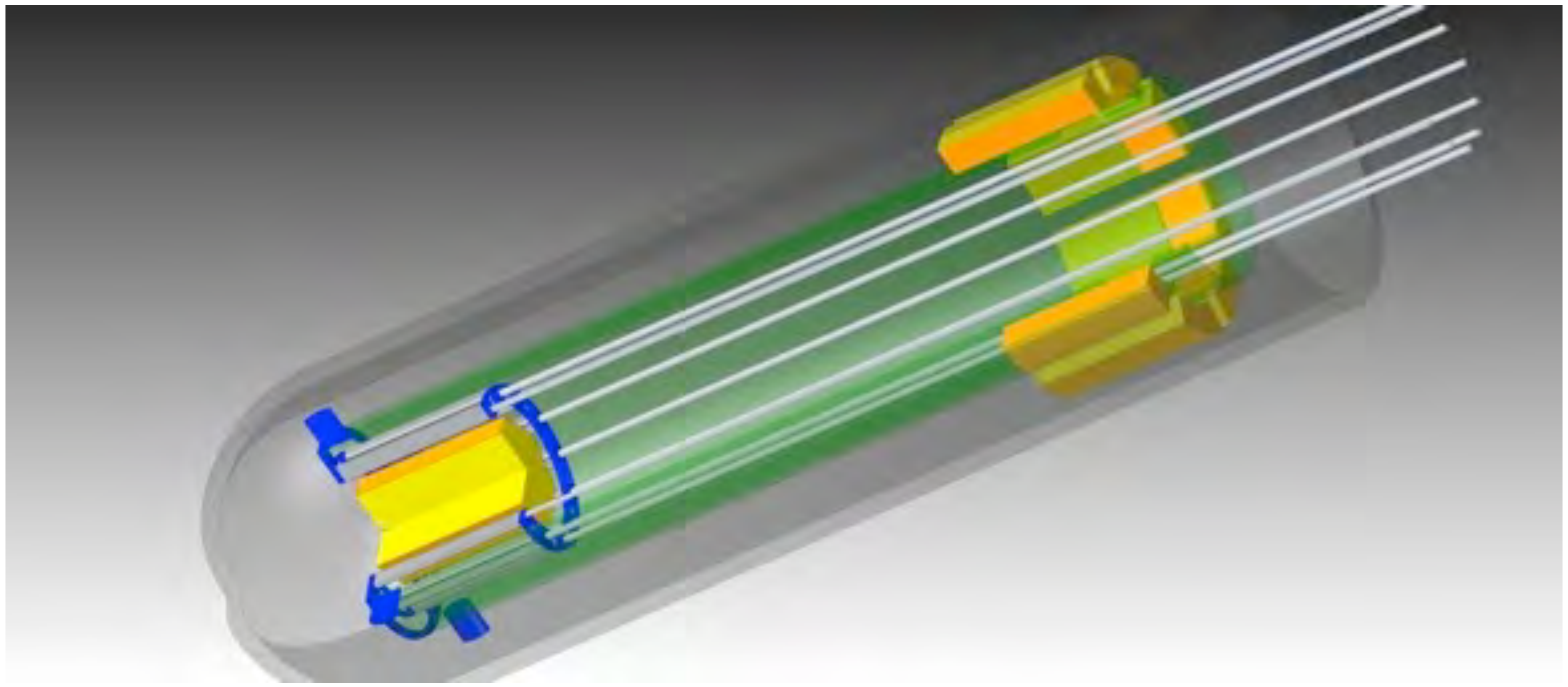
# New reactor technology – status of current research



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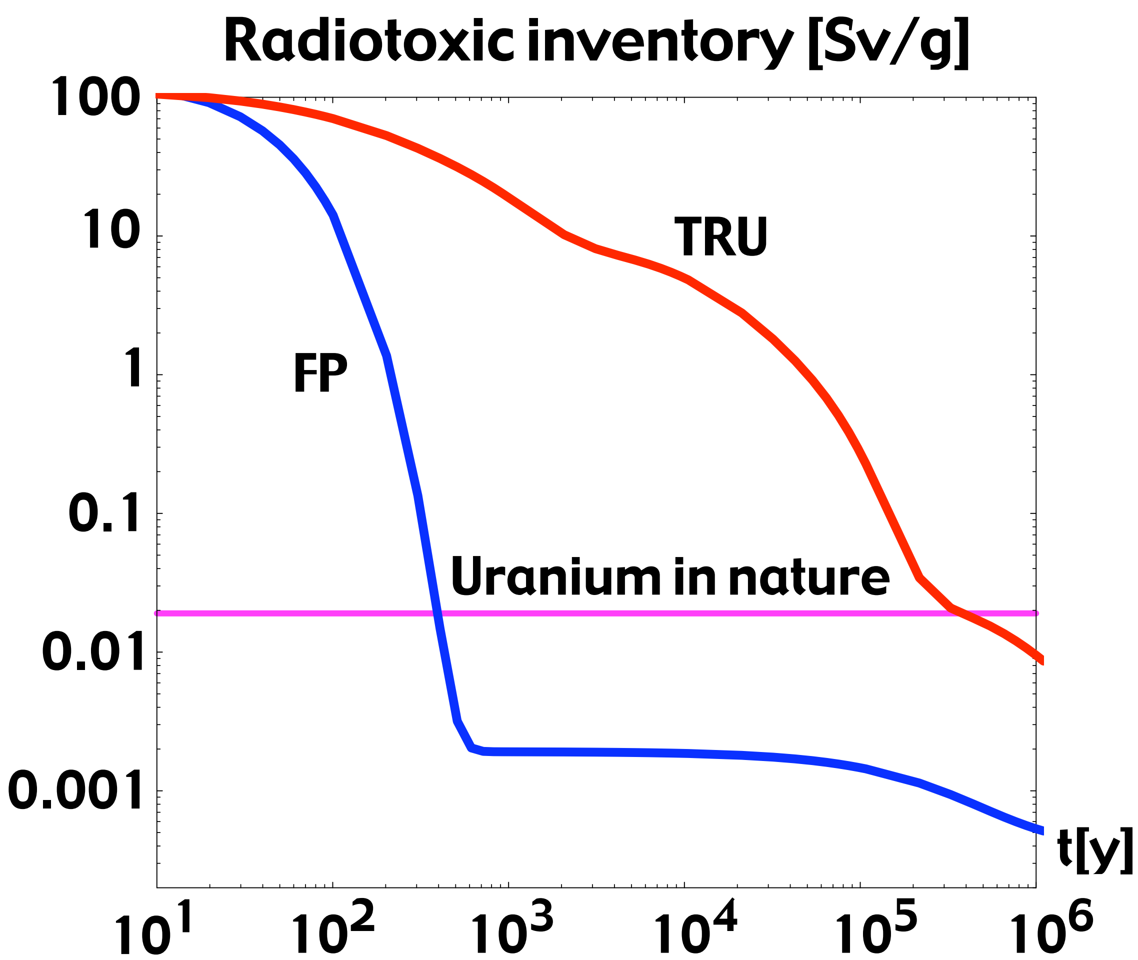
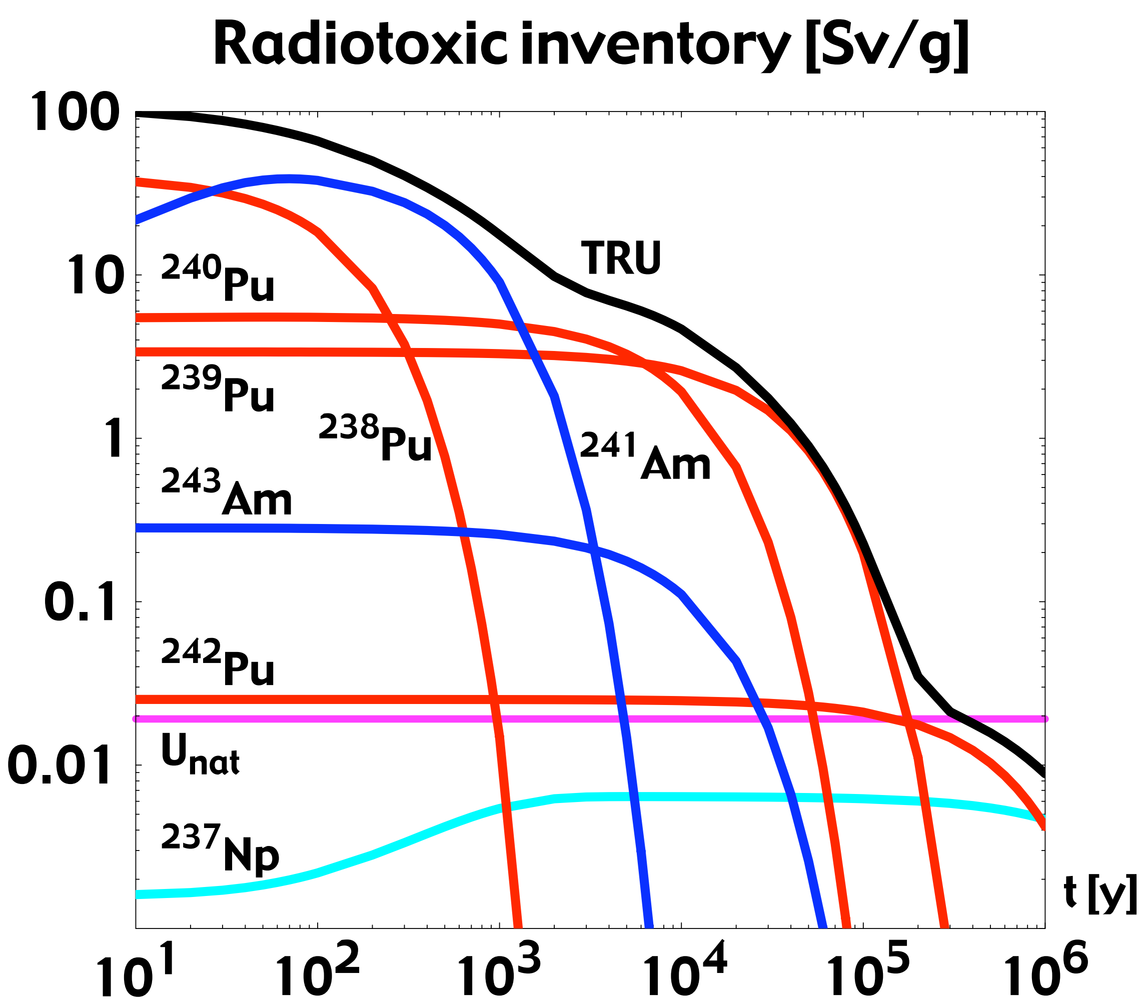
# Nuclear waste



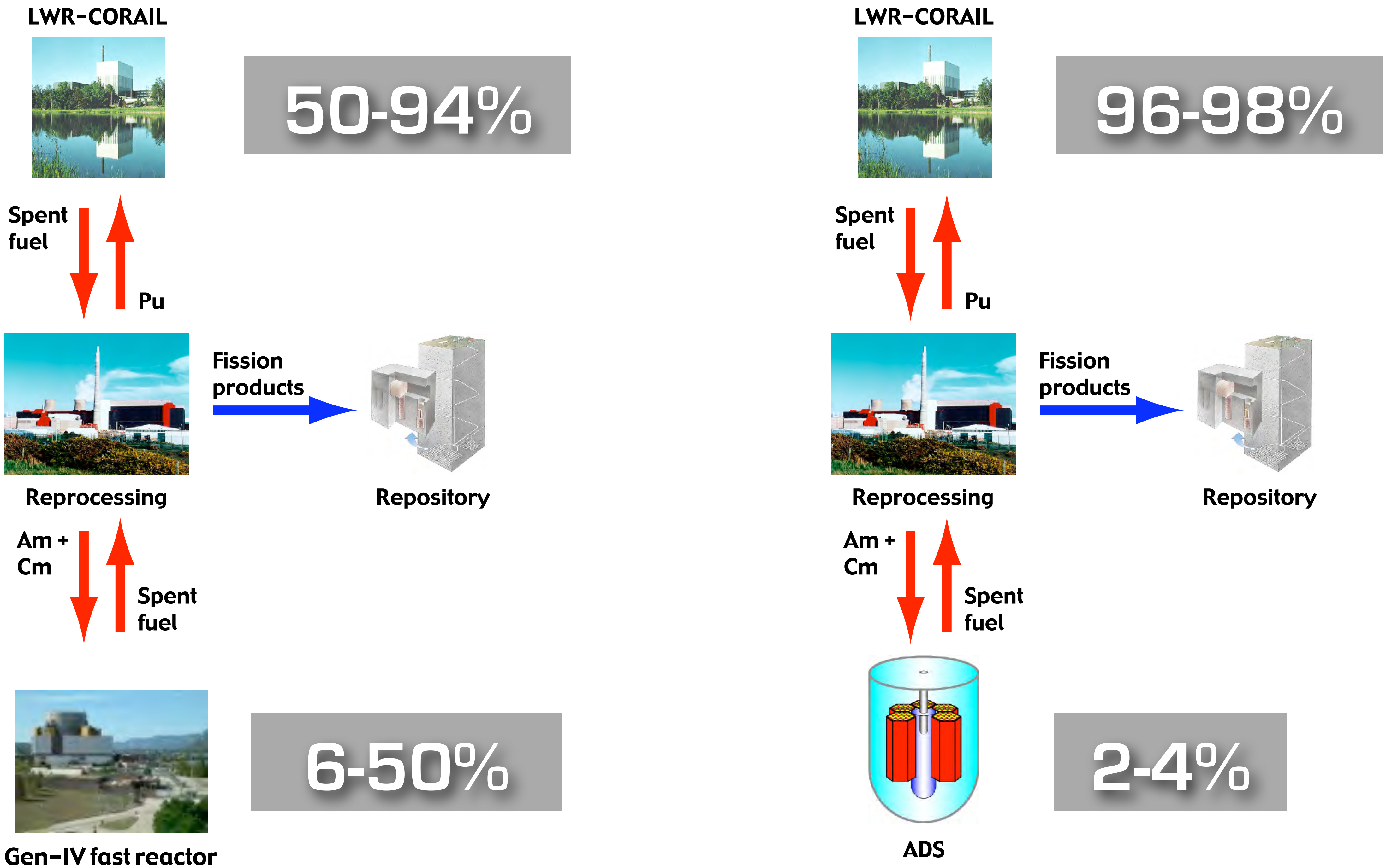

- Specific radiotoxic inventory of spent LWR fuel in the repository is dominated by transuranic elements (TRU).
- The fission product (FP) contribution to the radiotoxic inventory vanishes with the decay of $^{90}Sr$ and $^{137}Cs$.
- Equilibrium radiotoxic inventory of uranium in nature ~ 19 mSv/g.
- 300 000 years of storage required for spent fuel to return to "natural inventory".

# Radiotoxicity of transuranium nuclides




- Long term radiotoxic inventory of spent fuel is dominated by
- $^{241}Am$ ~ 1 000 years
- $^{240}Pu$ ~10 000 years
- $^{239}Pu$ ~100 000 years
- Radiotoxic inventory due to presence of $^{237}Np$ is less than that of uranium in nature.

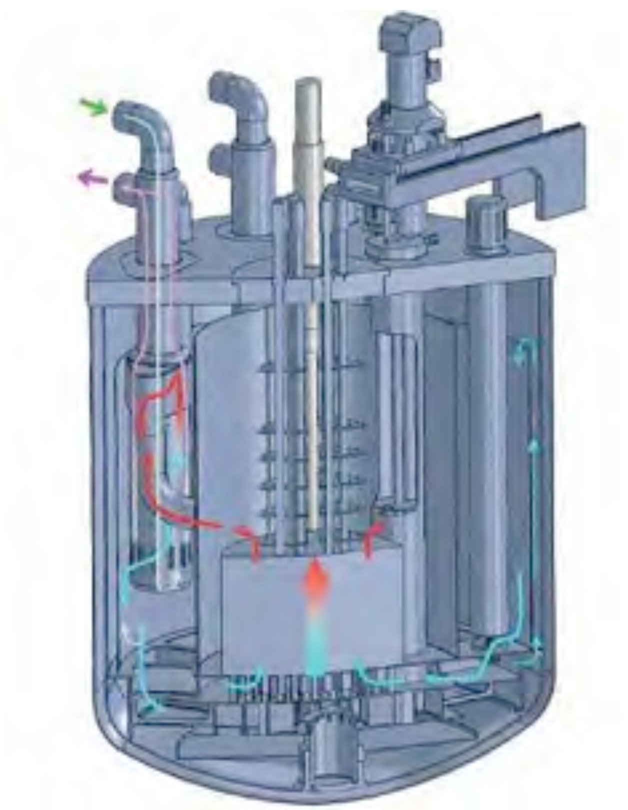
# Recycle and transmute?!



# What do we gain with Gen-IV reactors?

- 100 times more efficient use of uranium
- Use of nuclear power for 5000 years without mining of uranium
- Reduce the inventory of high level waste in repositories to 1%
- Shorten the time required for deep storage to less than 1000 years
- Increase the capacity of high level waste storage by factor 3-6

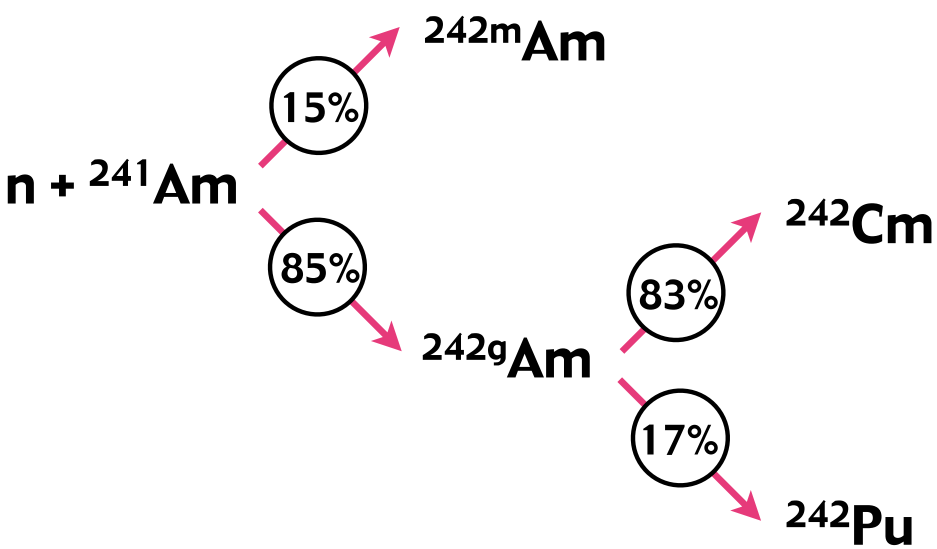
# ASTRID: first Gen-IV prototype



ASTRID

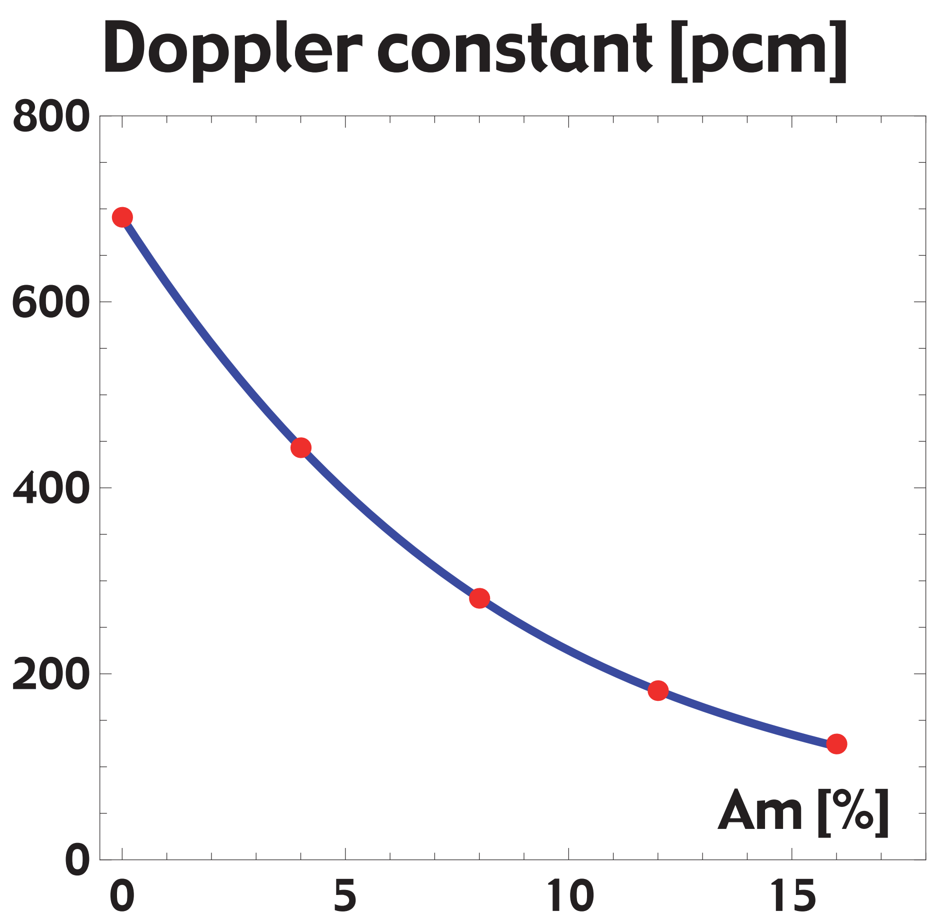
- 600 MWe sodium cooled fast reactor
- Operation in early 20's in Marcoule, France
- Heterogeneous transmutation of Am in dedicated $(U,Am)O_2$ blanket assemblies
- Americium concentration ~ 15%
- MARIOS test irradiation completed in the Netherlands
- Transmutation rate of 30% per irradiation feasible (mainly by conversion to plutonium and curium)
- Major issue: Decay heat of blanket assembly

# Origin of excess decay heat




- $^{242}$Cm is produced by transmutation of $^{241}$Am
- Half-life: 162 days
- Heating from alpha-decay is huge!

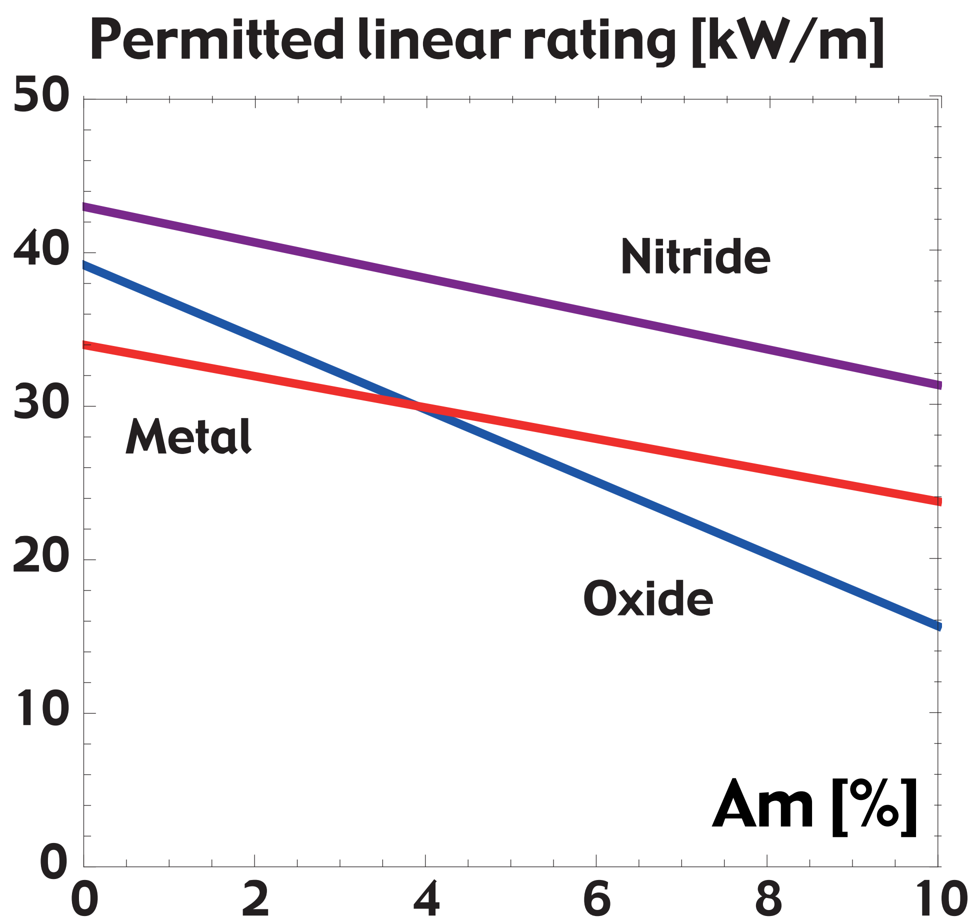
# Homogeneous recycle: Doppler issue




Fuel: $(U_{0.82-x},Pu_{0.18},Am_x)O_2$

- With homogeneous recycling, decay heat of $^{242}Cm$ is less of a problem.
- However, americium destroys your Doppler feedback.
- Transients become more severe.
- Nominal power density must be reduced when increasing americium

# Choice of fuel



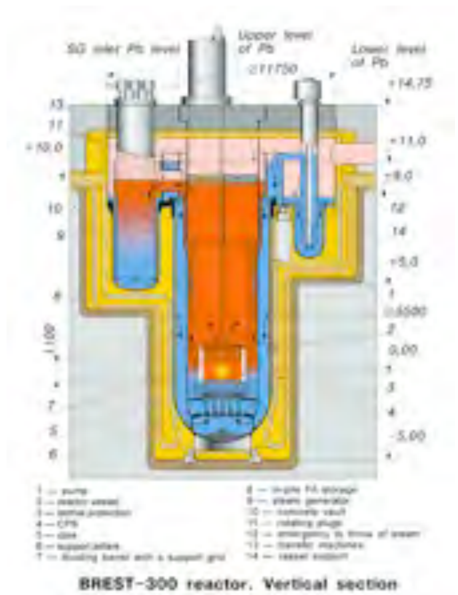

- A fuel combining high thermal conductivity with high failure temperature survives more severe transients.
- Such fuels may accommodate higher fractions of americium.
- With nitride fuels, less than 10% of the nuclear power produced must derive from Gen-IV systems!

# Choice of coolant

- Lead coolant would offer enhanced safety in terms of
- No rapid exothermic reaction with water
- High boiling temperature
- Excellent potential for natural convection
- Good chemical retention of fission products
- Good shielding for gamma radiation

# Lead fast reactor projects: Russia

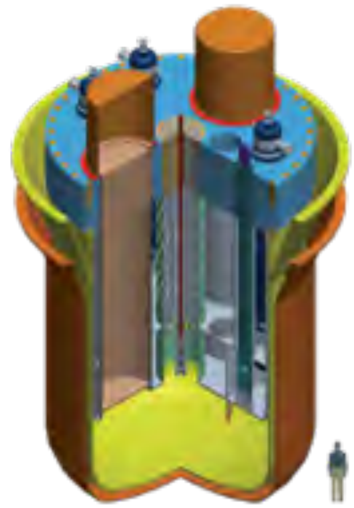
SVBR-100



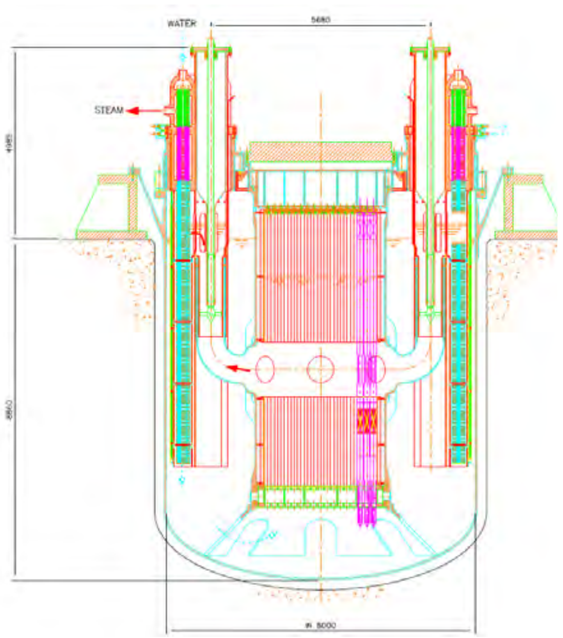

BREST-300

- **SVBR-100**: lead-bismuth coolant, 100 MWe, MOX fuel.
- Based on sub-marine reactor design
- Financed by Rosatom and private investors
- To operate in Dimitrovgrad by 2020
- **BREST-300**: lead coolant, 300 MWe, (U,Pu)N fuel.
- Financed by Rosatom with 1 billion € (including nitride fuel fabrication plant)
- To operate in Tomsk region by 2020

# Lead fast reactor projects: Europe



MYRRHA

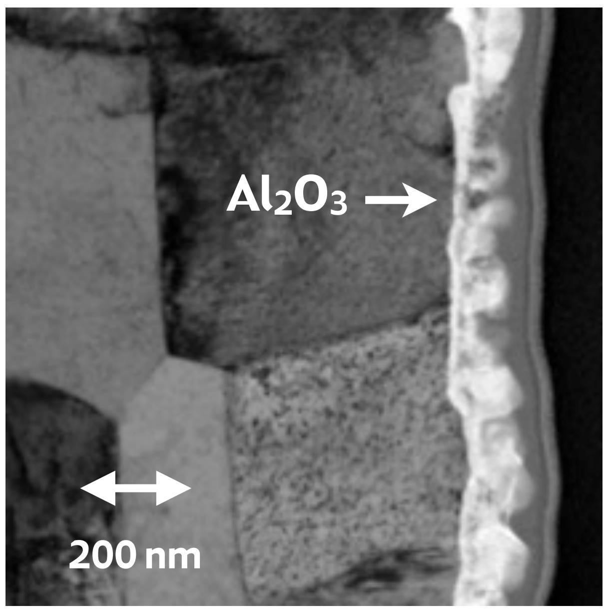



ALFRED

- MYRRHA: lead-bismuth coolant, 100 MWth, MOX fuel.
- Materials test reactor, proof-of-concept ADS
- Total cost: 1 G€, 40% funded by Belgian government
- To operate in Mol by 2024
- ALFRED: lead coolant, 130 MWe, MOX fuel
- LFR demonstration
- Romanian government offered to host ALFRED
- To operate in Pitesti after 2025

# Lead corrosion






Fe10Cr6Al-RE after 10 000 h @ 550°C

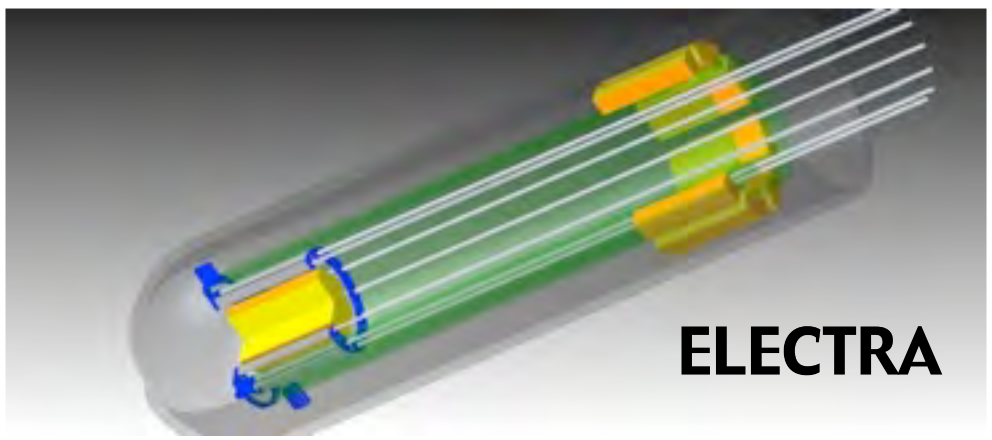
- Major issue with lead coolant: corrosion of cladding steel
- Protection by alumina forming surface has proven effective in long term out of pile tests
- The GESA technique, developed by KIT, entails low pressure plasma spray coating with FeCrAlY and surface alloying using pulsed electron beam.
- Novel aluminium bearing alloys are developed by Sandvik in collaboration with KTH

# ELECTRA:
# European Lead Cooled Training Reactor

ELECTRA

- 0.5 MW fast reactor with (Pu,Zr)N fuel cooled by 100% natural convection of liquid lead
- Wallenius et al, Nuclear Technology 177 (2012) 303
- Core size 30 x 30 cm! Reactor vessel ~ 1.5 x 3.0 m.
- Tentative cost: ~ 35 M€ (based on real cost of Swiss LBE spallation target with 0.7 MW power)

# ELECTRA fuel cycle centre in Oskarshamn

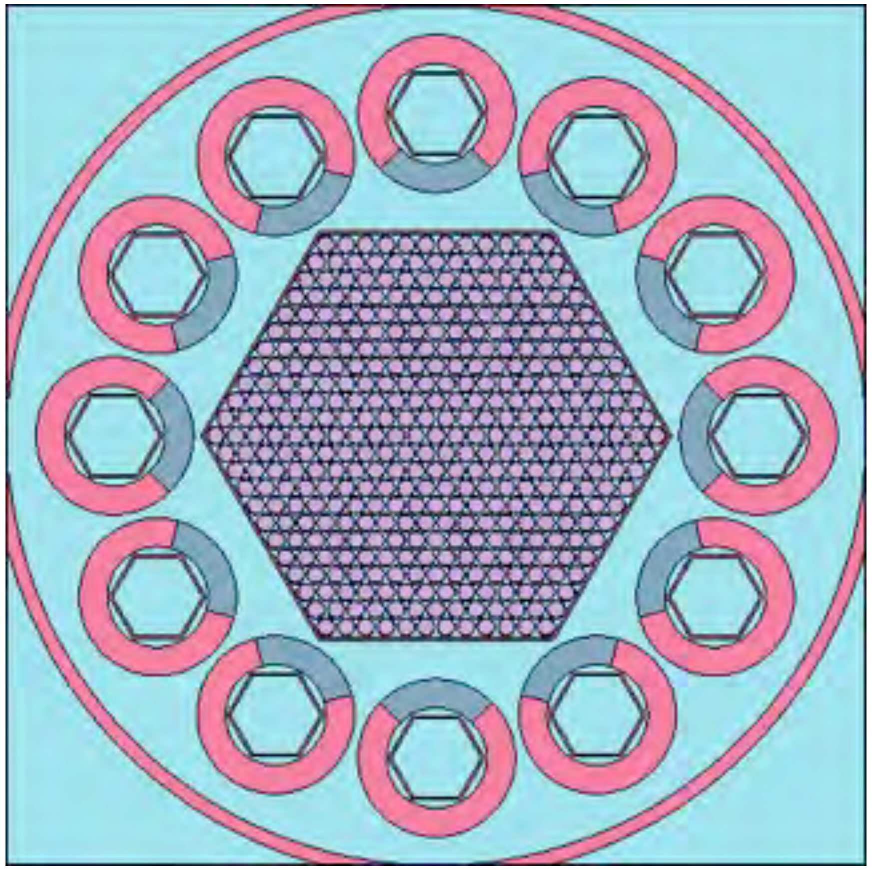




- KTH, Chalmers & Uppsala University proposed to construct ELECTRA-FCC in Sweden, a centre for Gen-IV system R&D, including
- Facility for processing of 4 tons of spent LWR fuel per year, relying on group extraction of Pu,Am & Cm.
- Fuel fabrication facility for (Pu,Zr)N fuels, with capacity of ~ 2 fuel pins per day
- ELECTRA – 0.5 MW lead cooled fast reactor with (Pu,Zr)N fuel

# Which purposes would ELECTRA-FCC serve?

- Test bed for LFR technology (1st LFR outside Russia)
- Research on fast reactor dynamics
- Training of LFR operators
- Education of nuclear engineering students
- R&D on fuel recycle & manufacture

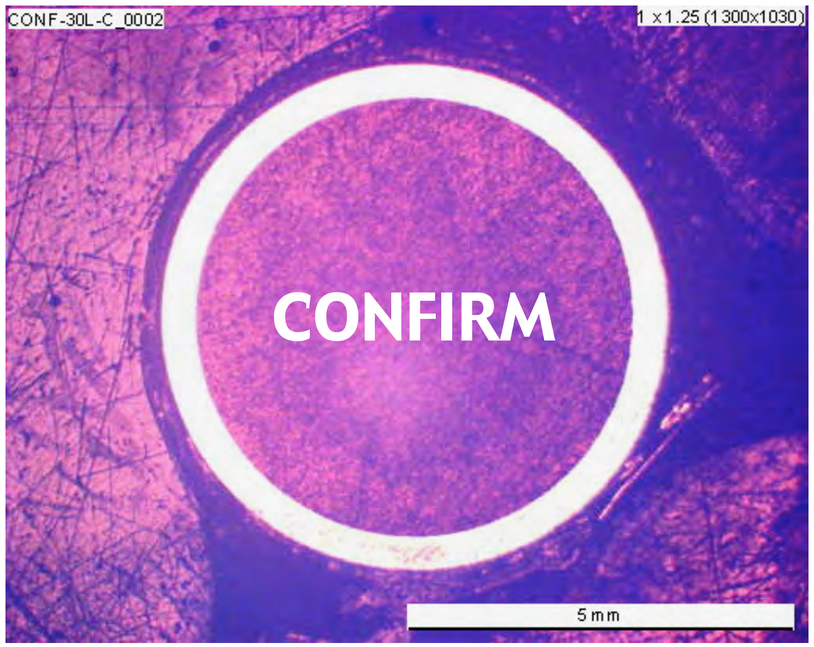
# ELECTRA: core design & control drums



$^{10}B_4C$/steel drums

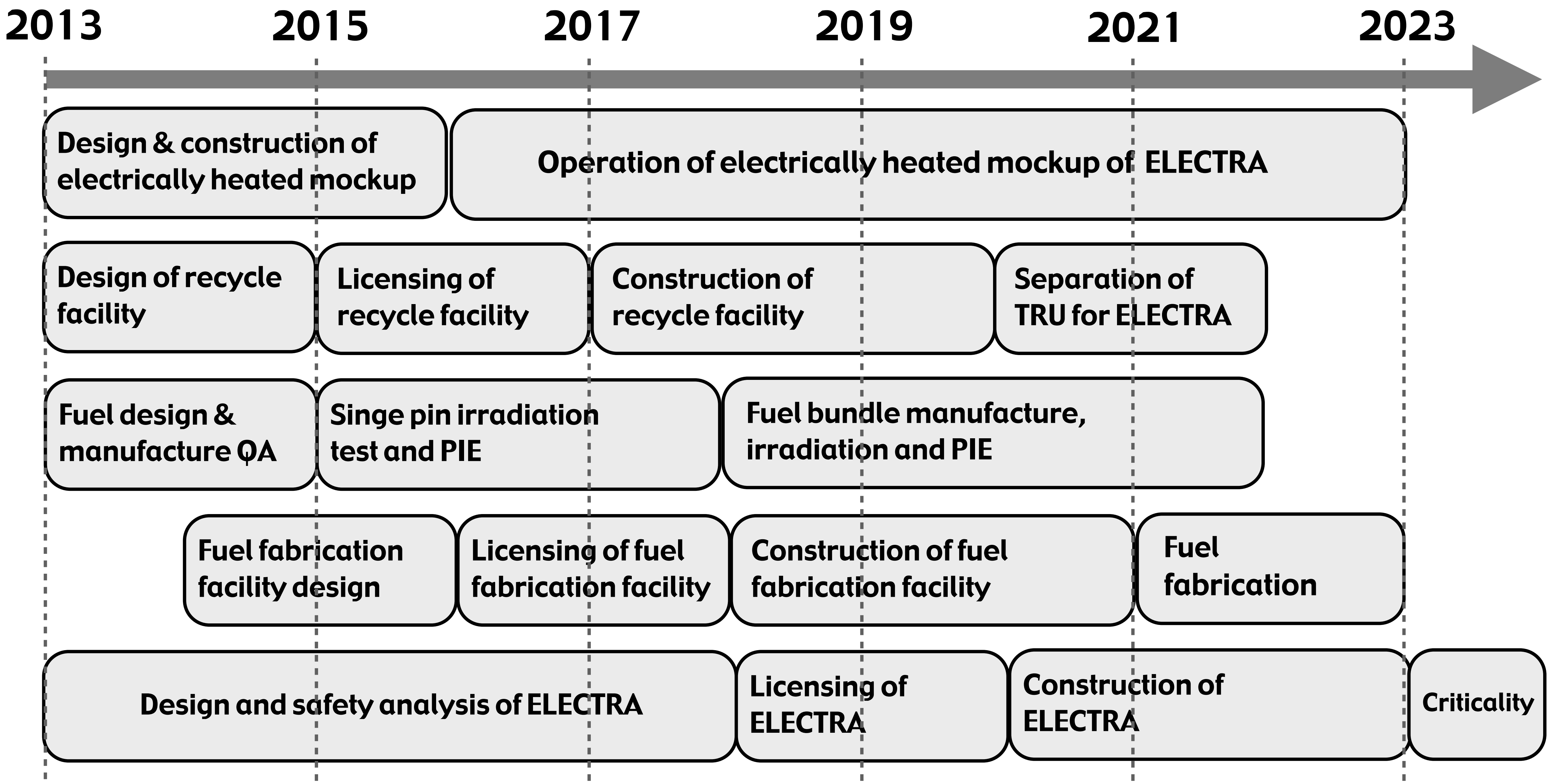
- $(Pu_{0.4},Zr_{0.6})N$ fuel. ~ 70 kg Pu from spent UOX
- 397 fuel pins, $D_{clad}$ = 12.6 mm
- Active core dimensions: ~ 30 x 30 cm
- Shutdown and reactivity compensation using 12 rotating $B_4C$ "drums".
- Core life: 14 full power years
- Burnup ~ 5% fission in actinides
- Maximum dose: 40 dpa

# The CONFIRM experience




- $(Pu_{0.3},Zr_{0.7})N$ fuel fabricated by PSI within CONFIRM project. Oxide source material.
- 20% initial porosity
- Irradiation to 10% burnup in HFR
- Linear rating: 43–46 kW/m
- Gas release: < 5% Xenon, 80% helium
- Swelling: 0.9% per percent Pu burnup
- No internal corrosion

# Best case timeline for ELECTRA-FCC



# Concluding remarks

- Generation IV reactors may increase fuel resources by a factor of 100 and reduce long term high level waste inventory to 1% of the present.
- Residual high level waste requires storage time less than 1000 years.
- Using Gen-IV fast reactors with nitride fuel, less than 10% of power must be produced in Gen-IV systems.
- ASTRID (sodium) and BREST (lead) will demonstrate Gen-IV technology on industrial scale.
- Proposal to build ELECTRA-FCC in Sweden!