THERMAL HYDRAULIC SAFETY ANALYSES IN SUPPORT OF SEALER

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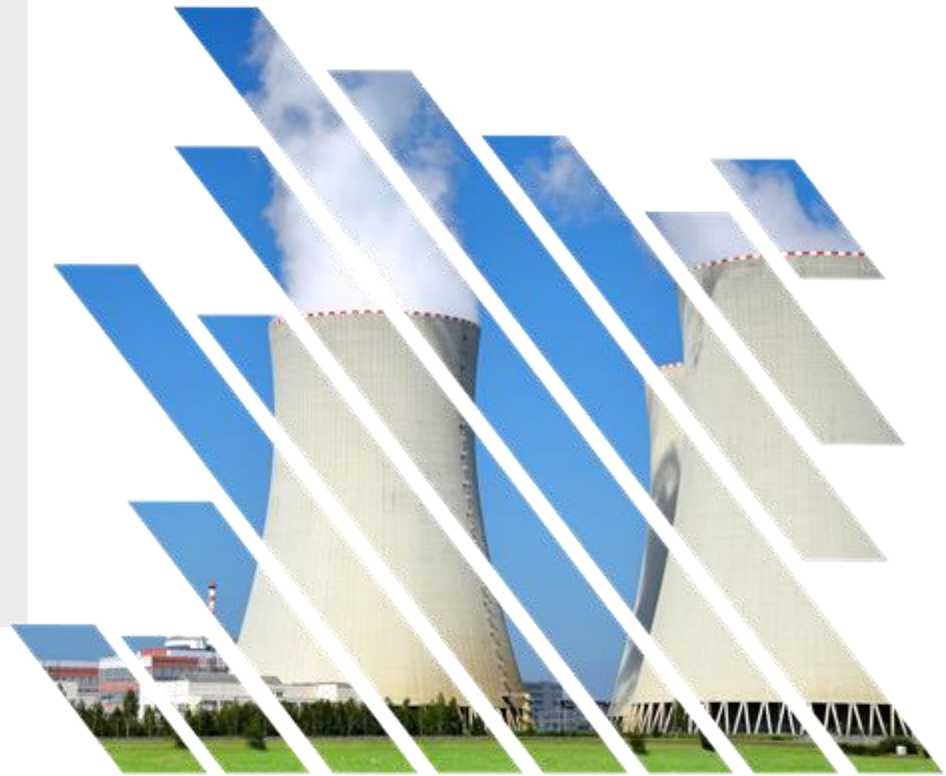

IAEA SMFR Technical Meeting
24 September 2019, Milano, Italy

EU DuC = N

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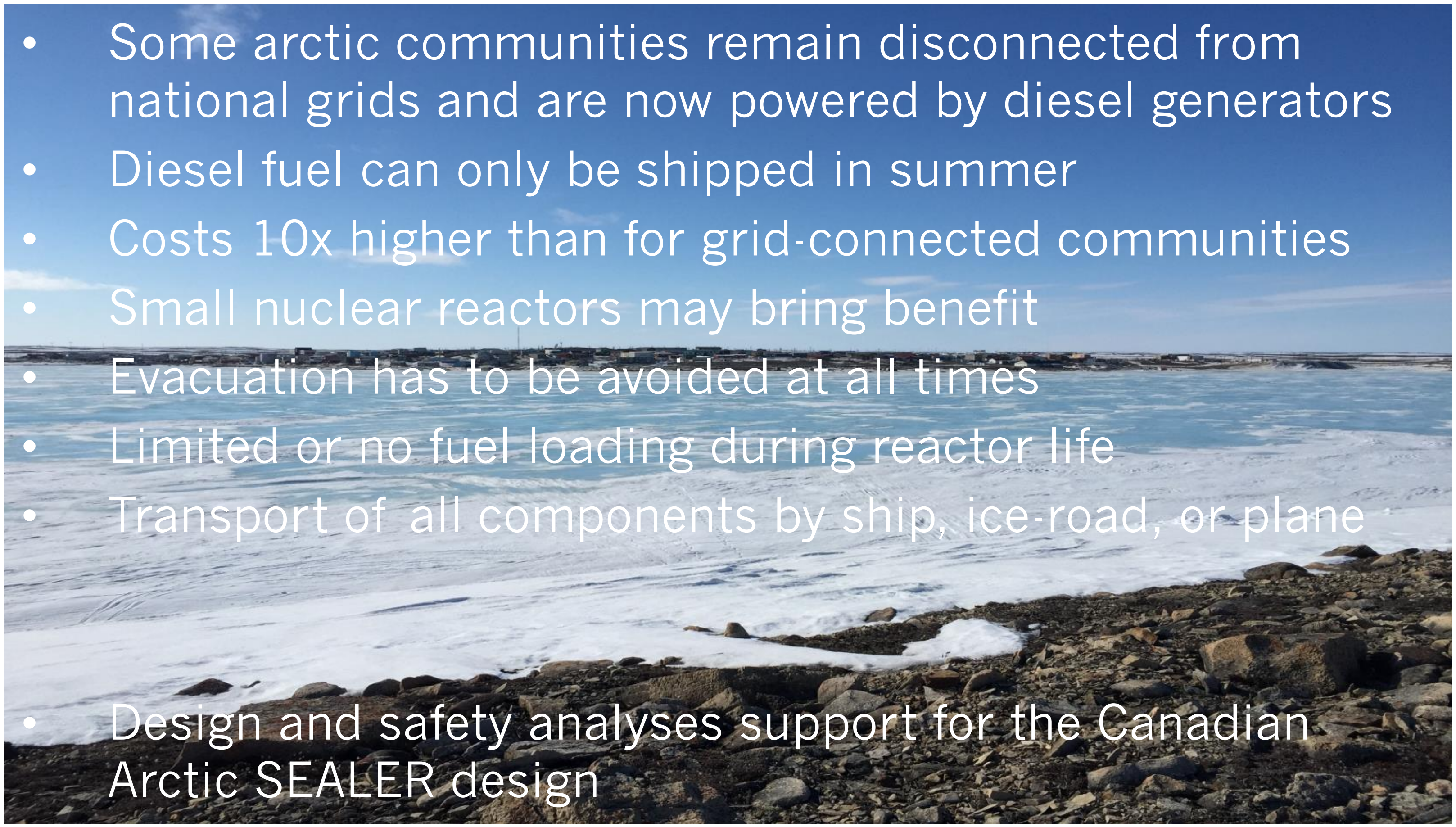
INTRODUCTION

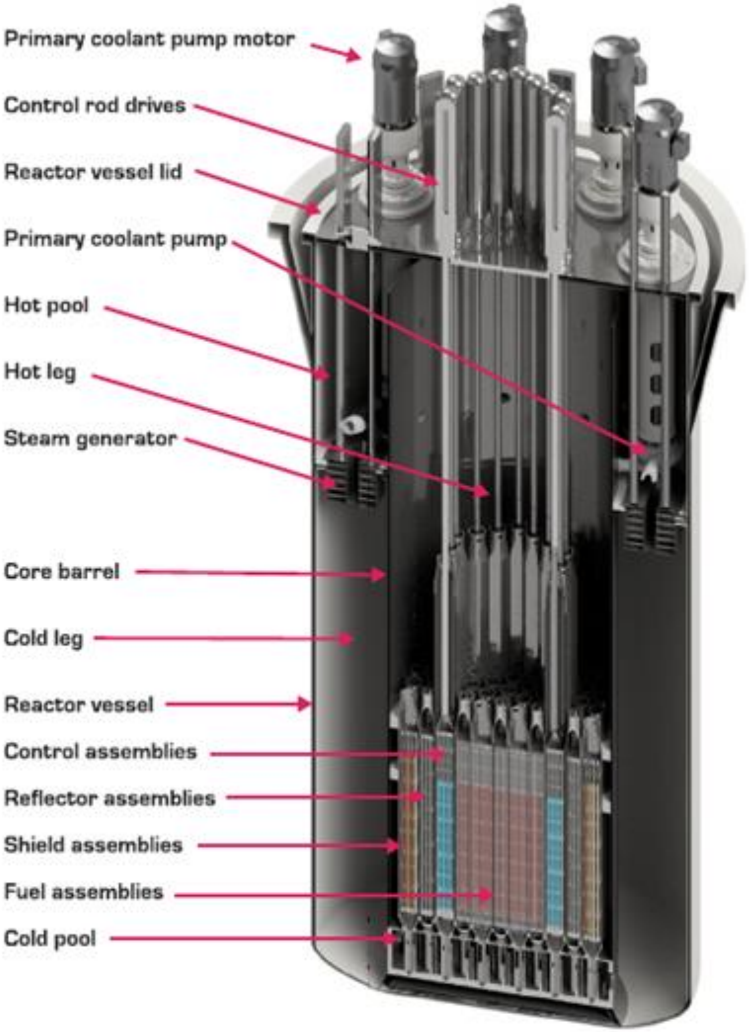


- Some arctic communities remain disconnected from national grids and are now powered by diesel generators
- Diesel fuel can only be shipped in summer
- Costs 10x higher than for grid-connected communities
- Small nuclear reactors may bring benefit
- Evacuation has to be avoided at all times
- Limited or no fuel loading during reactor life
- Transport of all components by ship, ice-road, or plane
- Design and safety analyses support for the Canadian Arctic SEALER design

CANADIAN ARCTIC SEALER

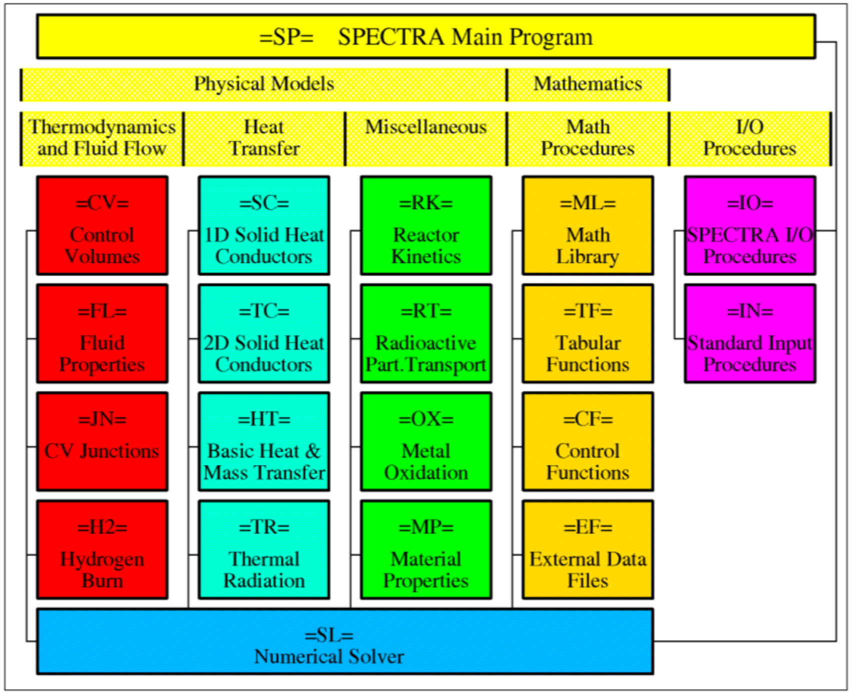
SEALER
SwEdish Advanced LEad Reactor

- Under development by LeadCold Reactors.
- Intended for commercial power production in remote, off-grid sites
- Small lead-cooled reactor
- 19.75 % enriched UO_2-fuel
- 3-10 MW electricity
- Core life: 10-30 years
- Reactor vessel: 2.7 x 6.0 m
- Transportable to/from site



SPECTRA

- SPECTRA is a thermal-hydraulic system code developed at NRG.
- Designed to analyze accidents, including loss-of-coolant accidents (LOCAs), operational transients, and other accident scenarios in nuclear (as well as conventional) power plants.
- Flexible definition of fluid properties and heat transfer correlations through user input (no need to modify the code)
- Applicability:
  - Light Water Reactors,
  - High Temperature Reactors,
  - Liquid Metal Fast Reactors,
  - Molten Salt Reactors,
  - Chemical reactors,
  - Conventional power plants

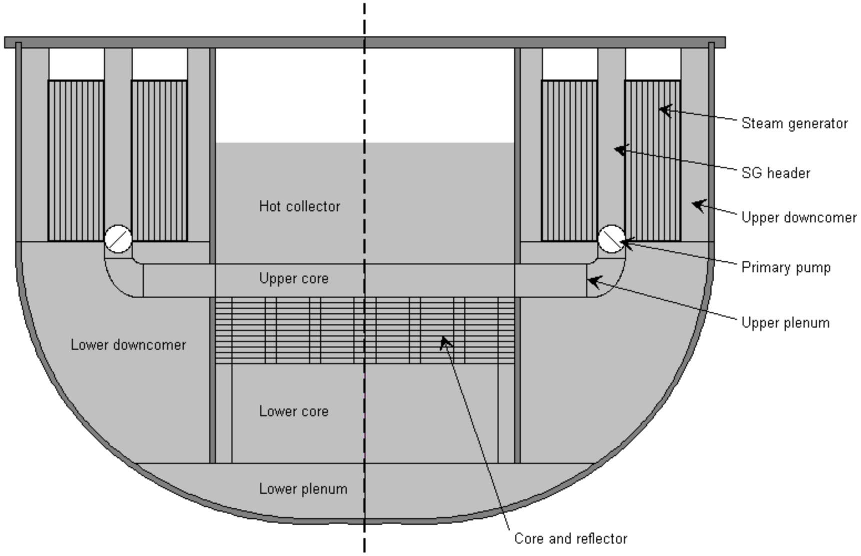


SPECTRA Code Structure

VALIDATION

VALIDATION
SPECTRA - ELSY

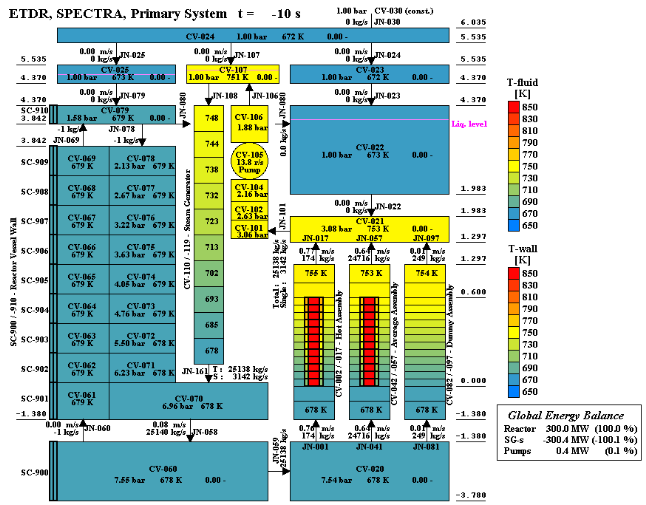
- ELSY = European Lead-cooled SYstem
- First SPECTRA application to Pb-cooled reactor design
- SPECTRA models of primary and secondary system
- Steady-state results consistent with ENEA RELAP5 model except for the fuel surface and centerline temperatures due to different assumptions on the fuel properties and topology

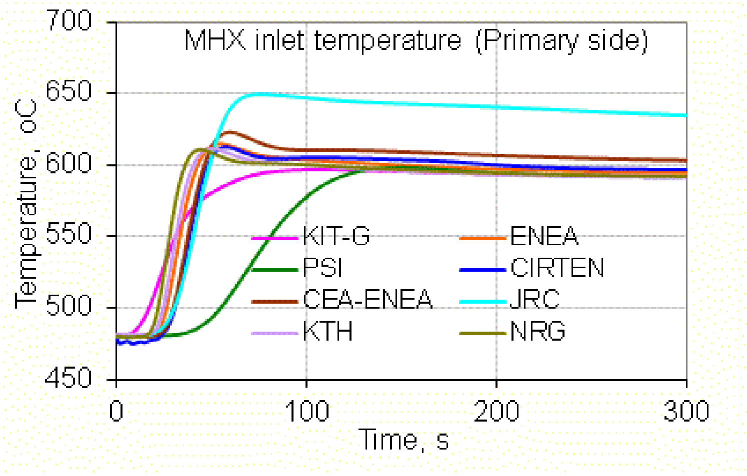


VALIDATION

SPECTRA - ALFRED

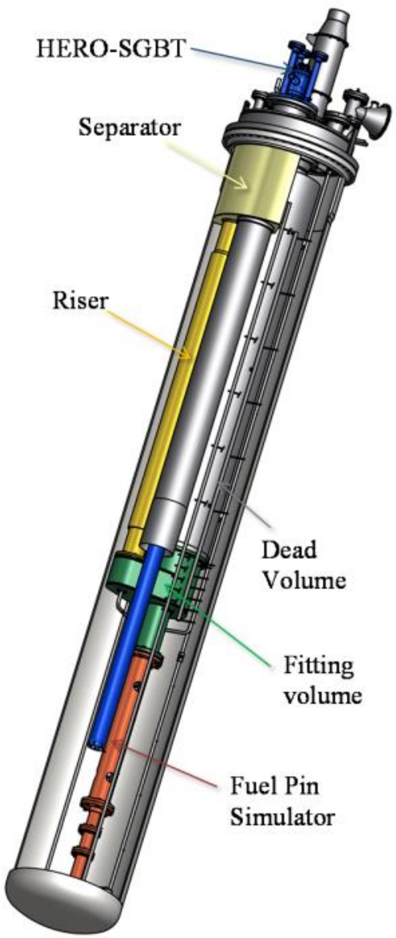
- ALFRED = Advanced Lead Fast Reactor European Demonstrator
- Code benchmark on UTOP, ULOF, ULOHS, LOOP (ULOF+ULOHS), SA blockage
- Comparison to RELAP5, SIM-LFR, TRACE, SIMMER, CATHARE
- Consistent results. Differences related to different details in cooling circuits and fuel gap model



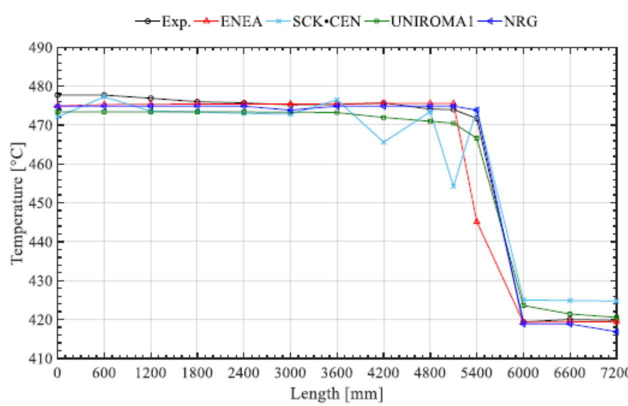


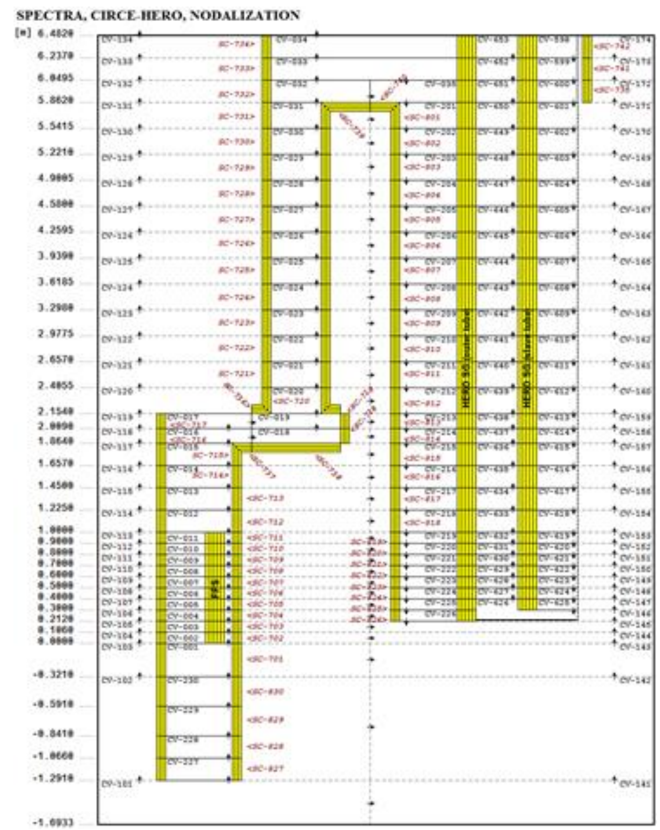
VALIDATION

SPECTRA - CIRCE



- Coolant is LBE
- Benchmark with RELAP5 results from 3 independent partners
- Benchmark demonstrates code capabilities to deal with relevant phenomena

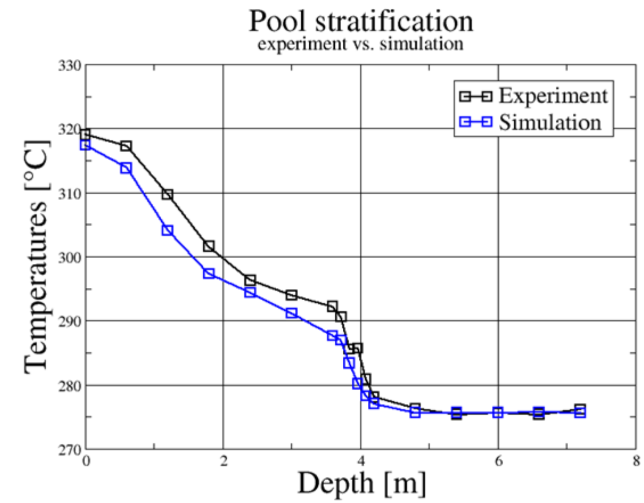


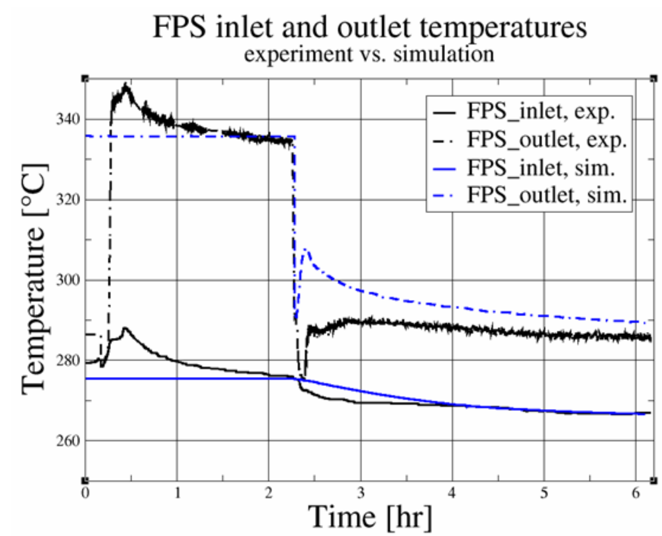


VALIDATION

CFD - CIRCE

- Good prediction of stratification in steady state
- Differences in PLOF transient
- Reasonable results given the experimental uncertainties and unknowns
- Importance of modelling heat transfer in inner walls and structures
- Importance of correctly characterizing heat losses to the environment

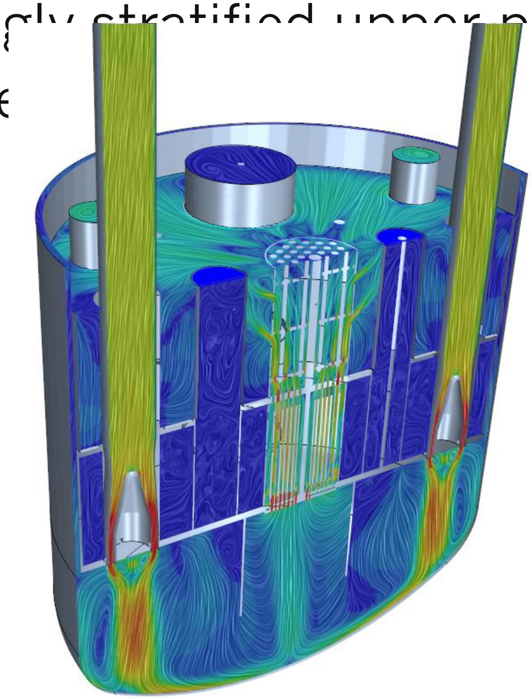


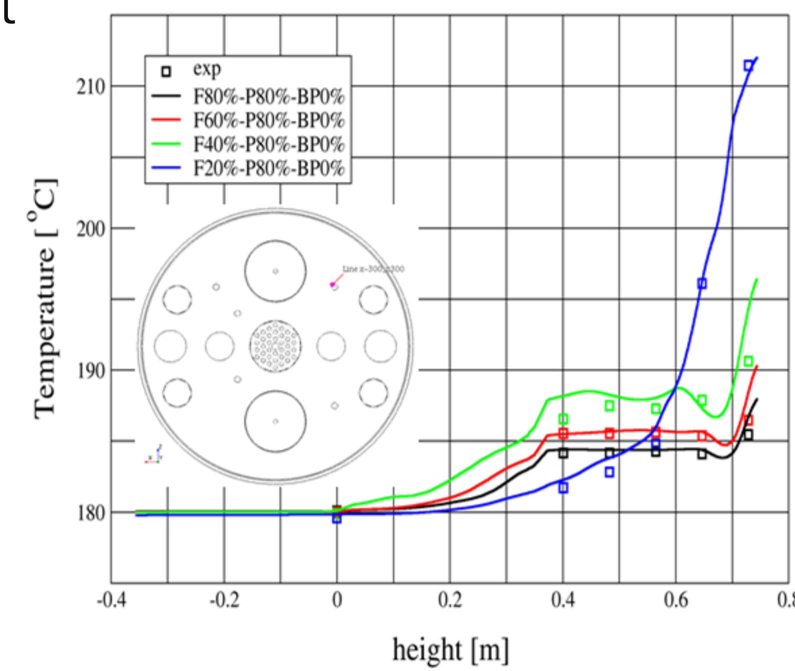


Zwijsen et al., 2019

VALIDATION
CFD - E-SCAPE

- Blind CCM+ simulations of ESCAPE (1:6 scale MYRRHA mock-up)
- Effect of mass flow rate on temperature distribution captured well
- Strongly stratified upper plenum at low mass flow rate
- Discre … tions



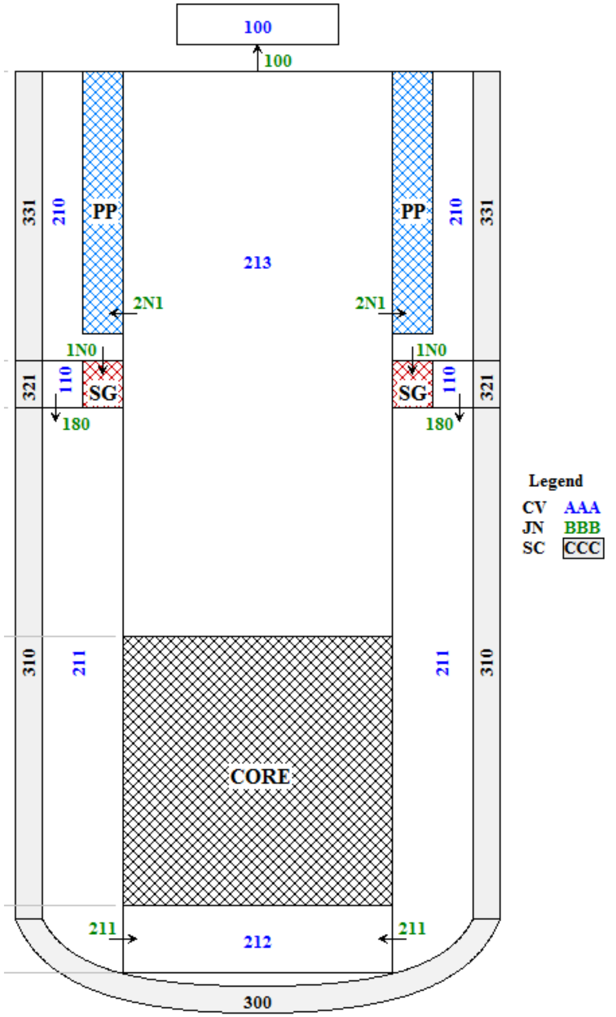


Visser et al., 2019

SEALER SAFETY ANALYSIS

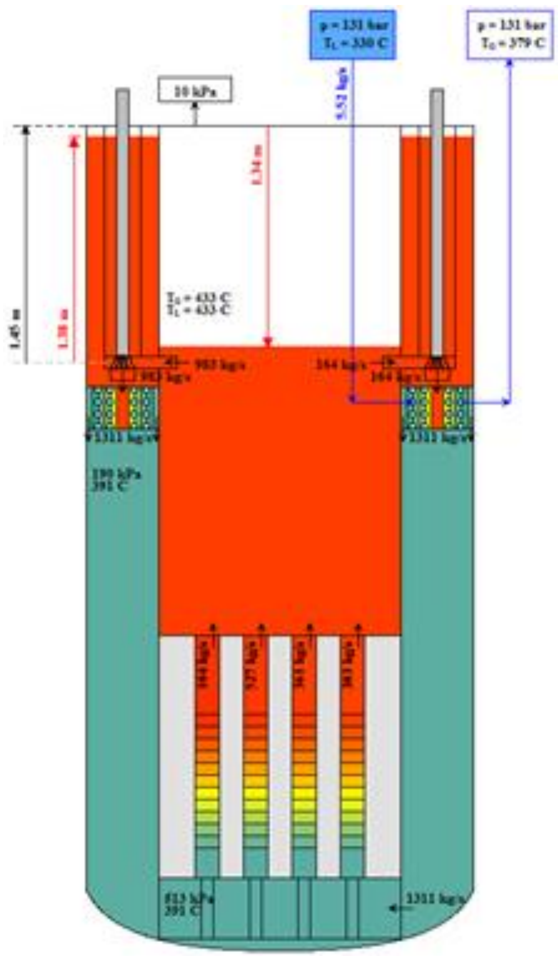
SEALER SAFETY ANALYSES
SPECTRA MODEL

- Complete SEALER model in SPECTRA
- Primary system & simplified secondary system
- Reactor vessel, core assemblies with the fuel rods, primary pumps, steam generators
- Point kinetic model with reactivity coefficients provided by LeadCold

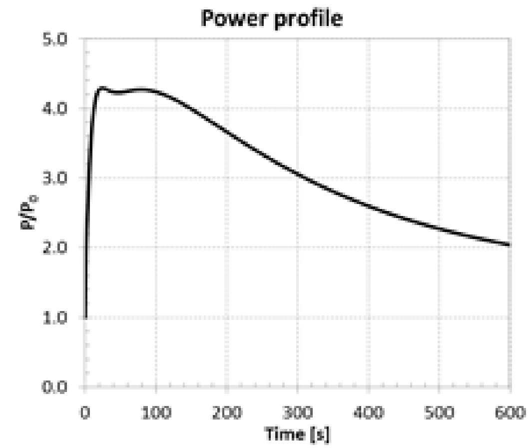


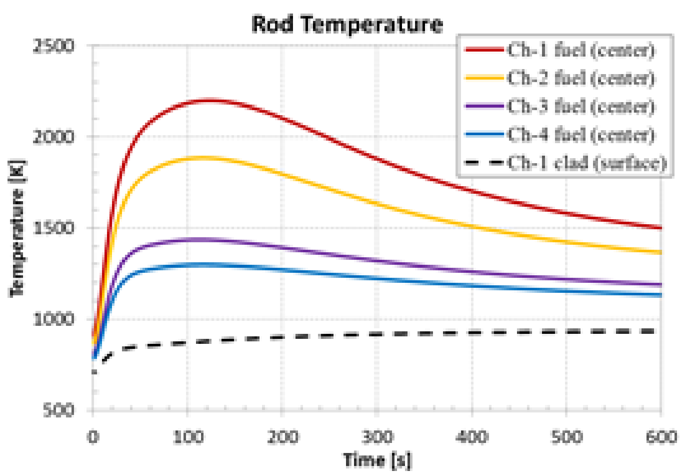
Item	Value
Effective neutron generation time	212 ns
Effective delayed neutron fraction	682 pcm
Doppler constant	259 pcm
Fuel axial expansion coefficient	-0.33 pcm/K
Grid radial expansion coefficient	-0.52 pcm/K
Coolant coefficient (core)	-0.35 pcm/K

SEALER SAFETY ANALYSES
UTOP



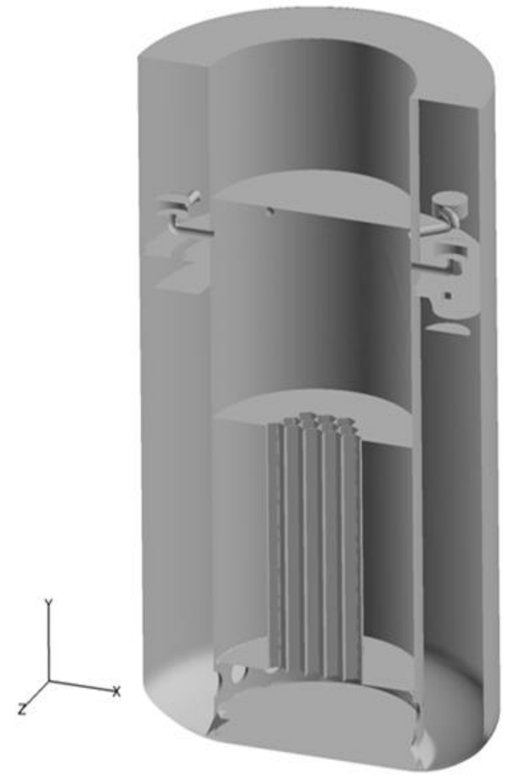
- Max core power achieved after ~24 sec.
- Peak centerline temperature is reached after ~100 sec.
- Maximum temperatures provide sufficient margin (~700K) to fuel melt





SEALER SAFETY ANALYSES
BOL STEADY-STATE

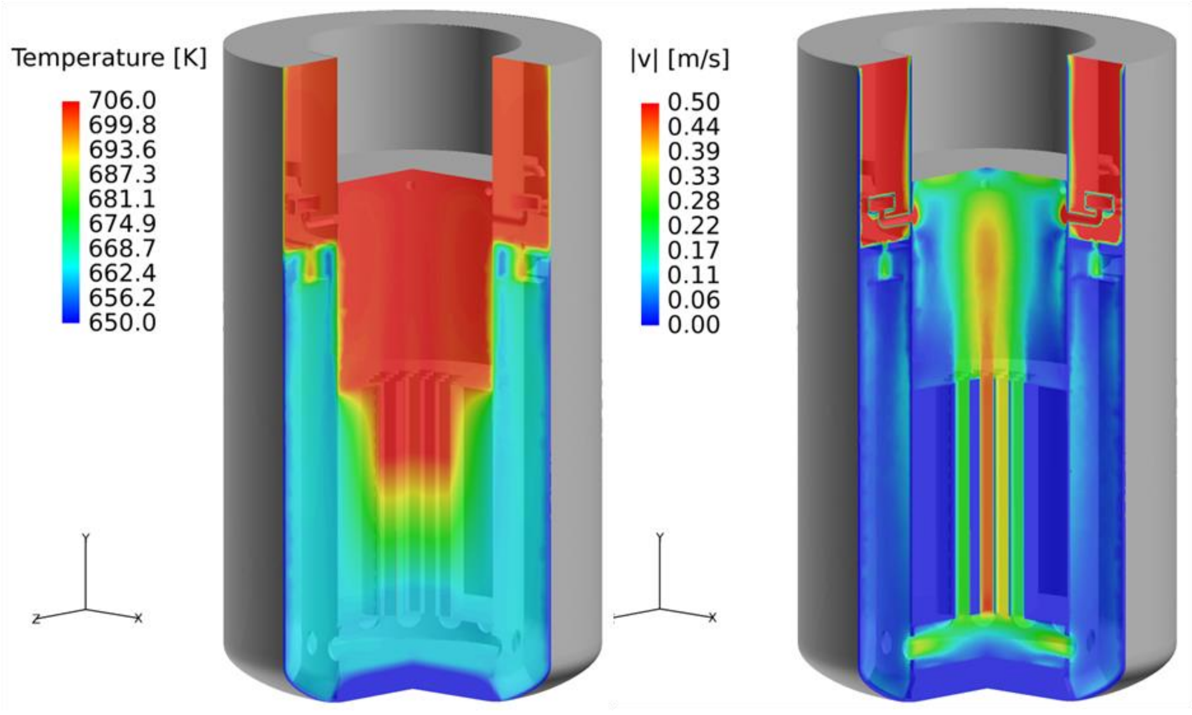
- ANSYS Fluent
- Model extends till free surfaces
- Mesh ~1.9 million cells
- Realizable k-ε turbulence model
- Enhanced Wall Treatment.
- $Pr_t = 2.0$ (Duponcheel et al., 2014)
- Core: volumetric heat source with porous medium and orificing
- HEX: modified volumetric heat sink and porous medium
- Pumps: volumetric momentum source
- Conjugate heat transfer inner walls
- Radiative heat transfer outer walls



SEALER SAFETY ANALYSES

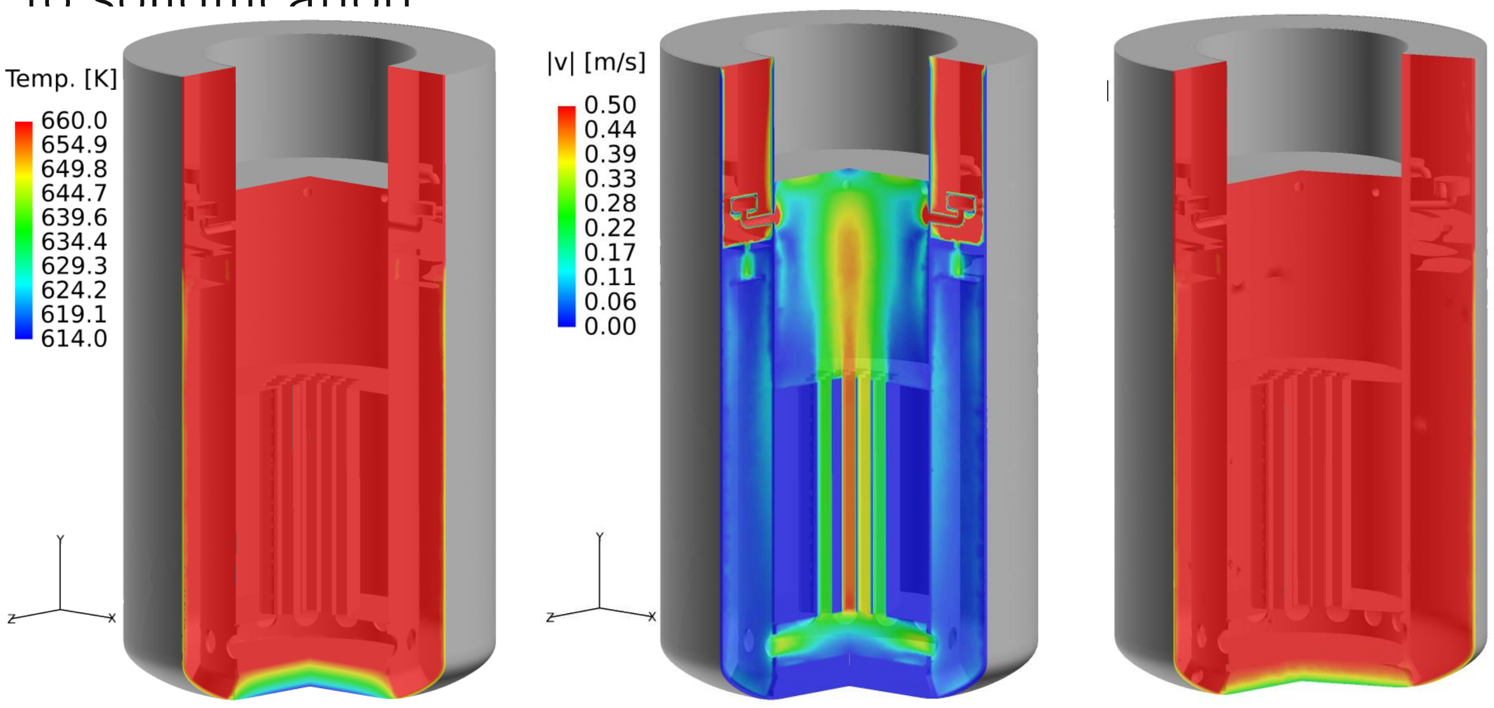
BOL STEADY-STATE

- Uniform core outlet temperature
- Central jet exiting the core
- Colder circulation zones form on the hot pool side of barrel wall



SEALER SAFETY ANALYSES
CORE SUPPORT ANALYSES

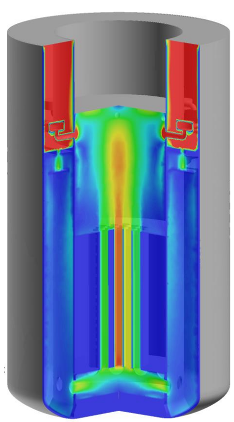
- Reference design: Stagnant region > Cold spot > Risk of solidification
- Proposed solution: Core support with 8 holes > sufficient margin to solidification



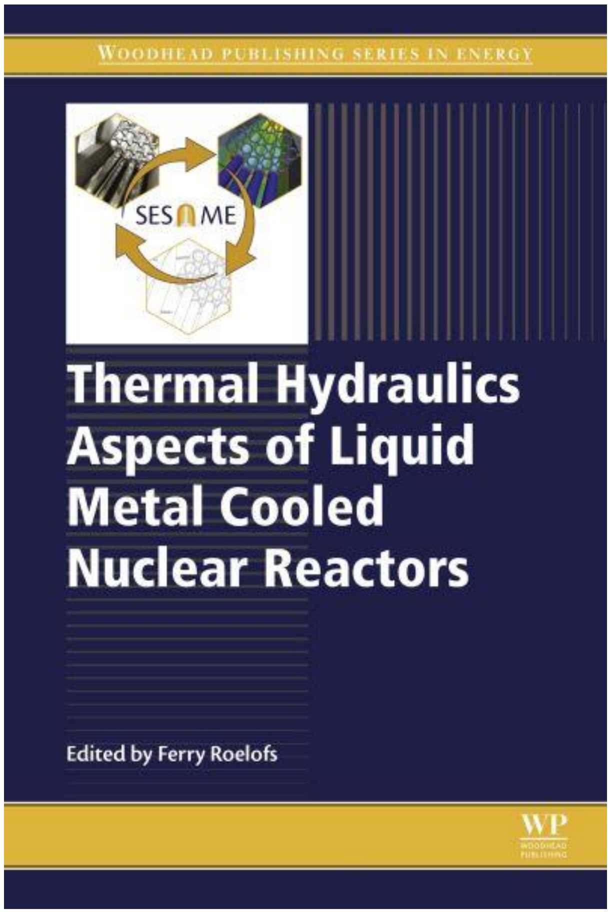
CONCLUSIONS

CONCLUSIONS & OUTLOOK

- Validation efforts in various benchmarks and comparisons provide confidence in SEALER numerical modelling with SPECTRA and CFD
- Preliminary safety analyses, in particular UTOP show forgiving nature of SMFR SEALER design
- 3-D CFD analyses reveal flow and temperature details not detected with system code analyses
- Design modification proposed to avoid cold spot based on CFD analyses



TEXTBOOK



- **Comprehensive textbook compiled by 55 authors in international collaboration**
- **Topics include**
  - Introduction Fast Reactors (incl. SEALER)
  - Liquid metal thermal hydraulics challenges
  - Experiment design, construction and operation
  - Measurement techniques
  - System thermal hydraulic codes
  - Sub-channel codes
  - Direct Numerical Simulations (DNS)
  - Large Eddy Simulations (LES)
  - Reynolds Averaged Navier Stokes (RANS)
  - Multi-scale approaches
  - Verification, validation and uncertainty quantification
  - Best practice guidelines

QUESTIONS?