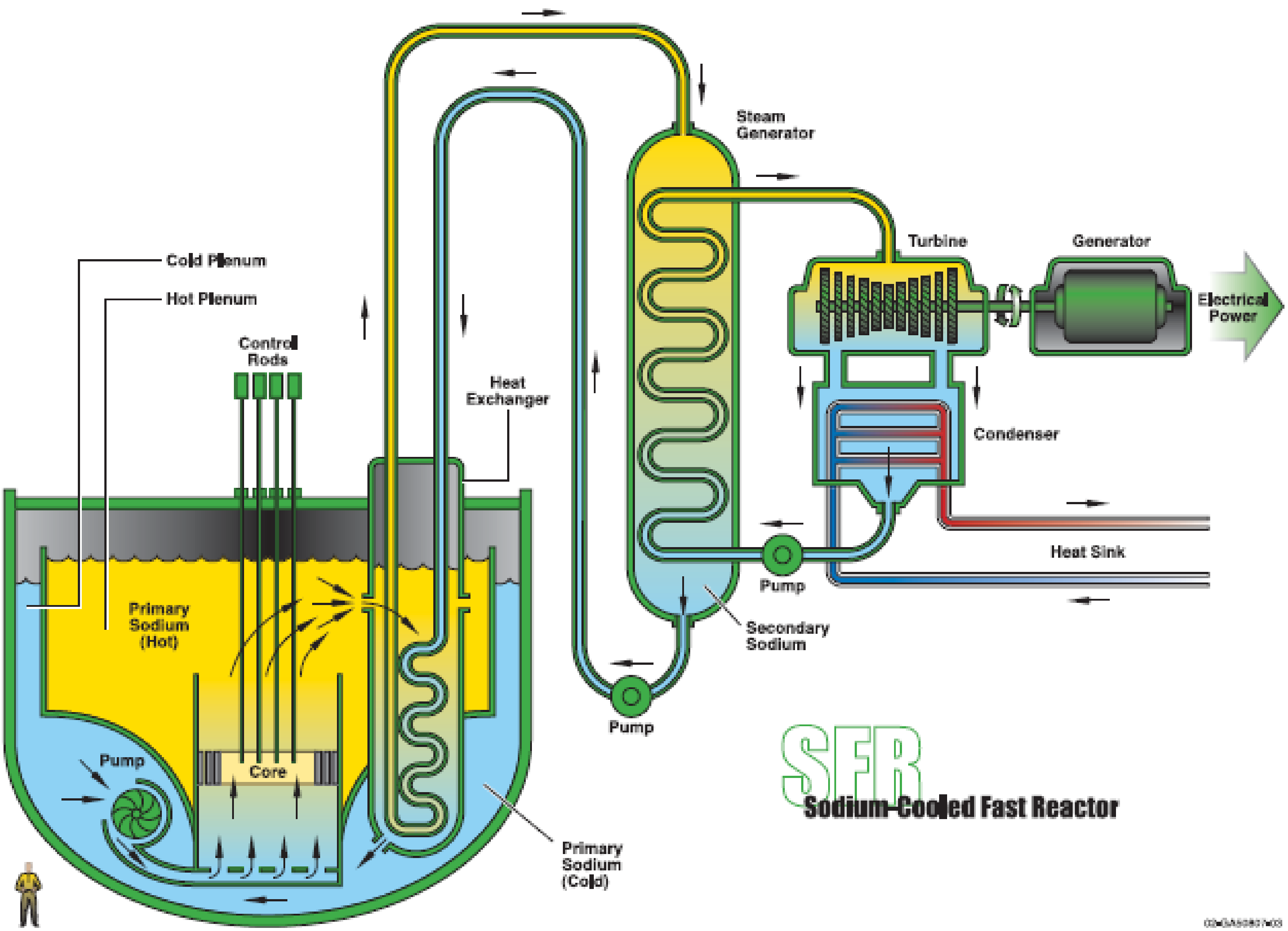


Challenges

- Fuel and fission products outside reactor
- Chemical separation, maintenance

SFR

- Fast neutron spectrum
- Low pressure in vessel
- Sodium-cooled
- Outlet 550°C
- Electricity production
- Closed fuel cycle, breeding
- Burn actinides

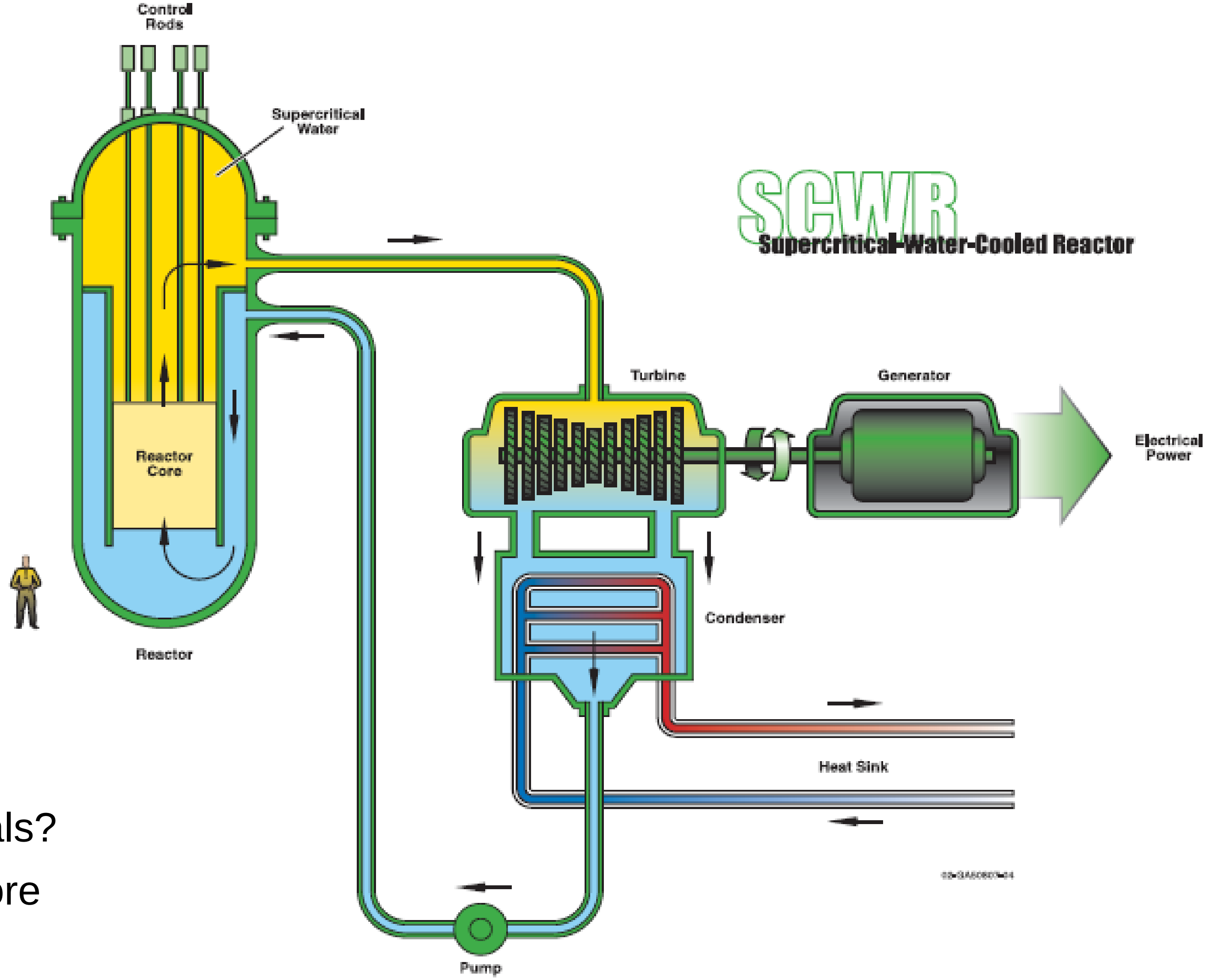


Challenges

- Sodium leakage control?
- Negative temperature coefficient?

SCWR

- Economical (simple)
- Super-critical-water cooled (no boiling)
- Outlet 550°C
- Electricity production
- High efficiency
- Open fuel cycle

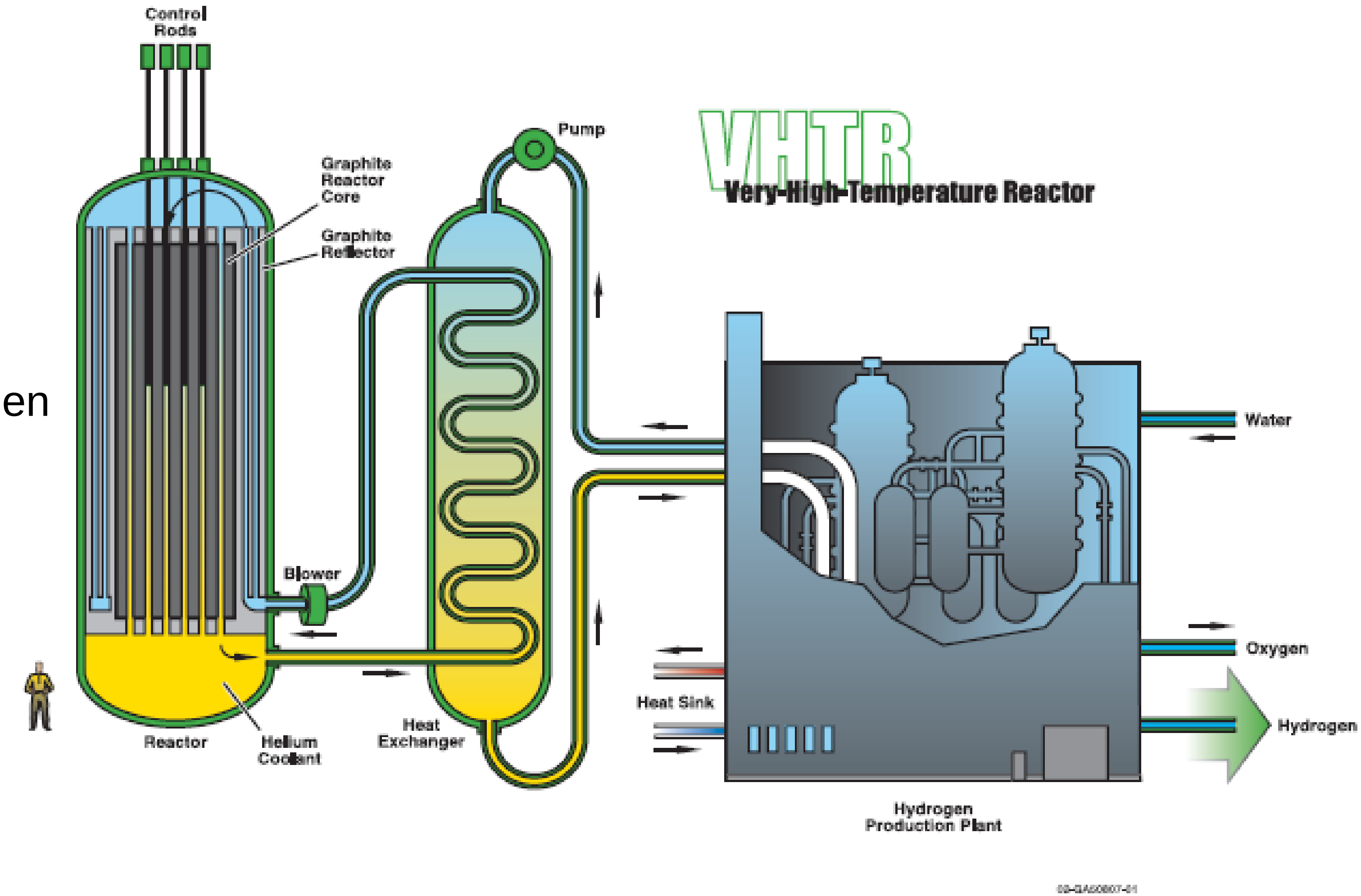


Challenges

- Structural materials?
- Coolant flow in core

VHTR

- Fast neutron spectrum
- Helium-cooled
- Outlet 1000+°C
- Heat for hydrogen separation
- Also electricity
- Open fuel cycle



Challenges

- Materials resistance?
- How to connect to a hydrogen plant?

What is the situation now?

- In 2009, Europe (SNETP/SRA2009) decided to focus R&D on SFR, LFR, GFR and MSR
  - some experience in fast and molten salt reactors exists!
- GenIV research in Finland
  - international collaboration led by big nuclear countries (France, Russia, USA, Japan, USA, China)
  - Gen4Fin (national network, http://virtual.vtt.fi/virtual/gen4fin)
  - Nomage4 (nordic network, http://nomage4.org)
  - materials, neutronics, fuel burnup, heat transfer, fluid dynamics
- SFR closest to being realized
  - BN-600 in Russia, Monju in Japan
  - ASTRID demo in France (2020)
- The rest is 2020+

Challenges for research

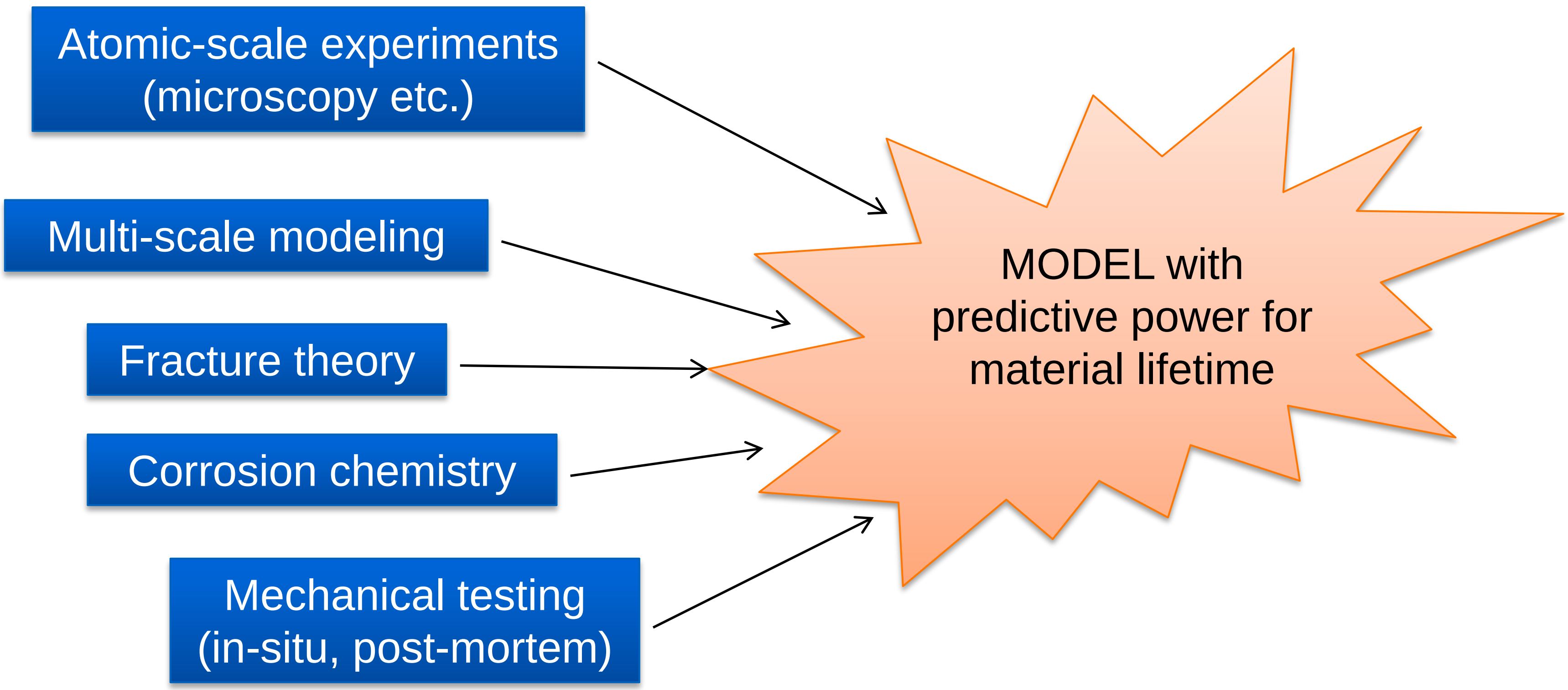
- Economics
  - mature vs. developing markets
  - prototypes expensive
  - how to combine with hydrogen production
- Safety, non-proliferation
  - credibility
- Fuel
  - materials development (oxides, nitrides, carbides, metallic)
  - closed fuel cycle
  - utilization of thorium
- Structural materials
  - high temperatures
  - fast neutron spectrum
  - new/challenging coolants (Pb, SCW)
  - manufacturing and construction

Materials!

- Science & engineering challenges
  - radiation damage (structural and fuel materials)
  - corrosion (structural materials, cladding)
  - these two combined + mechanical load, wear
- Similar issues in all GenIV reactors
  - and in the case of structural materials, also fusion reactors!
- Proper understanding missing on all scales
  - how to predict failure on the timescale of 50 years with experiments / theory taking clearly less time (hopefully)?

How to tackle the materials challenge?

Example: irradiation-enhanced stress-corrosion cracking (IESCC)



My background

- MSc (Tech.) in Engineering Physics from TKK in 2002
- DSc (Tech.) in Engineering Physics from TKK in 2005
- Research group leader at TKK and then Aalto 2006 →
  - defects in semiconductors
  - radiation damage in solids
  - positron annihilation spectroscopy (fast γ-ray spectroscopy)
  - design and construction of experiments & facilities
  - expat experience from Poland, France and USA

- Professor of Nuclear Engineering at Aalto 5/2012 →

What is happening in Aalto University?

- BSc/MSc system being enforced further
- Nuclear teaching: development of a multidisciplinary MSc-minor in Nuclear Engineering for engineering majors
  - reactor technology, nuclear and radiation safety, waste management, risk analysis, economics, radiochemistry, (digital) automation, materials physics/science/engineering
  - tunable depending on major
- Nuclear research (and training): Otaniemi area (and national) competences being gathered under ”nuclear safety” programme
  - YTERA doctoral programme
  - Research infrastructure a part of the national FIRI programme (VTT Otaniemi, LTU, JHR participation)