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Laboratory for Reactor Physics and Systems Behaviour

NES Kompetenzen und Highlights, October 18, 2016, PSI
Home of **Nuclear Data, Reactor Physics and Integral Safety Analyses**
- **Thermal** and **Fast** Reactor Systems
- **Multi-Physics Multi-Scale** Simulations
- **Uncertainty Quantification and Sensitivity Analyses**

Home of **Technical and Scientific Support** to
- **Nuclear Safety Authorities** (ENSI, STUK)
- **Industry** (swissnuclear, E.ON, Areva)
- **Swiss Nuclear Waste Management Organization** (NAGRA)
- **National Institutes and Universities** (e.g. Criticality Safety)

Home of **Experimental Reactor Physics**
- Until 2011, at PSI Zero-Power PROTEUS Research Reactor
- Since then, at EPFL Zero-Power CROCUS Reactor

Home of **Education and Teaching Programs**
- Neutronics, Special Topics on Reactor Physics, Nuclear Computation Lab @EPFL/ETHZ
- Supervision of **Post-Docs, PhDs** and **Semester/Master Students**
- Supervision of **Practicums and Guest Scientists**
**ERP**
Home of *Experimental Reactor Physics and Measurement Techniques*

**PROTEUS** Zero Power Facility at PSI (now being decommissioned)

**CROCUS** Reactor at EPFL

**STARS**
Home of *Multi-Physics Multi-Scale Modelling* for Integral LWR Safety Analyses

- Research
- Scientific Support
- Education

**FAST**
Home of *Multi-Physics Analyses of FAST Spectrum and Molten Salt Reactors*

- Goals:
  - Evaluation of performance and safety of Gen IV SFR
  - Search for design solutions for Gen IV SFR
  - Representation of Switzerland internationally
  - Teaching

- International:
  - Generation IV International Forum
  - OECD RNP on International Nuclear Data Evaluation
  - IEA Technical Working Group on Fast Reactors

**Today, Focus of FAST Activities mainly on SFR and MSFR**

Sodium Fast Reactors (ASTRID)

Molten Salt Fast Reactors (MSFR)
Validation on reactivity effects of spent fuel with uncertainty quantifications

LWR-II spent fuel samples
40-cm long UO$_2$ and MOX samples with burn-up up to 120 and 70 GWd/t

Past Reactivity effect measurements @ PROTEUS
• Central test tank of PROTEUS
• 3 moderation conditions

Uncertainty methods for CASMO-5: SHARK-X
• Consider nuclear data XS uncertainty (SCALE-6.0)
• Consider spent fuel composition uncertainty (Mst)
• Direct perturbation (DP) and statistical sampling (SS) methods

Results
• SS and DP methods agree and give consistent uncertainty
• Future work to propagate nuclear data uncertainty through improved irradiation history (QUASAR)
Void profile measurements at CROCUS through neutron noise

Development of an experimental setup to reconstruct axial void profile in BWR through neutron noise measurements of in-core detectors

- A **theoretical method**\(^1\) to reconstruct the void profile within a BWR channel using in-core neutron noise has been developed at Chalmers University
  - Transit time of the bubbles is measured by correlations in detector signals at discrete locations
  - Relationship between void and transit time is known
  - Third order polynomial fit of void profile
- The method will be tested **in clean conditions in CROCUS** with a channel containing a two-phase flow with known void distribution
- **Separate characterisation** of the bubble distribution using existing visualization techniques.

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Verification/validation of single-phase RANS CFD models for full-length PWR fuel assembly
- Largest CFD model in LRS to date
- 122 Mio cells, 4032 CPUs
- Swiss National Supercomputing Centre (CSCS)

Bayesian calibration of statistical uncertainty in reflood model parameters using SET data

Studies of PWR fuel assembly bowing effects using subchannel codes
- Fuel rods may bow (bend) due to non-uniform power distribution
- Local power peaking and flow distortion impacts major safety parameters

Core Power Distribution
Impact on DNBR

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**Core Analyses with Uncertainty Quantification**
Upgrade of the PSI Swiss Core Model Platform CMSYS
Nuclear Data Uncertainty “from CASMO to Disposal”
Preliminary Pilot Study conducted for KKB1

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**Major Challenge:**
Statistical Convergence
\(\Rightarrow 1\) UQ Analysis
\(\Rightarrow \sim 400\,000\) CPU*hours
1 TB Storage

**BOHR Method for Spent Fuel Characterization**
Reconstruction of Pin-Wise Nuclides from Core Models
Significant Enhancement of Cm244 Predictions

**Full Core Monte-Carlo Modelling with MCNP for the Swiss Reactors**
Development of Methodology for Initialization of Pin-Wise Nuclide Compositions of Burned Cores
Model Optimization for High-Resolution Calculations of Intra-Pin Azimuthal Flux/Power and Nuclide Distributions

**KKG (PWR)**
**KKM (BWR)**

Sample burn-up (MWd/kgU)

Thermal flux
Fast flux
**STARS/Fuel Behaviour**

**LOCA Fuel Behaviour**

Development of Fuel Dispersal Model with coupled mass flow rate equations for solid-gas discharge

- Fragmentation
- Ballooning
- Pulverization
- Relocation
- Rupture

**Uncertainties**
- Fragment size
- Fragment Sphericity
- Rupture Opening

**Multi-Scale Fuel Modelling**

Validation of XAFS spectra simulation for UO$_2$

- Collaboration:
  - LRS
  - AHL
  - LNMM
  - ISSP (Latvia)

**FALCON Code Development**

(Coll. EPRI/PSI/ANATECH/Objexx)

- PSI/GRSW-A model integration close to completion
- Plan for official release with Falcon V.1.4 (2017)
- Preliminary V&V completed:
  - (basic regression, KKL_AEB rod, FUMEX, SuperRamps)
- Next Phase: Analysis of full V&V GRSW-A matrix
Dryout in modern BWR Fuel Designs
Hypothesis Testing and Cause Analysis with Multi-Physics Studies

CORE ANALYSIS
CMSYS (CASMO/SIMULATE)
- Assembly MCPR
- Power Distributions
- Review Cycle Operation
- Channel Flow & Void Behaviour

REACTOR PHYSICS
CASMO5 / MCNP6
- Uncertainty Analysis
- High-Resolution Pin Power Analysis
- U235 and Gd Design Effects
- Review PROTEUS Experiments
- R-Factor vs. CPR DB Range

THERMAL-HYDRAULICS
COBRA-TF / TRACE / CFD
- Flow & Heat Transfer Regimes
- Sensitivity Analysis
- Sub-Bundle Stability
- CHF Margins

FUEL BEHAVIOUR
FALCON/GRSW-A
- Sensitivity Analyses
- Oxide Layer Build-up
- Pellet/Clad Interactions and Heat Conduction
- Azimuthal Heat Flux Distributions

STABILITY AND TRANSIENTS
S3K / TRACE-S3K
- Hot Rod Analyses
- Sensitivity Analyses
- Hot Channel Analyses
- Stability
- Transient CHF/CPR
- Coupled Plant/Core Transients

SIGNAL ANALYSIS
PSI TSA Methodology
- Design of Measurement Campaigns
- Causality Analysis
- Noise Trends and Signatures
- Neutron and Process Noise
- Monitoring and Diagnostics
**Nuclear Data - TENDL Library**

- **“TALYS Evaluated Nuclear Data Library”**
- Combines theoretical calculations and measurements into a single library for general applications,
- Launched in 2008 with releases every year
- Development now at LRS/STARS (tendl.web.psi.ch/home.html)

**Partner with US.DOE/CASL**

- VERA Platform for High-Fidelity High-Resolution Multi-Physics LWR Core Simulations
  - Full Core Sub-Pin Resolved 3-D Neutron Transport
  - Full Core Sub-Channel resolved 3-D thermal-hydraulics
  - Full Core pin resolved 2-D/3-D thermo-mechanics
  - Coupling to chemistry and structural material modules

*Prediction of CRUD Build-up and Power Shift with VERA*

http://www.casl.gov

- LRS/STARS as first international associated partner
- Collaboration on further development and validation of VERA for Swiss applications
  - Experiments, fuel/core designs, reactor operation
  - Steady-State/Transient analyses
  - Advanced Audit Tool for BWR Safety Analyses
MSR Neutronics & fuel cycle: **MSR safety evaluation:**

**Tools:** EQL0D & EQL3D equilibrium cycle routines based on SERPENT and ERANOS codes.

**Aim:** fuel cycle safety and performance characteristics.

**Tools:** TRACE-PARCS, TRACE-point-kinetics, GeN-Foam (Open-FOAM).

**Validation:** based on available reactor data from MSRE (ORNL) and MSFR benchmark.

**MSR design studies:**

**Aim:** waste minimization and high fuel utilization.

**Cases:** Moderation level, hybrid spectrum core, refueling strategies, reprocessing strategies, breed-and-burn mode.

Molten Salt Fast Reactor Concept

Molten Salt Reactor Experiment

Hybrid spectrum MSR
ESFR-SMART
European Sodium Fast Reactor Safety Measures Assessment and Research Tools
proposal submitted to H2020 framework program; budget ~10 MEUR (5 MEUR from EU)

Use legacy experiments
-- SFR operational data (SPX1/CEA)
-- sodium boiling (KNS-37/KIT)
-- molten fuel ejection (CABRI/IRSN)
-- molten pool behaviour (SCARABEE/IRSN)
-- aerosols in containment (FAUST/KIT)
-- aerosols in containment (NALA/KIT)
-- aerosols from sodium fire (FANAL/CEA)

Calibrate and validate codes
Assess new safety measures for ESFR
-- low void effect core design
-- corium discharge tubes
-- passive decay heat removal
-- large-inertia and passive pumps
-- improved natural circulation, etc

Conduct new experiments
-- MOX fuel properties (CEA → ITU)
-- forced-to-natural convection (KASOLA/KIT)
-- sodium boiling (SOLTEC/KIT)
-- chugging boiling (CHUG/PSI)
-- corium jet/catcher (JOLI/LEMTA)
-- corium/catcher (LIVE/KIT)
-- corium jet/concrete (MOCKA/KIT)

Develop new instrumentations
-- eddy current flowmeter (HZDR)

Establish new networks
-- students mobility grants to work at EU Na facilities
-- workshops and summer school

Demonstrate new reactor concept features
-- iso-breeder (produces fissile fuel for own needs)
-- safer than LWRs (no core meltdown in Fukushima-like accident)
-- safer than SFRs (low void effect)
**LRS**

**Schwerpunkte 2017**

**ERP**
- **Remove fuel from PROTEUS building** and transfer facility dismantling to PSI/LOG
- Launch **“PROTEUS Legacy Project”** for knowledge preservation and validation center
- Perform **spent fuel neutron source measurements**
- Conduct **new experiments at CROCUS** (e.g. VOID, Colibri)

**STARS**
- **Methodologies for CFD Fuel Assembly Flow Analyses**
- **H-Uptake modelling for fuel behavior** during operation and towards dry storage (LNM Coll.)
- **Multi-physics research on BWR dryout** and new **high resolution simulation** methods (CASL)
- **Spent fuel analyses** and new ILL measurement of Nd147 cross-section (LRC Coll.)
- Development of **advanced PSI Fluence/Activation scheme** for decommissioning (GFA coll.)

**FAST**
- Development of MRS **burnup calculation method for moving fuel** (CROSS)
- Launch **EU/H2020 ESFR-SMART project**
- Consolidate **nuclear data uncertainty methods** in collaboration with STARS
Thank You!