H. Ferroukhi :: Paul Scherrer Institut

Laboratory for Reactor Physics and Systems Behaviour

Overview, Samples 2017 and Perspectives

NES Kompetenzen und Highlights, October 24, 2017, 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

Develop and Qualify Simulation Methodologies for Current and Advanced Reactors

Perform conceptual studies on innovative reactors for waste reduction as well as safety enhancements

- Home of **Technical and Scientific Support** on
  - Deterministic Safety Analyses (e.g. ENSI, STUK)
  - Neutronics/Multi-Physics aspects of Long-Term Operation and/or Fuel Cycle Optimization (e.g. swissnuclear, E.ON, Areva)
  - Criticality Safety/Burnup Credit (e.g. NAGRA)

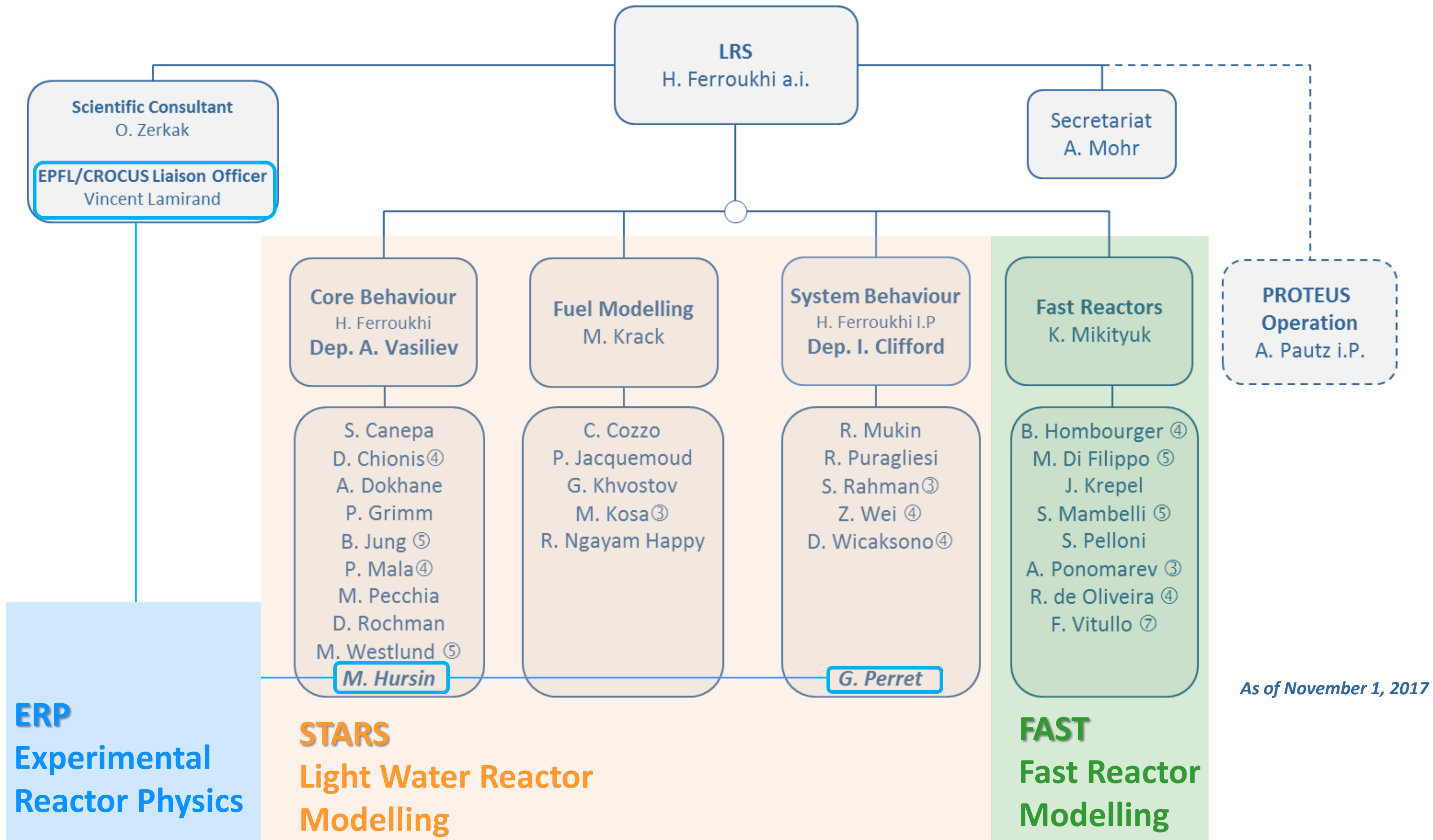
Support safe & long-term operation of current and future nuclear power plants

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

Design, conduct and interpret measurements to validate reactor physics codes and nuclear data

- 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

Contribute to the education of the future generation of nuclear engineers and scientists



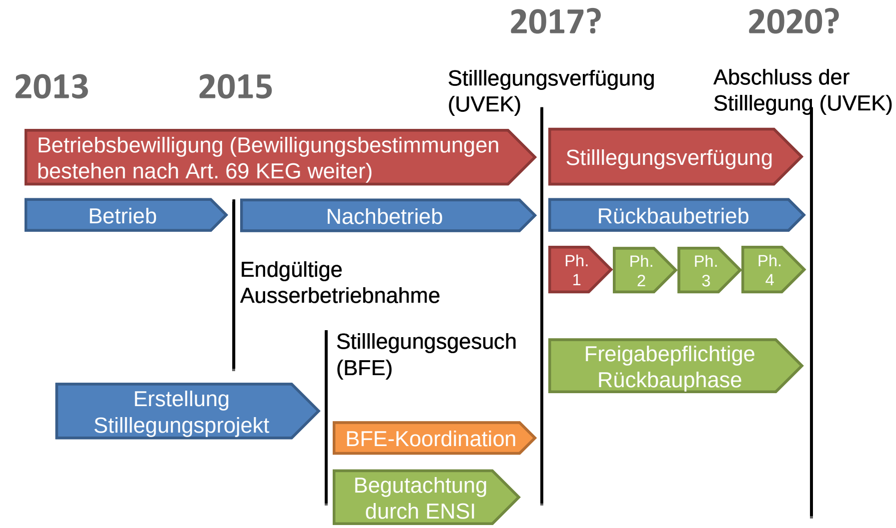
4 Research Groups

3 Research Programs - ERP, STARS, FAST

35 Team Members **=** **19** Scientists **+** **2** Administrative Staff **+** **3** Post-Docs **+** **6** PhDs **+** **5** MSc/Prac. Students

Legal Framework

- 2011: Stop activity on reactor
- 2013: Application for decommissioning
- 2015: Post-operation phase approval
- 2016: Public obligation of the project w/o objections
- 2017: Decommissioning ordinance?
- 2020: End of decommissioning?

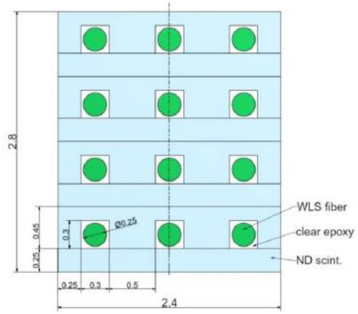


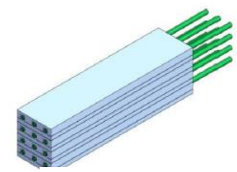
Progress on the Ground

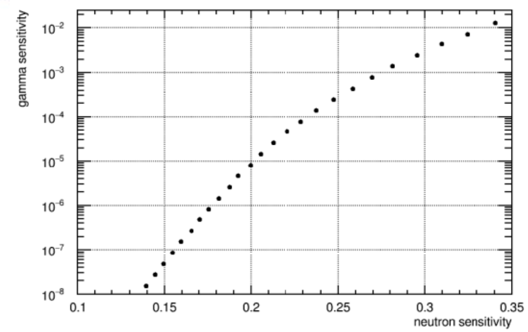
- 2012: Reactor unloaded
- 2013-2016: Disposal of experimental material *(D_2O, glovebox, detector)*
- 2017: Fuel characterization of utilized metallic Uranium and UO_2 (5%) completed
  → *To be considered as irradiated fuel*
- 2017: Potential customer for acceptance of PROTEUS Uranium fuel found *(formalities are being negotiated)*
- 2018: Take-over of PROTEUS building by PSI LOG

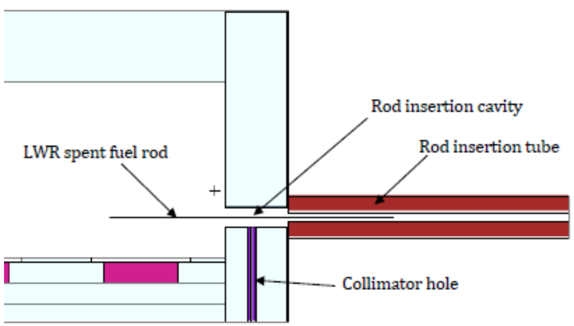
MCNP Design of Measurement Station for Spent Fuel Neutron Source based on Novel **Fast Neutron Detectors with Plastic Scintillators**

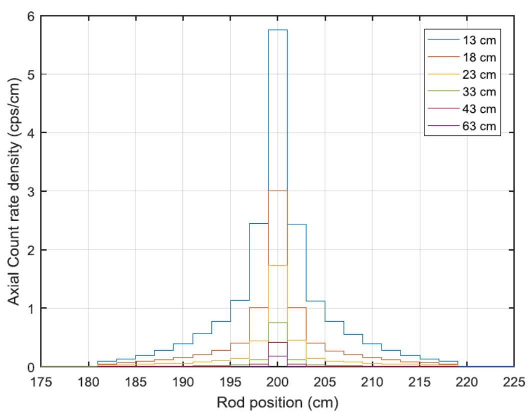
- Detector based on a composite ZnS(Ag) scintillators with embedded wave-length shifting optic fibers
- High neutron sensitivity and gamma-ray blindness essential for measurement on spent fuel were measured











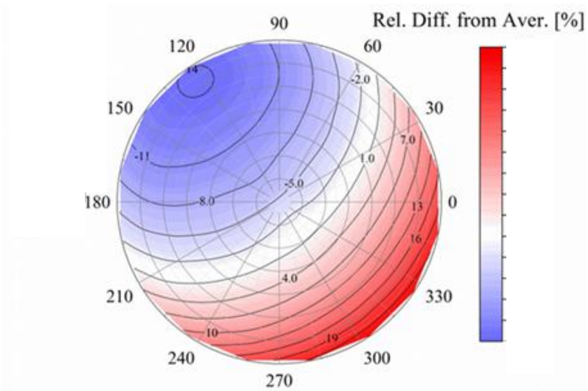
- Detection system (collimation, shielding and detection mechanism) simulated with Monte Carlo codes
- Count rate and transfer function demonstrated a possible measurement on spent fuel segments
- Future work will extend the result to full-length rods.

ANS Student Conference 2017
- Best Paper – Overall Research
- Best paper – Detection & Measurements

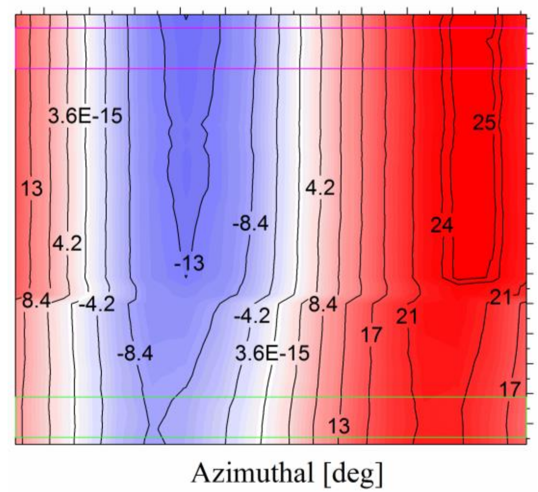
High-Resolution Deterministic/Monte-Carlo Neutron Transport Models

Studies of 3-D Pin Power for and Effects of Local Perturbations

Radial Distribution



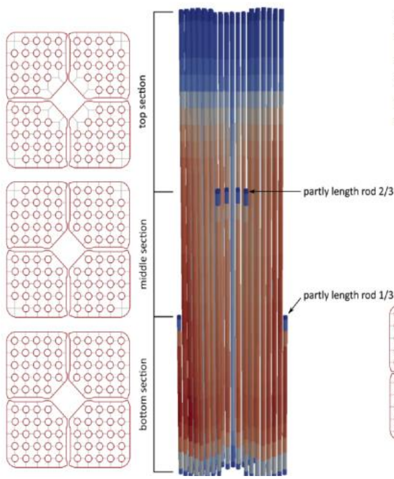
Axial Distribution



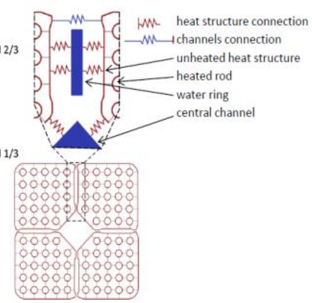
Sensitivity Analyses

	10	9	8	7	6		5	4	3	2	1
J		-16.6	-17.0	-16.9	-16.2		-15.1	-14.3	-12.2	-8.1	
I	-16.5	-10.4	-12.7	-7.4	-10.7		-9.8	-5.1	-6.3	-1.1	3.7
H	-16.5	-12.6	-5.3	-6.6	-5.8		-4.5	-3.2	-0.3	4.8	10.2
G	-16.3	-7.1	-6.6	-3.0				0.0	2.9	4.7	13.9
F	-15.5	-10.5	-5.7						4.6	9.8	15.4
E	-14.5	-9.4	-4.4						6.2	11.4	16.9
D	-13.5	-4.8	-3.1	0.1				3.5	7.1	7.8	18.0
C	-11.2	-5.7	0.0	2.9	4.6		6.0	7.1	5.7	14.1	18.4
B	-7.1	-0.8	4.9	4.8	9.9		11.3	7.7	14.0	11.6	18.8
A		4.2	10.4	14.0	15.5		16.8	17.9	18.5	18.8	

Development/Optimization of **COBRA-TF** Methodology for Sub-Channel Analyses



- 3 sections
- 411 subchannels
- 684 gap connections
- 96 heated rod
- 209 unheated structures
- Total 5615 lines



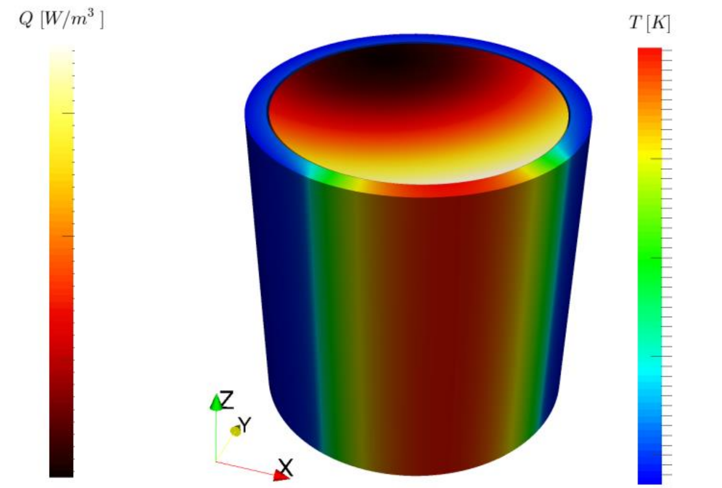
5.32	2.11	2.48	2.68	3.16
2.11	2.46	2.85	3.50	3.17
2.48	2.86	3.90	2.79	2.59
2.70	3.52	2.76	2.02	3.86
3.19	3.22	2.56	3.87	

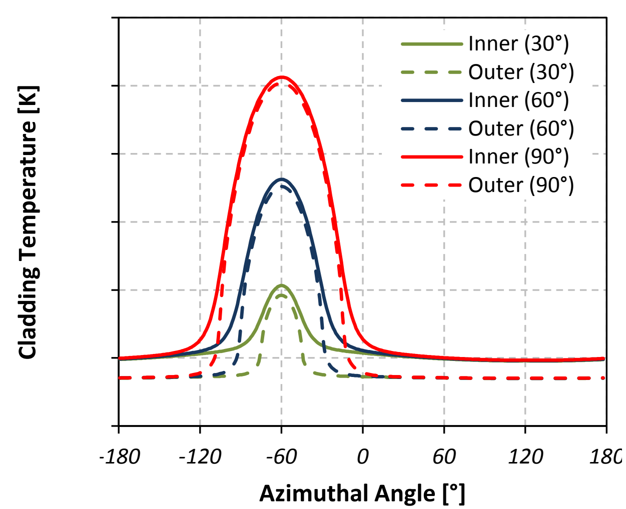
3.15	2.67	2.42	2.07	5.14
3.18	3.52	2.80	2.41	2.05
2.65	2.87	4.01	2.79	2.40
3.90	2.60	2.81	3.49	2.63
	3.89	2.59	3.15	3.09

3.22	3.26	2.63	3.94	
2.72	3.58	2.85	2.60	3.94
2.49	2.88	4.05	2.89	2.66
2.10	2.46	2.85	3.54	3.19
5.25	2.09	2.45	2.67	3.13

	4.06	2.53	3.08	3.03
3.81	2.00	2.72	3.38	2.57
2.63	2.82	3.79	2.72	2.35
3.10	3.39	2.73	2.32	1.98
3.05	2.57	2.35	1.98	4.98

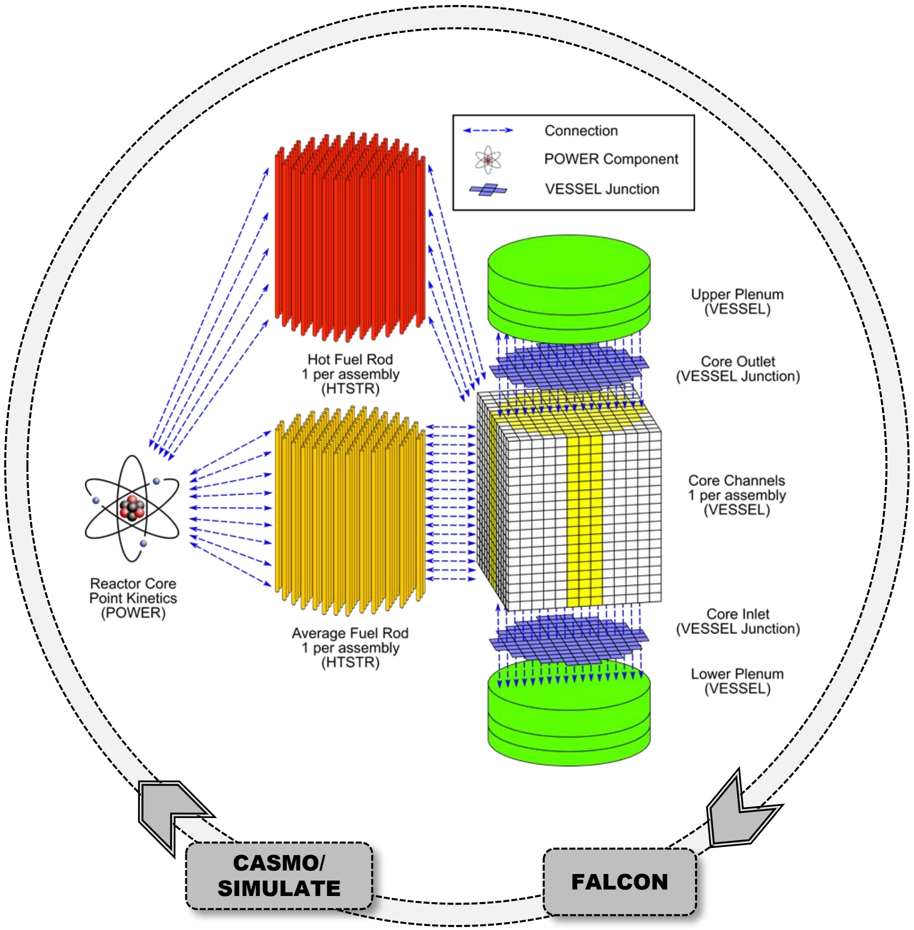
Development of **OpenFOAM** Solver for Fuel Rod Thermo-Mechanics Analysis of Local Multi-Physics Effects



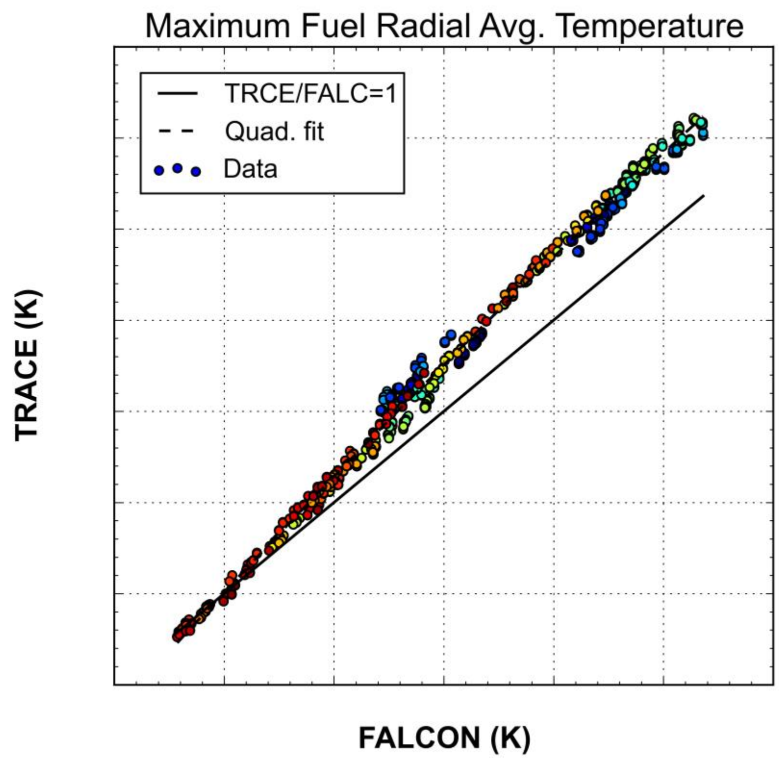


Multi-Physics Full-Core LOCA Analyses for Core-Wide Estimations of Fuel Behaviour

Development of Novel **TRACE** Hybrid Nodalization Scheme for PWR LOCA



Assessment of TRACE **New Dynamic Gap Conductance Models**

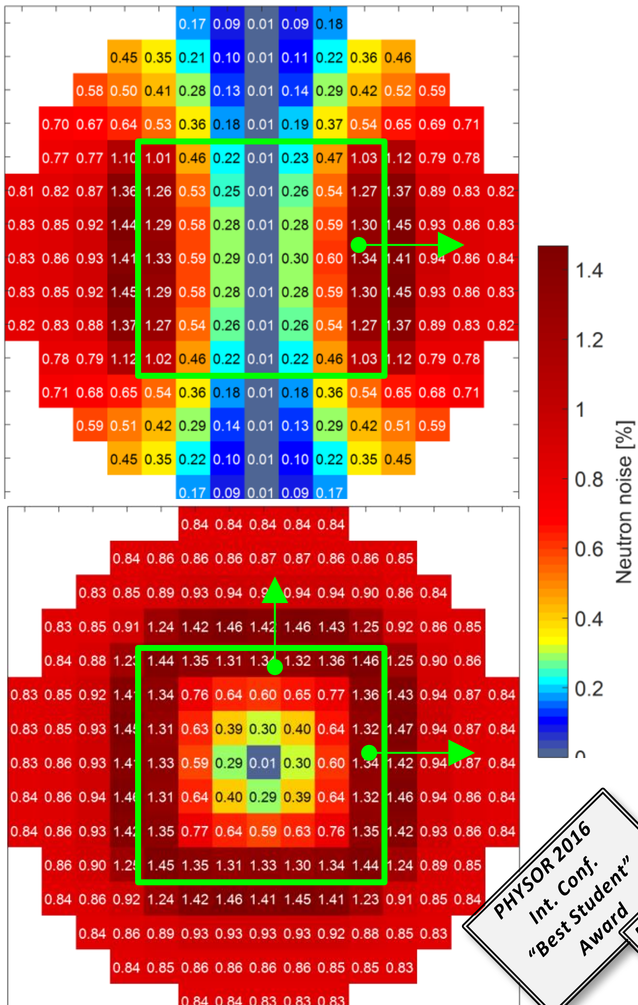


Numerical Noise Simulations with PSI Core Models (CMSYS/S3K)

PWR Noise Response to Fuel/Cluster Vibrations

1-D Vibration

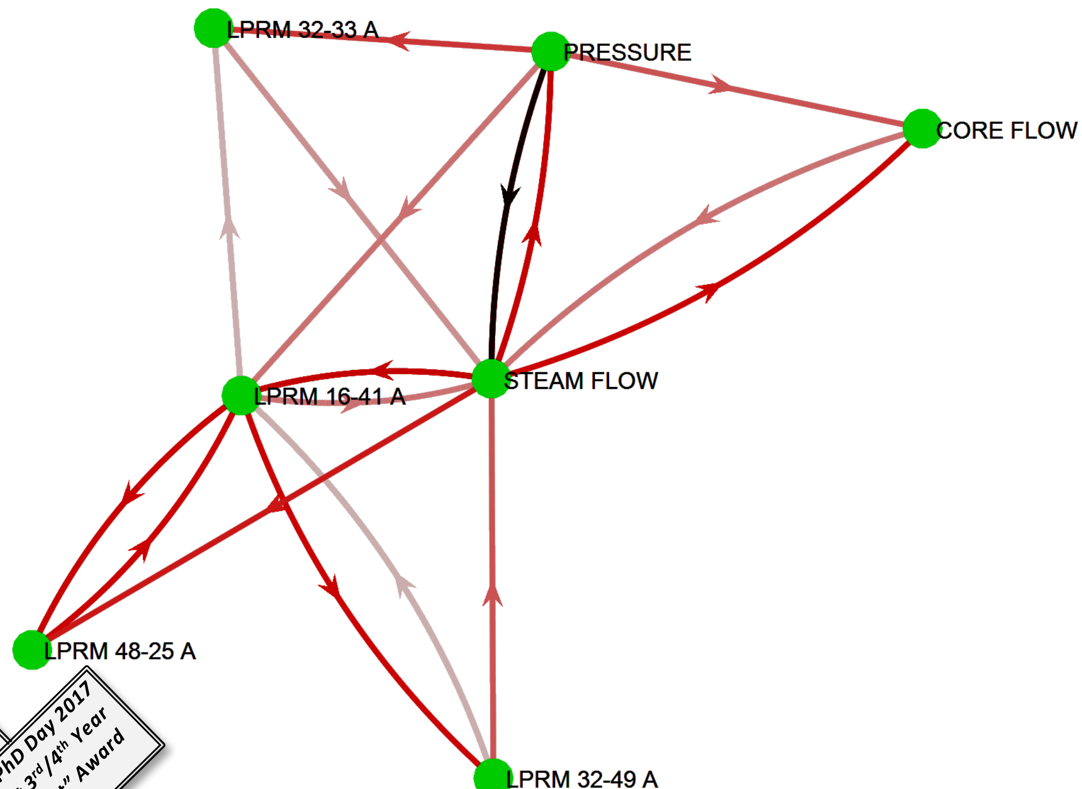
2-D Vibration



PHYSOR 2016 Int. Conf. "Best Student" Award

Noise Measurement Evaluations with PSI Time Series Analysis (TSAR) Methodology

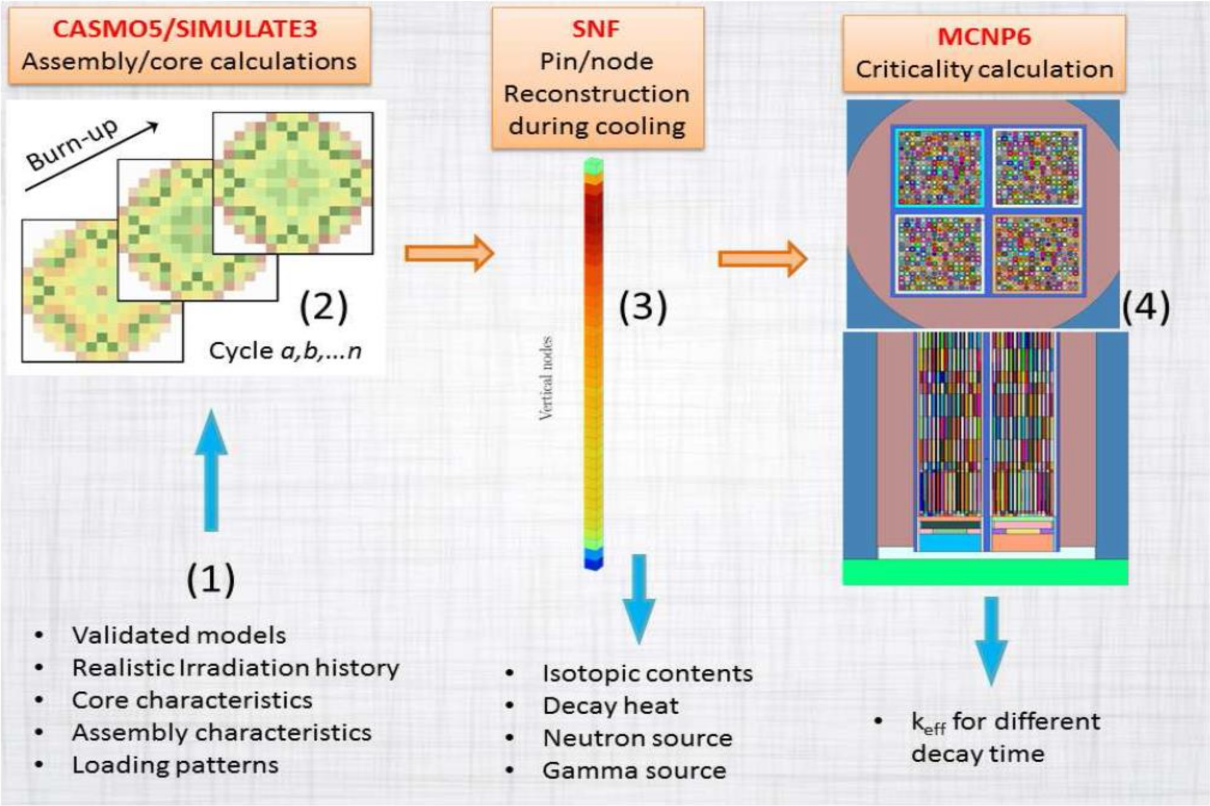
Application of Causality Analysis Method for Assessment of "Chicken-Egg" Relationships between Measured Signals



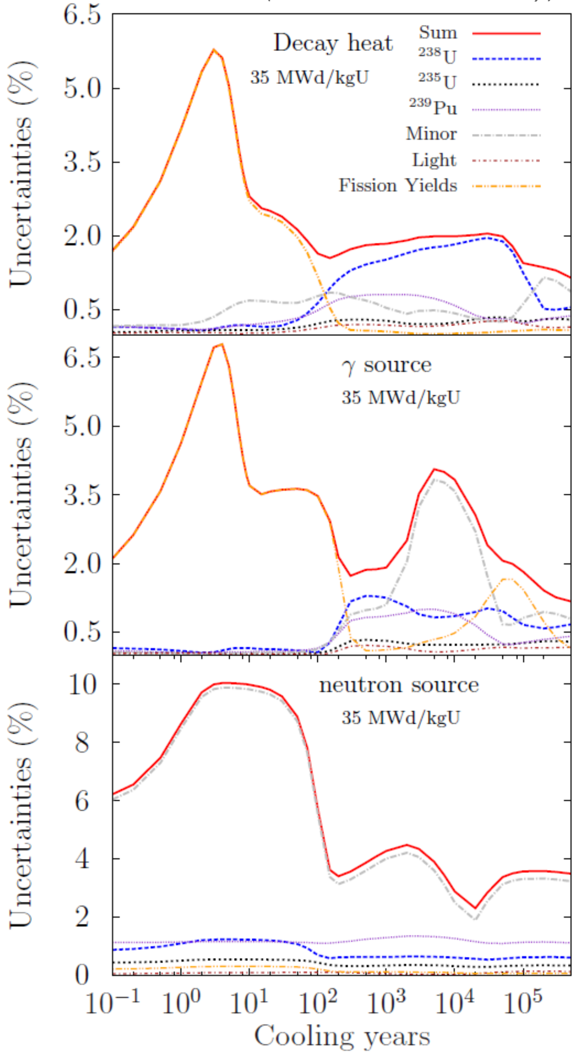
NES PhD Day 2017 "Best 3rd/4th Year Student" Award

Development of Best-Estimate Plus Uncertainty (BEPU) Analysis Methodology for
Integral Core-, Spent Fuel- and Criticality Safety Analyses

- Validated Core Models for All Swiss Reactors, Cycles and All Assemblies
- Nuclear Data Uncertainty Quantification
  - *with PSI SHARK-X for CASMO-to- SNF nuclides and source term evolution*
  - *With PSI-NUSS for MCNP reactivity and criticality analyses*

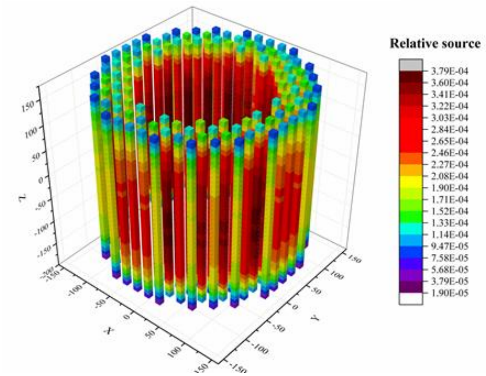


Spent Fuel Heat Load and Source Term Uncertainties (Swiss PWR Test Study)

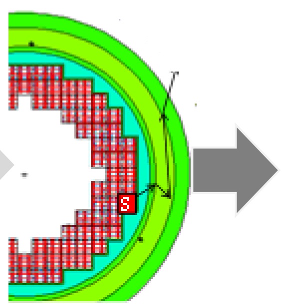


Enlargement of PSI Fluence Scheme to **Ex-Vessel Neutron Transport and Activation**

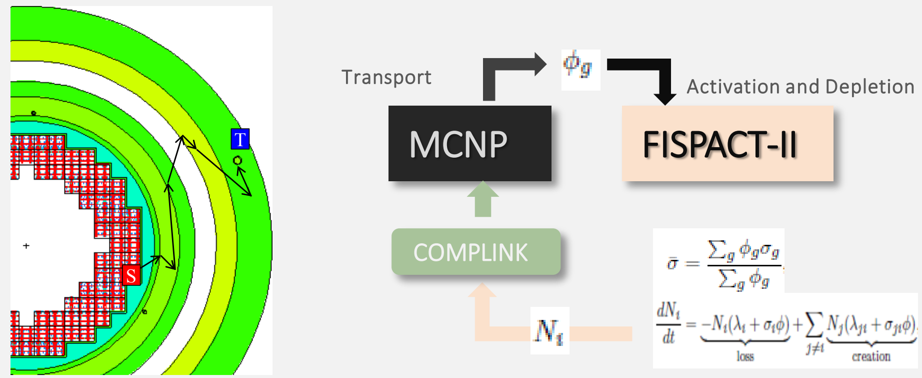
Swiss Core Models for
Cycle-specific neutron source



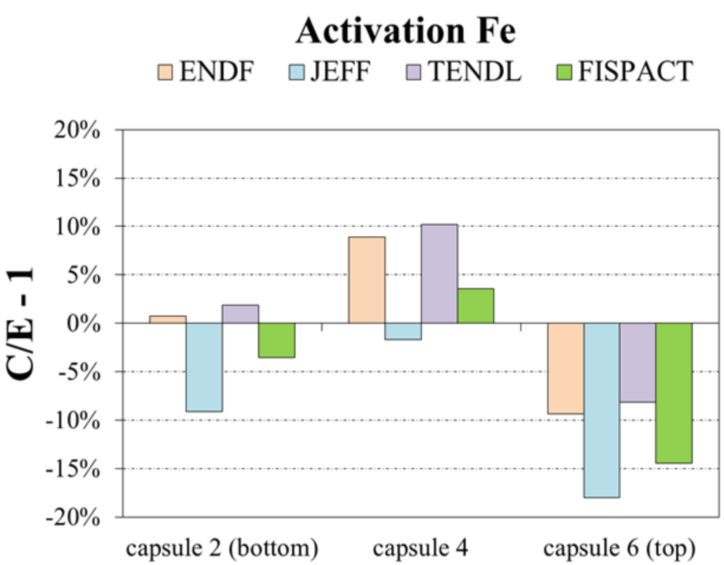
MCNP for
In-Vessel Radiation Transport



Development of **XVA⇔MCNP/FISPACT-II Coupling**



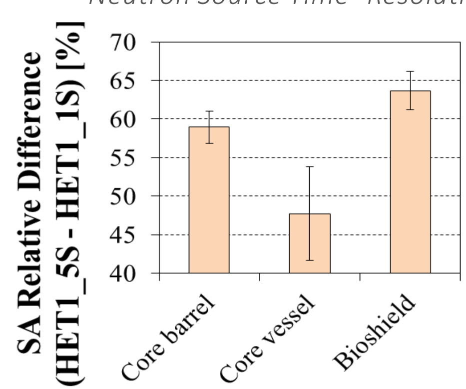
First Validation for KKG Gradient Probes



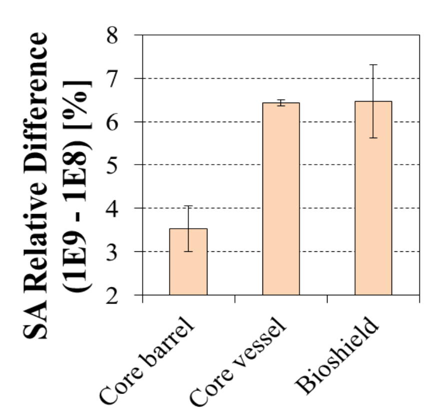
Test Study for Simplified Ex-Vessel Model

Sensitivity of Predicted ^{60}Co Specific Activity

Neutron Source Time -Resolution

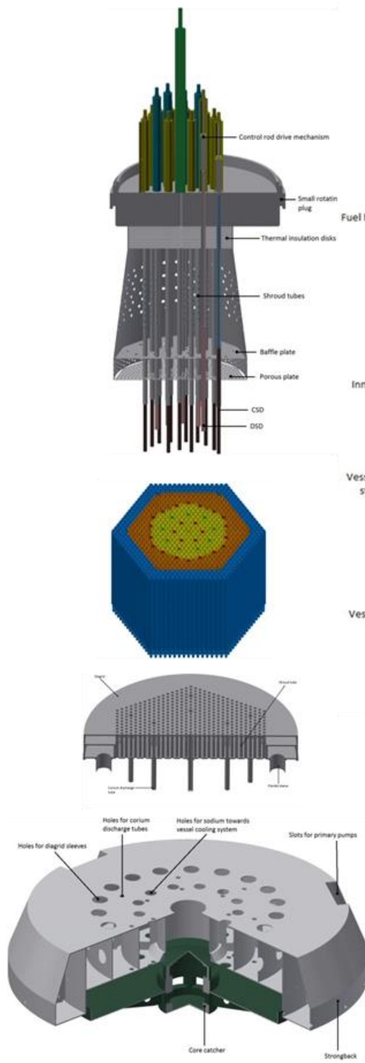


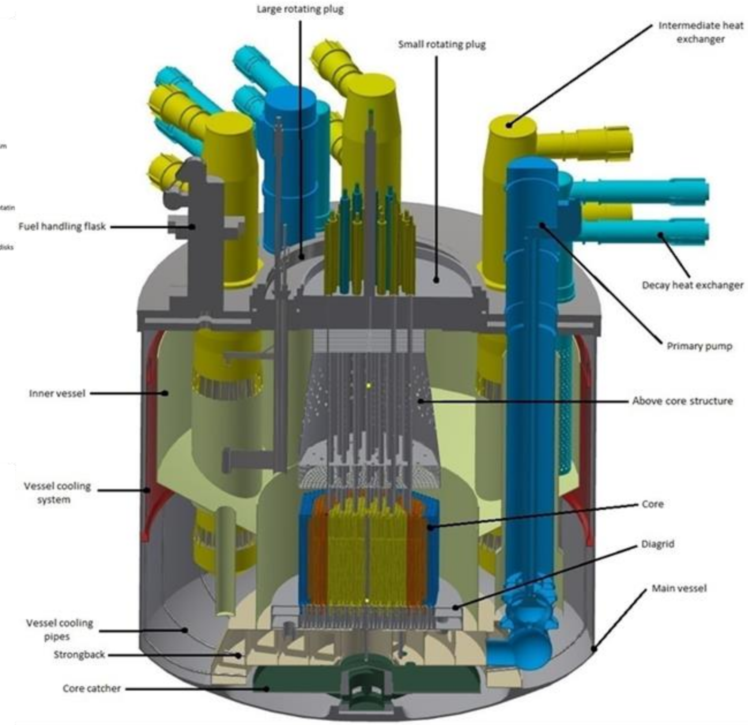
Statistical Precision

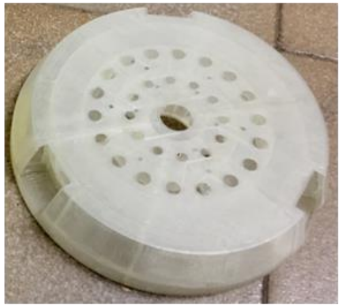


ESFR-SMART
sodium fast reactor safety

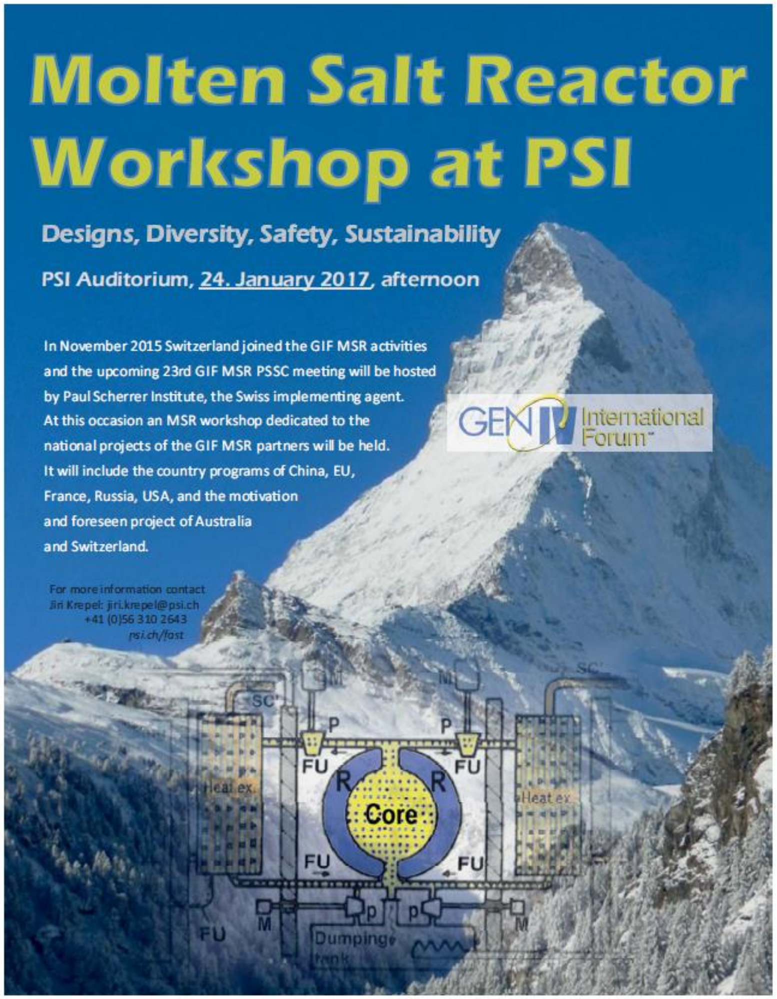
- Horizon-2020 ESFR-SMART project coordinated by PSI started on September 2017.
- MS thesis completed at PSI on development of CAD model for ESFR.
- CAD drawings will be design specifications to be used by all partners to develop code inputs.
- To be also used for 3D printing of ESFR mockup.







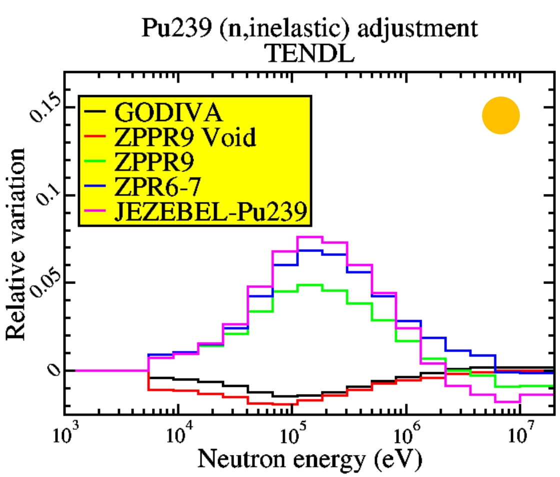
Organization and Hosting of
2017 International MSR Workshop



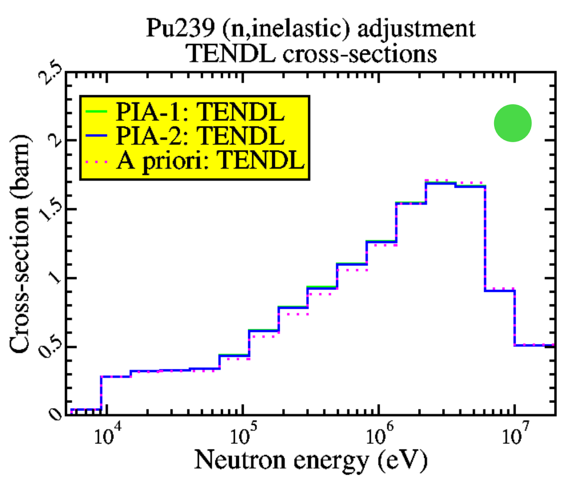
- Welcome to the molten salt reactor workshop at PSI
  Andreas Pautz, PSI, Switzerland
- MSR provisional system steering committee
  Jérôme Serp, France
- Status and perspective of TMSR in China
  Hongjie Xu, China
- U.S. MSR development programs & supportive efforts
  David Holcomb, USA
- EU SAMOFAR project goals and contents
  Jan-Leen Kloosterman, Euratom
- Introduction to ANSTO and contributions to GIF with focus on MSR related materials
  Lyndon Edwards, Australia
- Concept of molten salt fast reactor
  Elsa Merle-Lucotte, France
- Developing the next generation of molten salt reactor systems in Russian Federation
  Victor Ignaev, Russia
- Molten salt reactor research in Switzerland
  Jiří Křepel, Switzerland

Development of **Asymptotic Progressive Individual Adjustment (APIA) Method**

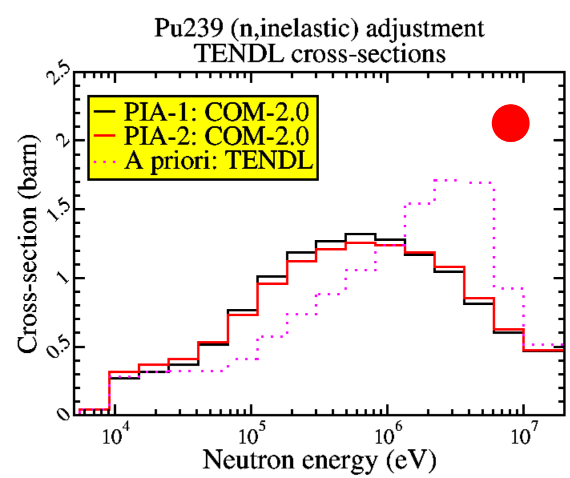
- **Enhance confidence of current nuclear data (ND) adjustment techniques in the fast energy range** on the basis of
  - *progressive assimilation* by considering at a time small groups of experiments performed in the same configuration, by accounting for nonlinearity from which the name "asymptotic".
- **Allows (to a large extent)**
  - obtaining *a posteriori C/Es within experimental uncertainties*; reducing uncertainties of Cs due to ND uncertainties.
  - Separating *effects provided by the adjustment* :
    - Distinct links between assimilation steps and specific cross-section adjustments.
  - Providing *automatic criteria* for judging the reliability of individual adjusted cross-sections:
    - Suitable adjustment does not depend on APIA sequences.
    - Non suitable adjustment depends on sequences and leads to contradictory trends.



PIA-1: Primarily due to ZPPR9 spectral indices



PIA-1 = PIA-2: reliable



PIA-1 ≠ PIA-2: non reliable

Lab Organization

- NES restructuration → LRS will be "split & spread" across two labs
- LRS Research Programs will continue

ERP

- PROTEUS Decommissioning *Removal of Fuel and Declassification of Nuclear facility*
- Spent Fuel Measurements *New neutron source measurement campaigns at PSI/Hotlab*

STARS

- Dry-Out Phenomenology *Coupled Local Effects Analyses and Transient Fuel Behaviour*
- LOCA Phenomenology *H-Uptake Modelling*
- RIA Phenomenology *Uncertainty Analysis (WGFS Phase-3)*
- Reactor Noise Analysis *Start participation to new H2020 CORTEX Project*
- Spent Fuel Characterization *Analysis of JOPRAD/SKB CLAB Decay Heat Blind Benchmark*
- Decommissioning *Optimization of XVA Scheme with Swiss Ex-Vessel Model Refinements*

FAST

- Sodium Fast Reactors *Experimental Studies of CHUG Flow Boiling Regime*
- Molten Salt Reactors *Burnup Calculation Methods for moving Liquid Fuel Salt*

Thank You !

to all National Partners

- ENSI
- swiss*nuclear*
- Nuclear Power Plants
- Axpo/BKW/Alpiq
- ESB
- NAGRA

to all «Homies»

- PSI
- NES
- LRS
- LTH/LNM/AHL/LES/LEA/LRC
- GFA/NUM
- EPFL/ETHZ

and also to all International Partners e.g.

- EU
- OECD/NEA and IAEA
- STUK
- E.ON/Preussen Elektra/AREVA
- CEA
- ETSON/GIF
- NRC/Studsvik/EPRI/SNU
- etc….