Lead cooled Generation IV reactors in the light of Fukushima

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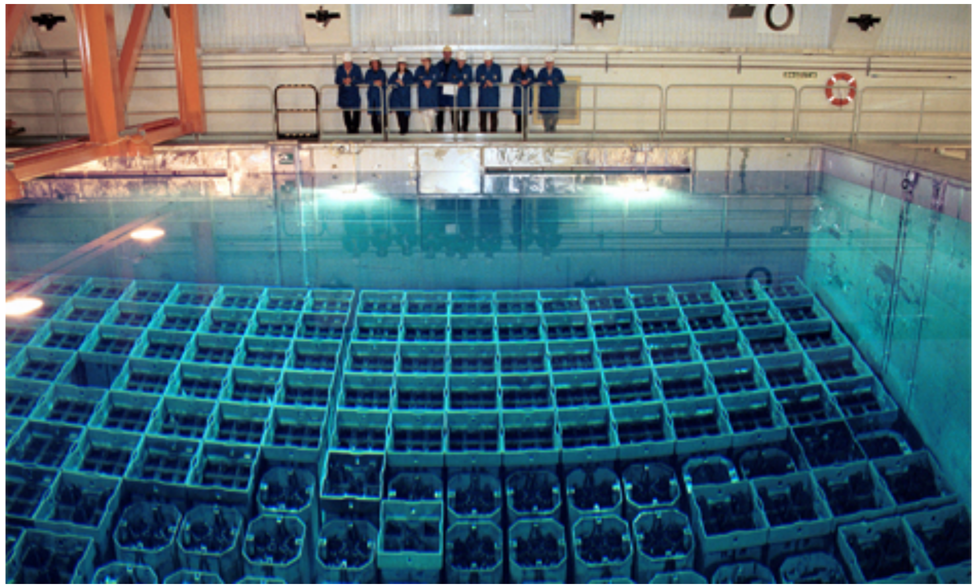
Objectives of Generation IV

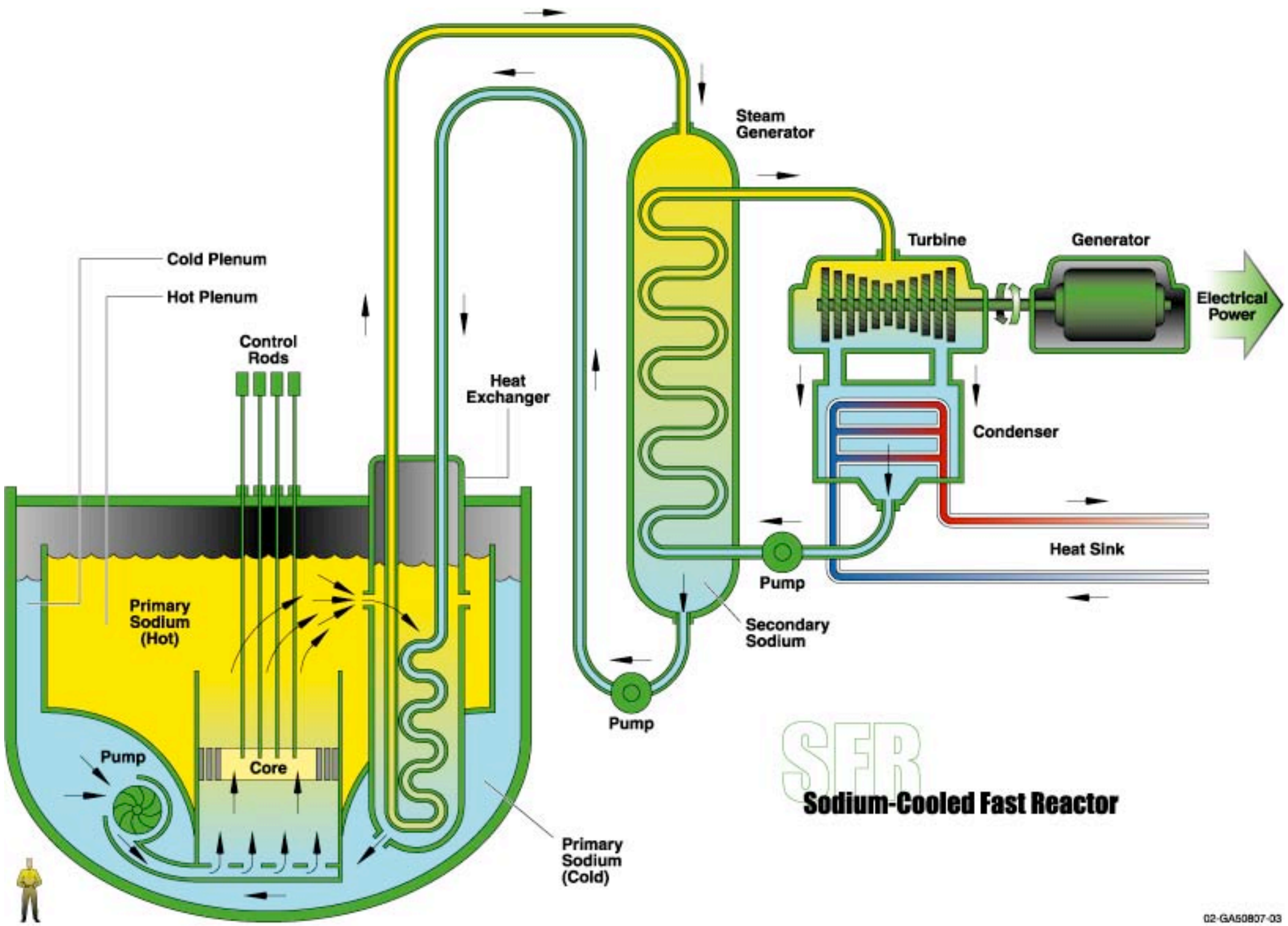


- Using uranium waste from enrichment plants and plutonium from spent LWR fuel, Gen-IV reactors may substitute the present LWR fleet and operate for the next 10 millenia. At least.
- High level actinide waste (Am & Cm) may be recycled, reducing the waste stream by a factor of 100.
- The capacity of the Swedish repository increases by factor of 6.

What about severe accident and core melts?

- Generation IV criteria:
- Core melt frequency < 10^{-6}/y
- Compare e.g. with ESBWR: 3×10^{-8}/y
- In addition:
- No evacution should be necessary in case of core damage (!)
- Dose limits: less than 50 mSv beyond 800 m from plant; less than 5 mSv beyond 3 km.

The sodium cooled reactor

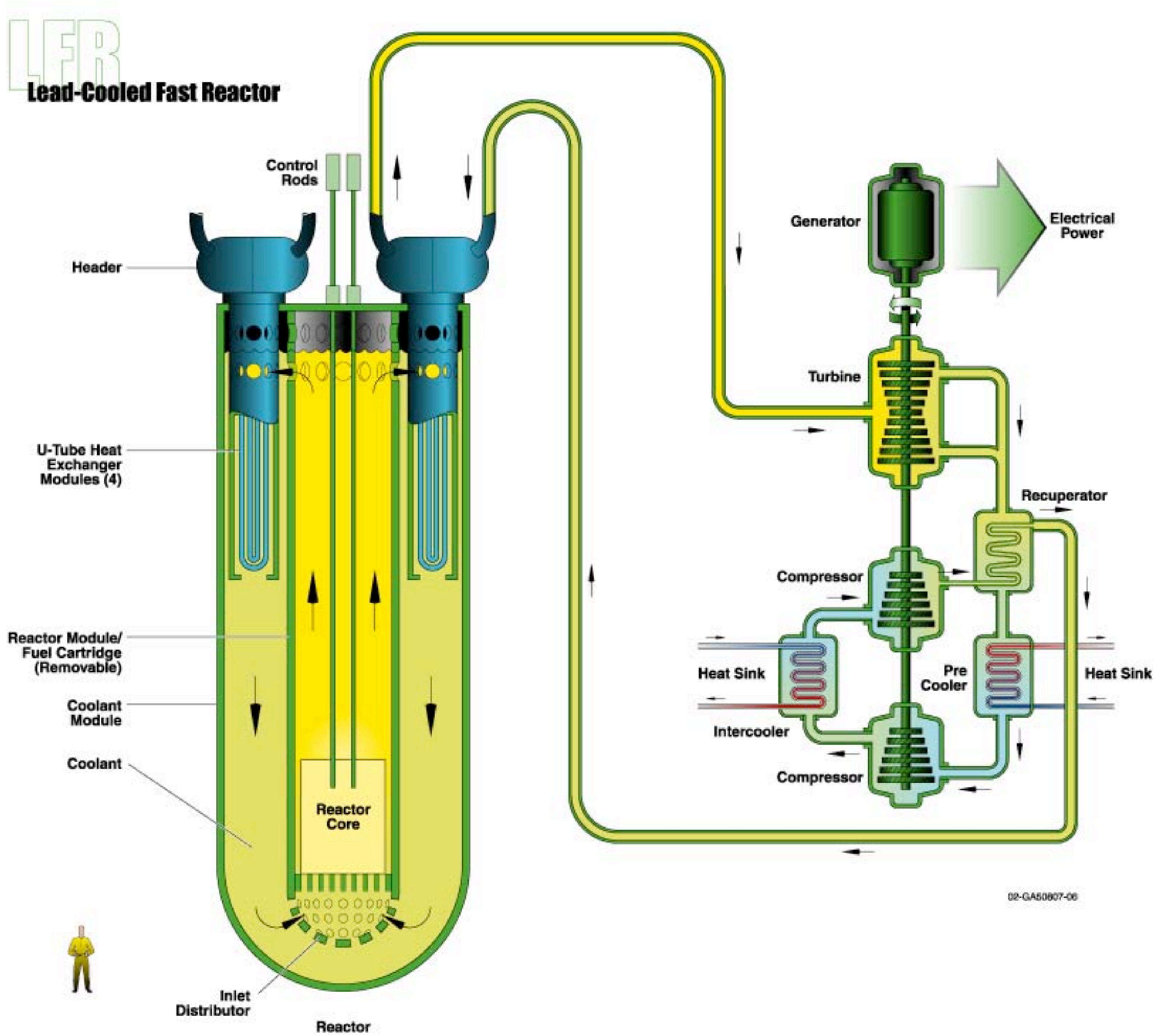


SFR

- Industrially mature (BN-600, Phénix)
- ASTRID 600 MWe prototype may be taken into operation in early 20's
- Good breeding ratio
- High cost for prevention of sodium leaks
- Safety problems related to coolant boiling and severe accidents

Phénix
Marcoule
France

The lead cooled fast reactor



LFRs

K745

Soviet submarine

\+ No rapid exothermal reaction with water. Heat exchanger may be located in primary circuit

\+ High boiling temperature (2000 K)

\+ High absolute expansion coefficient. Buoyancy forces may be used for decay heat removal

\+ Lead is good for retaining iodine & caesium (chemically) and gamma radiation (physically)

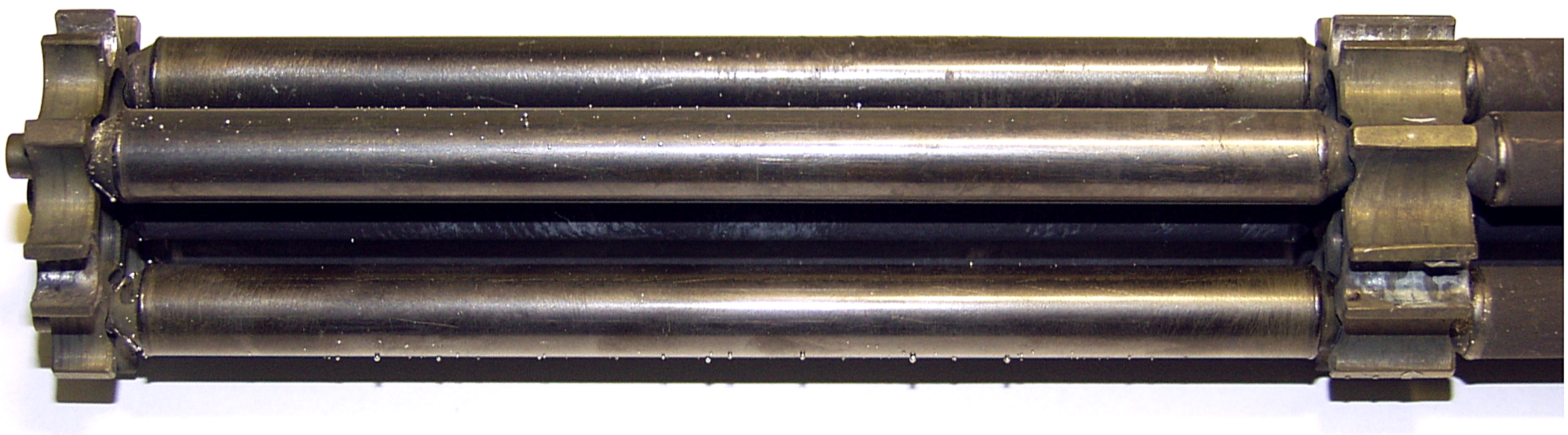
– Coolant technology only used in military reactors with ”intermediate” neutron spectrum

– Costs for oxygen control and surface protections

– Erosion of pump materials

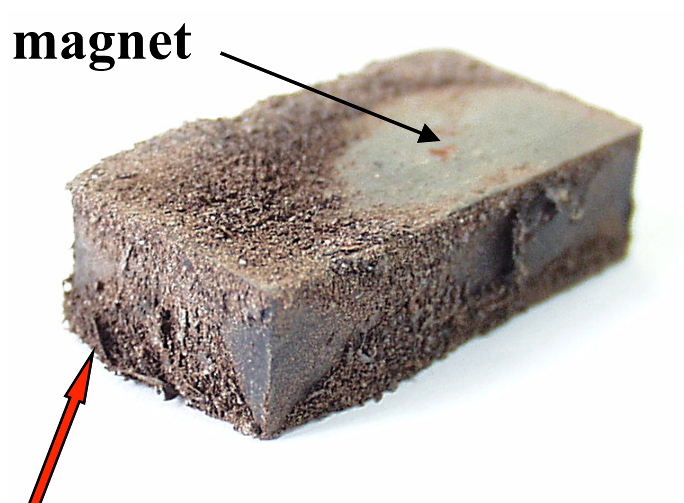
Corrosion in lead

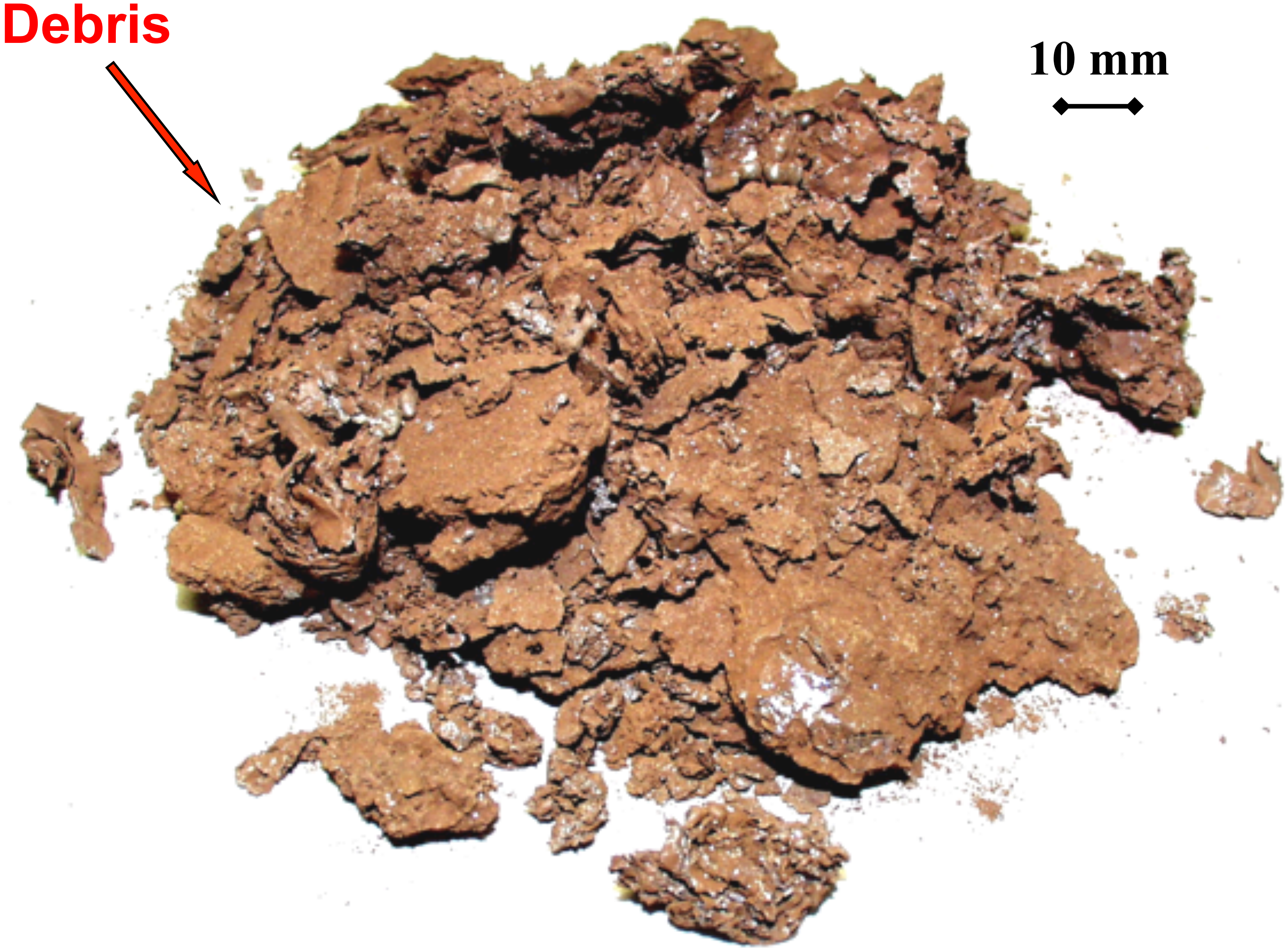
- Russian ferritic-martensitic steel EP823 (2% Si) after 16 000 h in flowing lead at 650°C (~2 ppm oxygen)
- 30 000 h tests at 600°C show equally good performance



Corrosion in lead

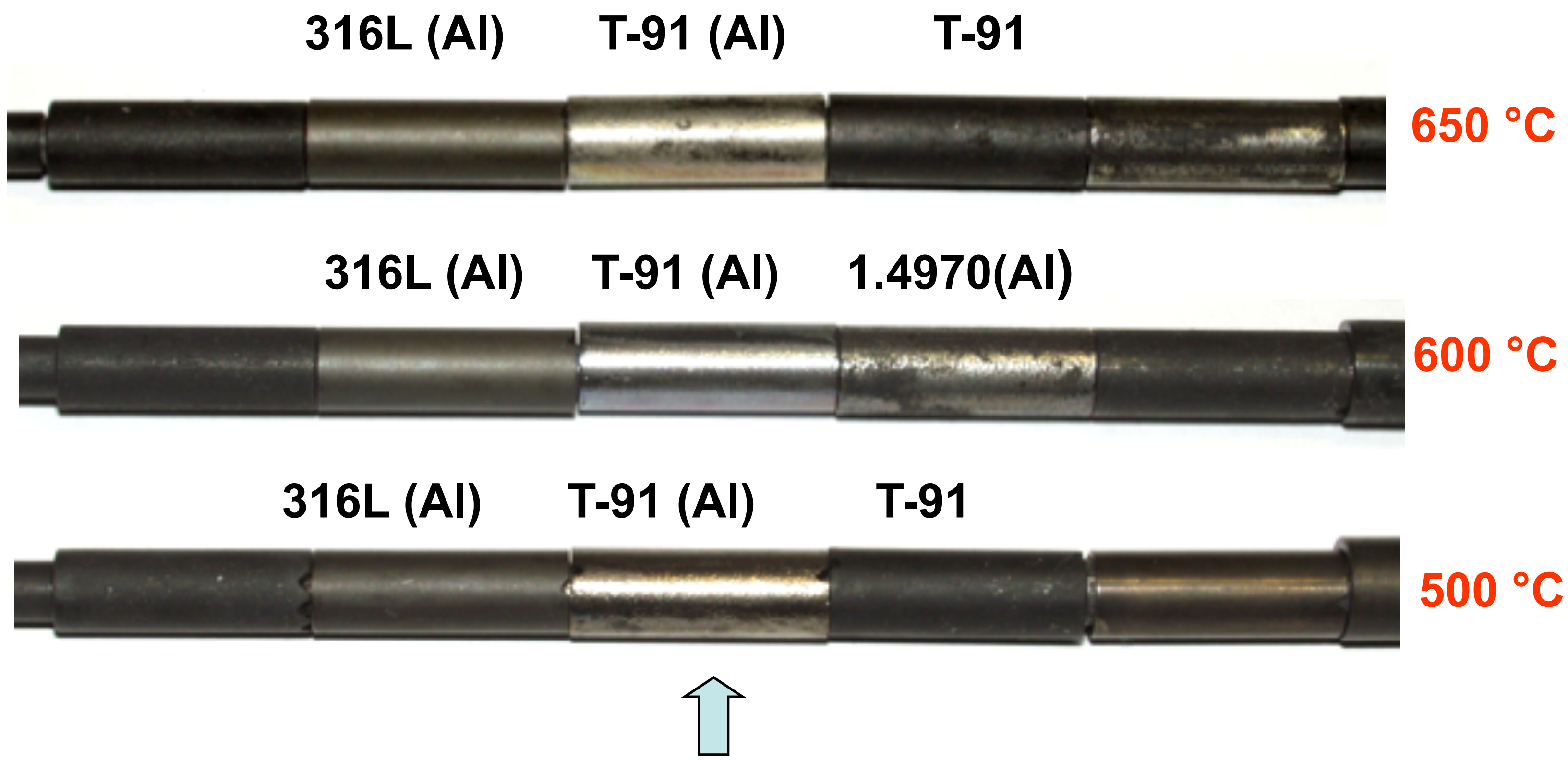
EP823 in flowing lead at non optimal oxygen concentration





Alumina protection

- 1500 h corrosion test in flowing liquid lead at 50 ppm oxygen

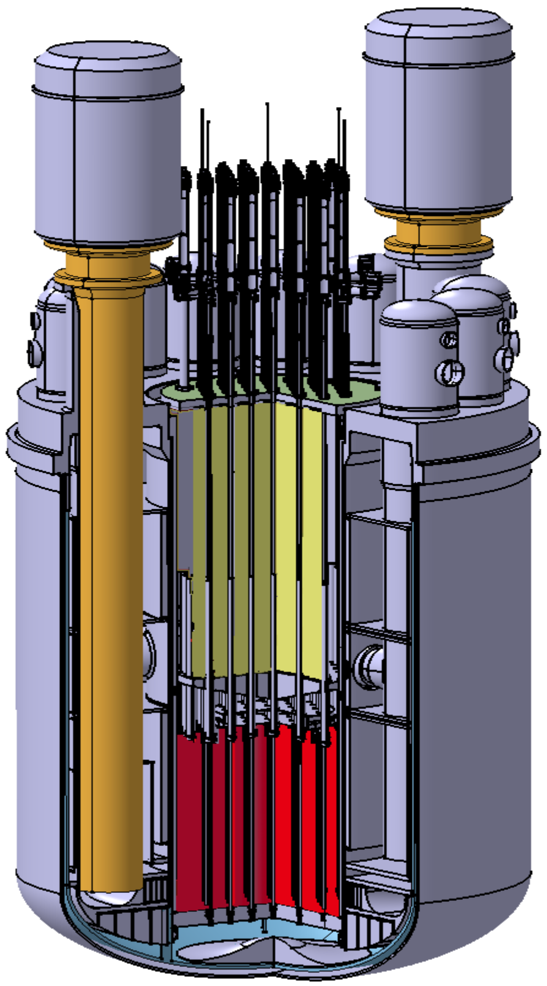


- GESA treated T91 in perfect condition after > 17 000 h at 550°C

Pump material issue

- Pump impeller blade in MYRRHA and ALFRED will be operating at 10 m/s relative velocity to the coolant
- Ferritic martensitic steels are severely eroded even at optimal oxygen conditions

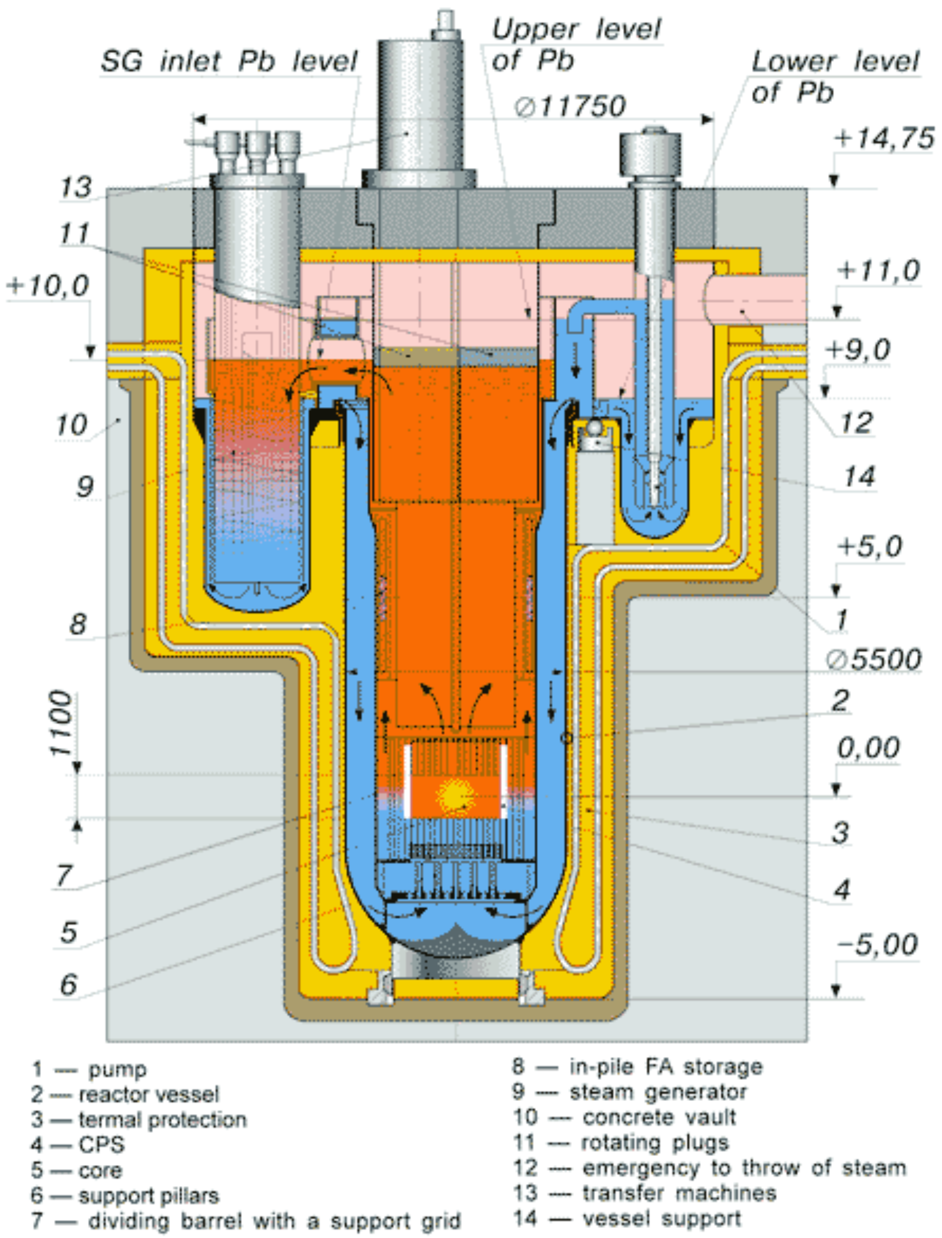
Commercial reactor deployment: SVBR-100



SVBR-100

- Based on Silicon oxide protected ferritic-martensitic steel cladding, the submarine reactor design has been converted to a commercial concept
- SVBR-100: lead-bismuth cooled reactor with 100 MWe power, using MOX or nitride fuel. MOX gives breeding ratio ~ 0.84, nitride ~ 1.0
- Development financed by consortium between Rosatom and private investors
- Construction to start 2017 in Dimitrovgrad
- http://www.akmeengineering.com/svbr100.html

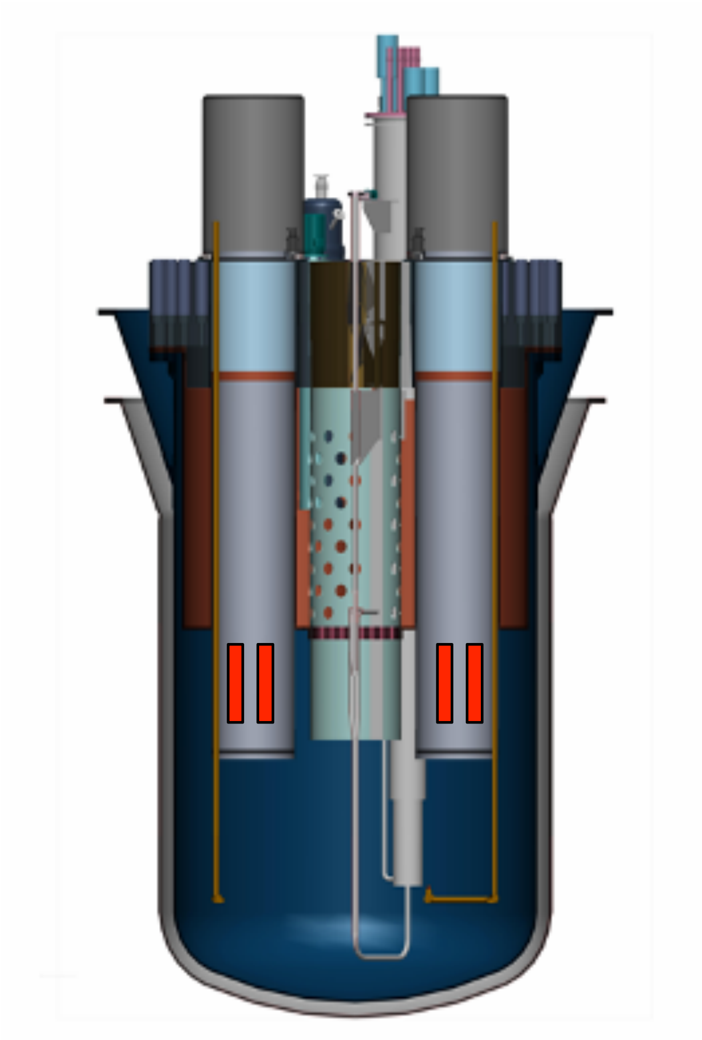
The BREST reactor



BREST-300 reactor. Vertical section

- Lead cooled reactor with (U,Pu)N fuel
- 300 MW electric power
- Developed by NIKIET since 1994
- Passive safety features are paramount
- Planned start of construction: 2019
- http://www.nikiet.ru/eng/structure/mr-innovative/brest.html

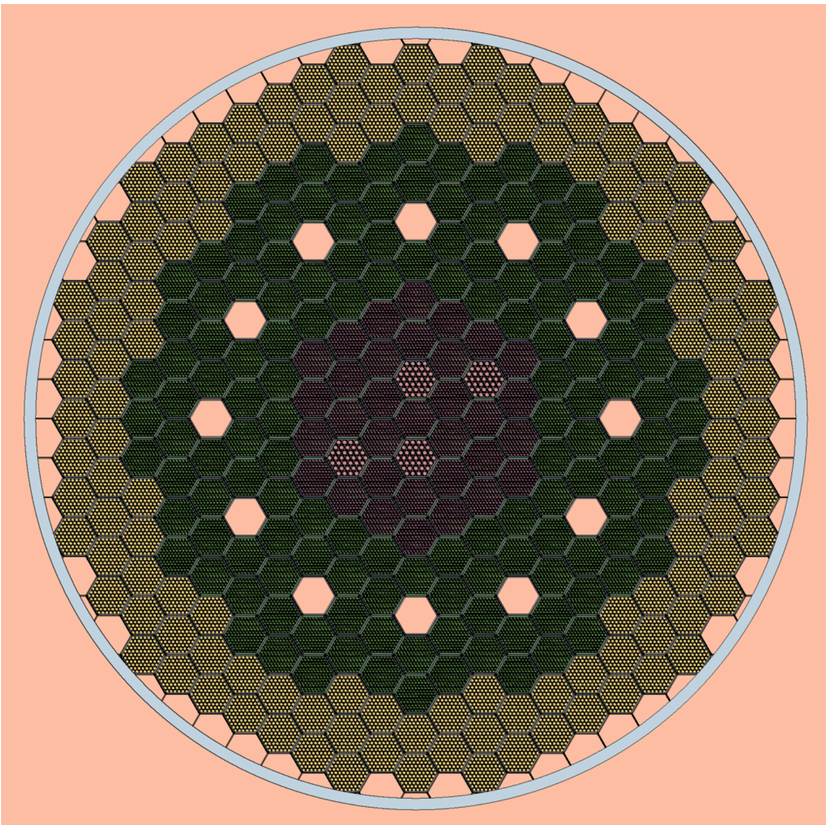
MYRRHA



MYRRHA

- Lead-bismuth cooled reactor för research, materials testing and production of medical isotopes
- 65-100 MW thermal power, MOX fuel
- Developed by SCK-CEN in Belgium
- Start of construction: 2016, operational in 2023
- Cost calculated at 1.0 G€. Belgium funds 40%.
- Swedish participation within the ESFRI frame to be discussed at VR hearing on June 14
- http://myrrha.sckcen.be/

ALFRED



ALFRED

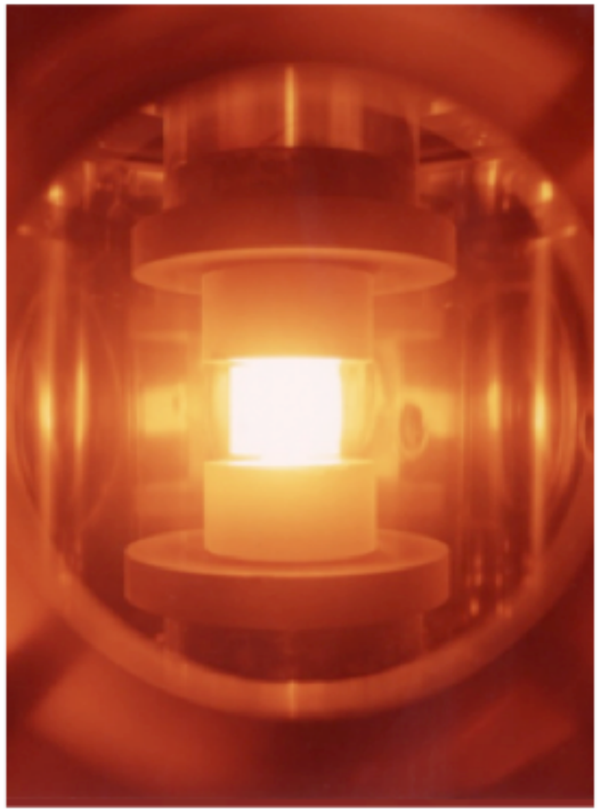
- Advanced Lead Fast Reactor Demonstrator
- Lead coolant and MOX fuel
- Aluminum oxide protected steel (GESA method)
- 120 MWe power. Operational in 2025 (?)
- Under development in the LEADER project, coordinated by ANSALDO.
- Romanian candidacy for hosting ALFRED
- KTH participates in safety analysis and coordinates training & education

GENIUS

- Generation IV research in Swedish Universities (KTH, Chalmers & UU)
- 4 M€ funding from VR for 2009-2012. Ten PhD students fully funded by programme.
- Three work packages
- Fuel development (Nitride fuel fabrication)
- Materials research (Corrosion tests, radiation damage modelling)
- Safety & security (lead-fuel compatibility...)
- http://genius.kth.se

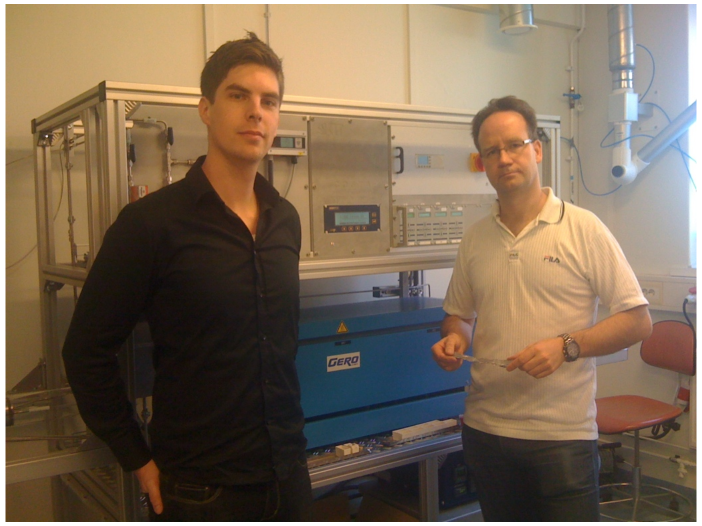
UPPSALA UNIVERSITET

GENIUS: Fuel fabrication



- UN powders fabricated at KTH by hydridation/nitridation of metallic source materials (Mikael Jolkkonen, Pertti Malkki)
- Pellets fabricated in collaboration with DIAMORPH, using spark plasma sintering (SPS) technique. Equipment resides in AlbaNova!
- Hot pressing under 5000 ampere current
- UN pellets with 98.2% density obtained when holding for 5 minutes at 1650°C!

GENIUS: Corrosion protection



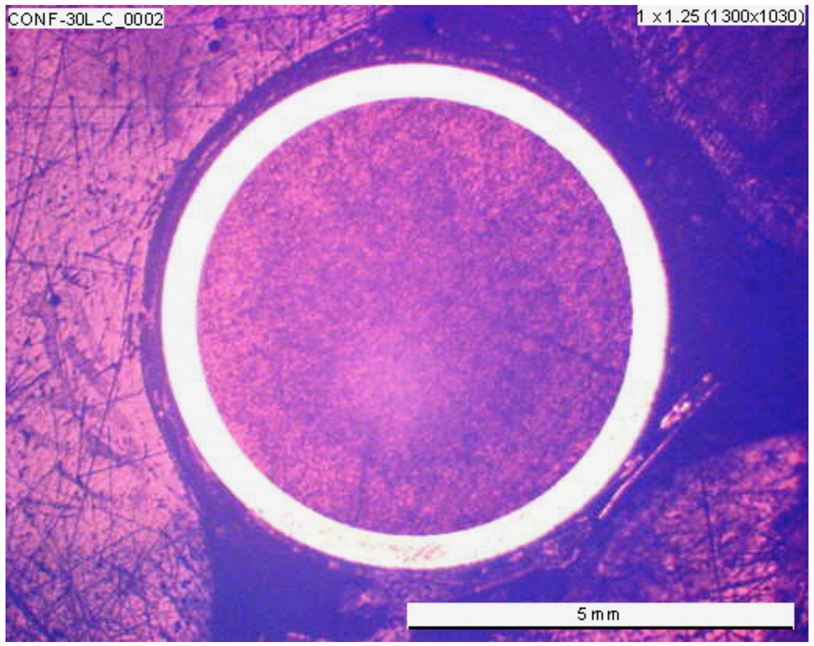
- Corrosion lab with lead furnace purchased from Karlsruhe in operation since February 2011
- Premises: Surface and corrosion science (Peter Szakalos and Jesper Ejenstam)
- Tests of novel FeCrAl alloys provided by Sandvik ongoing
- First batch ready in June (2000 hours). 2nd batch will go to 10 000 hours.
- Tests of advanced pump materials under planning

Earlier achievements: Natural convection

TALL

- 6 m TALL lead-bismuth loop operational at KTH since 2004.
- Unique facility in Europe
- T = 450°C.
- Extensively used for investigation of natural convection studies and experimental validation of heat transfer models
- Weimin Ma, Aram Karboijan, Raj Sehgal

Earlier achievements: Fuel irradiation



CONFIRM fuel

- (Pu,Zr)N fuel fabricated and irradiated within CONFIRM project in FP5
- 10% burnup of plutonium at 43-46 kW/m achieved in the High Flux Reactor
- Fuel temperature < 1500 K
- Post irradiation examination: < 5% release of Xenon, 80% release of helium
- Swelling: 0.9% per percent burnup

ELECTRA:
European Lead Cooled Training Reactor

ELECTRA

- Successful reactor development starts in small scale. Difficult however to design small fast neutron core with MOX fuel
- 0.5 MW core with (Pu,Zr)N bränsle may be cooled by100% natural circulation of lead. Core size 30x30 cm! Reactor vessel ~ 1.5x3.0 m.
- Test reactor with long term use for education and training
- Pump free design with 400 fuel pins in core –> Technology is available today, fuel can be fabricated in small scale pilot plant.
- May be operational by 2020, perhaps in Oskarsham!

Summary

- Lead cooled generation IV reactors may be the long term solution for safe and sustainable nuclear power
- Significant progress on corrosion protection has been achieved
- Lead (or LBE) fast reactors under planning in Europe:
- SVBR-100 (Russia)
- BREST (Russia)
- MYRRHA (Belgium)
- ALFRED (Romania)
- ELECTRA (Sweden)