



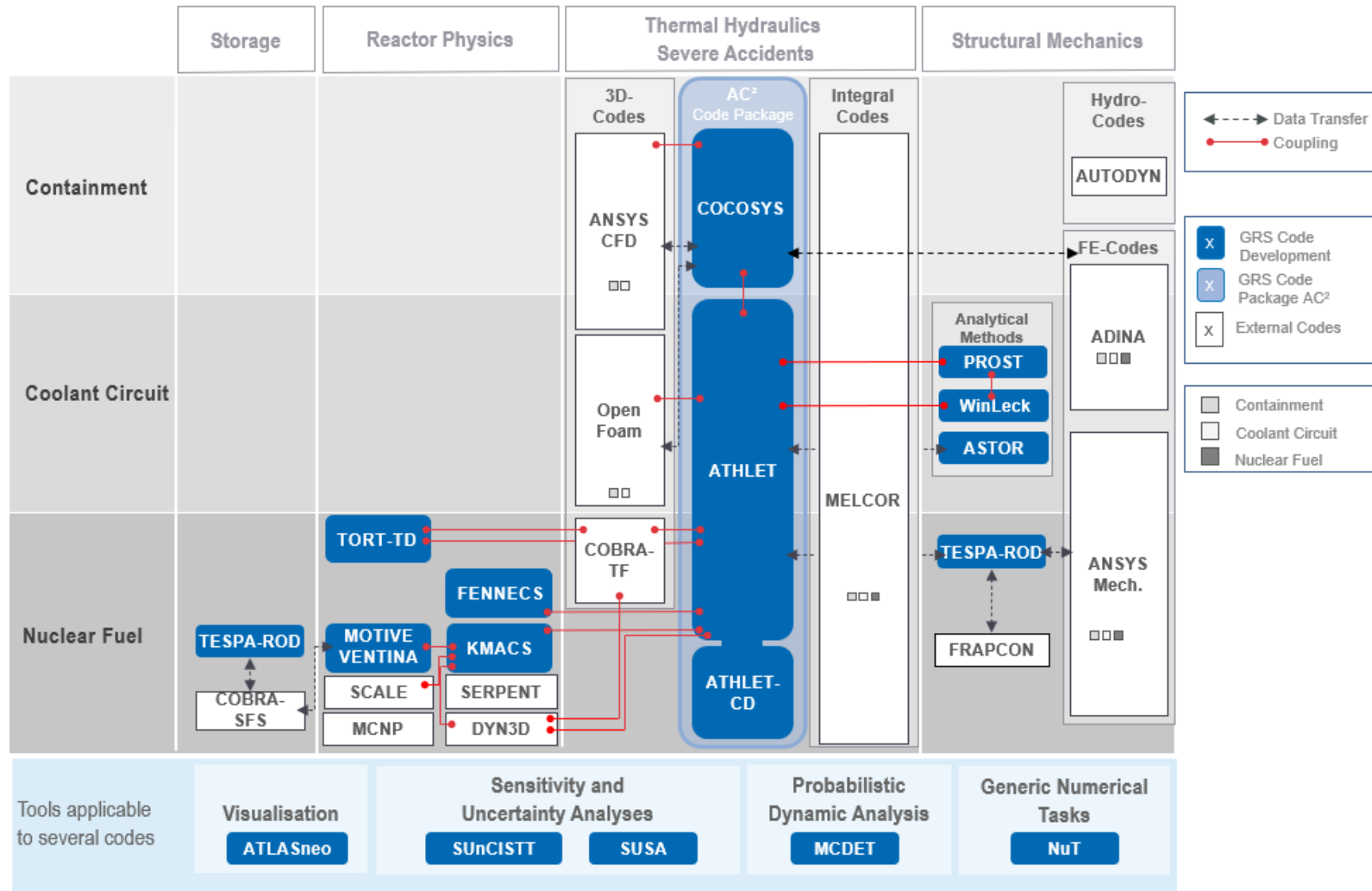
The Program Package AC² 2023

Fabian Weyermann, GRS

27.11.2023

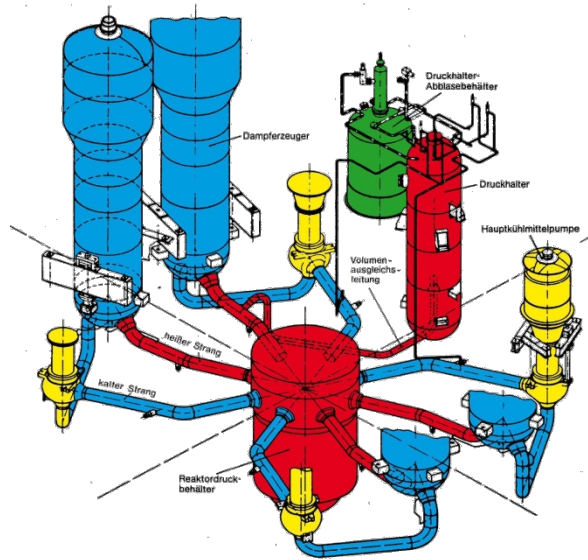
AC² User Meeting 2023

AC² within the GRS Simulation Chain



What is AC²?

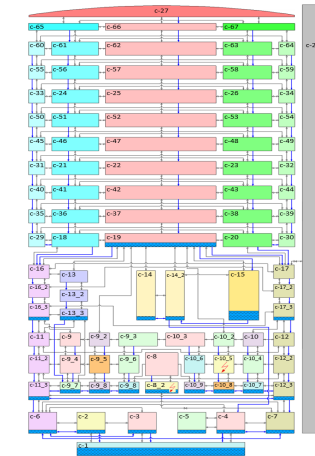
$$AC^2 = \underline{A}THLET + ATHLET-\underline{C}D + \underline{C}OCOSYS$$



ATHLET
Cooling System

- Thermohydraulics
- Neutron kinetics
- I&C

Mass and Energy Transfer



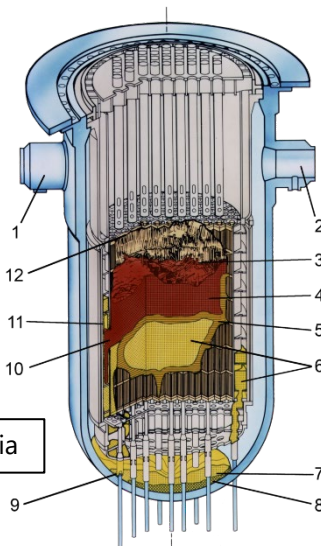
COCOSYS
Containment

- Fission products
- Hydrogen
- Core Melt

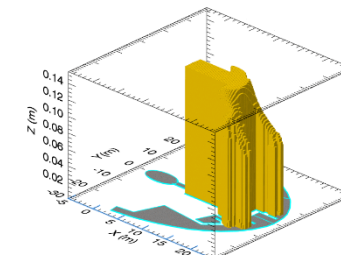
Hydrogen, Fission Products

ATHLET-CD
Core Degradation

- Hydrogen
- PV failure



From: 11), Wikipedia



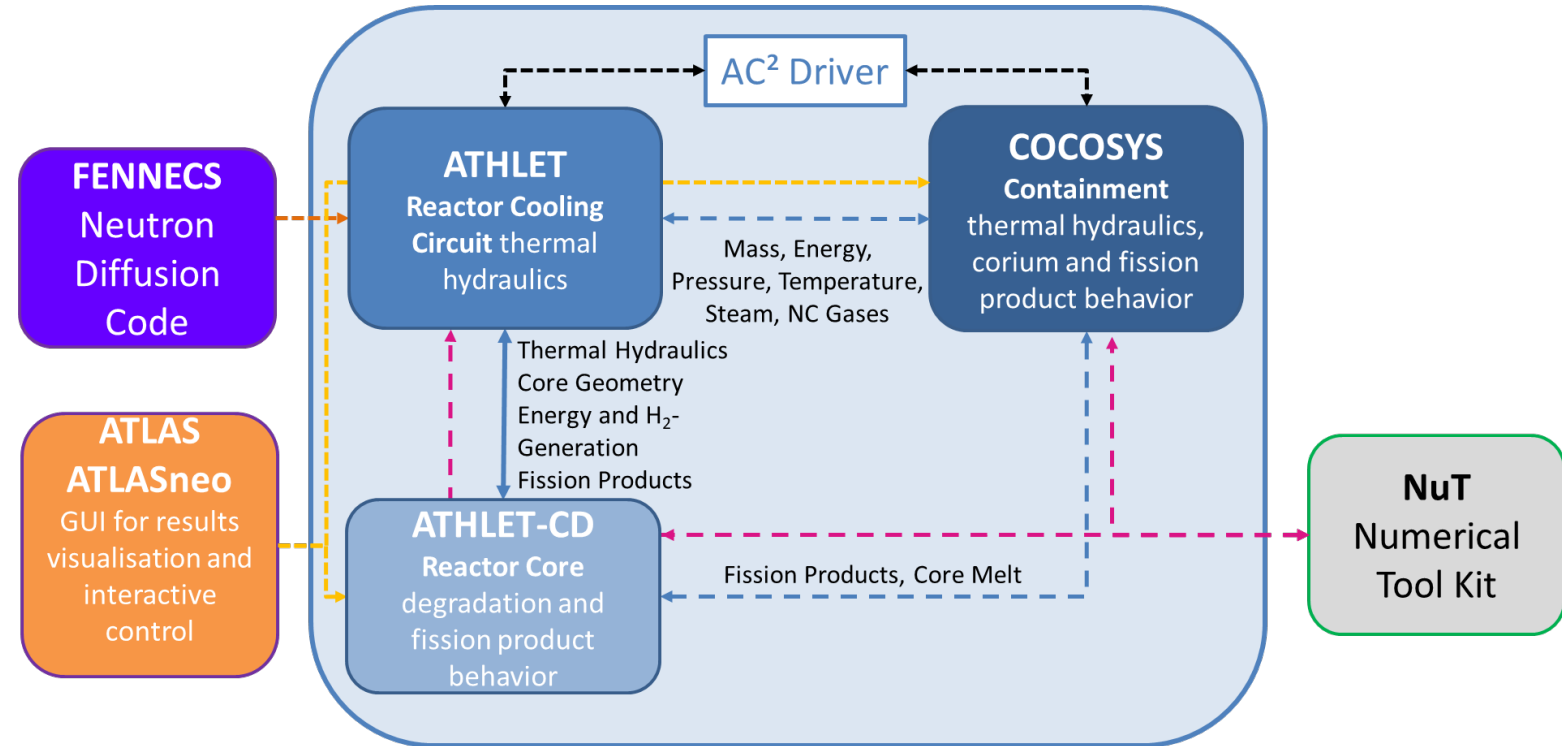
AC²: Overview and Components

AC² : System code package of GRS

- simulation of normal operation, design-basis accidents
- design extension conditions up to severe accidents including fission product release
- nuclear power plants, research reactors, advanced reactor designs and FE storage pools

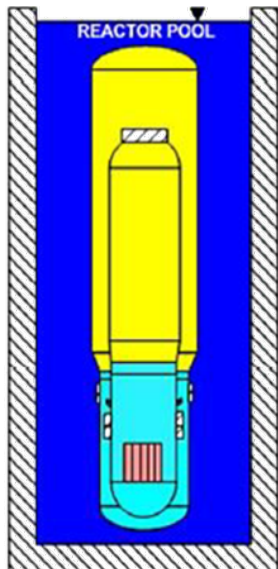
AC² features:

- **integral simulation of design basis and design extension conditions**

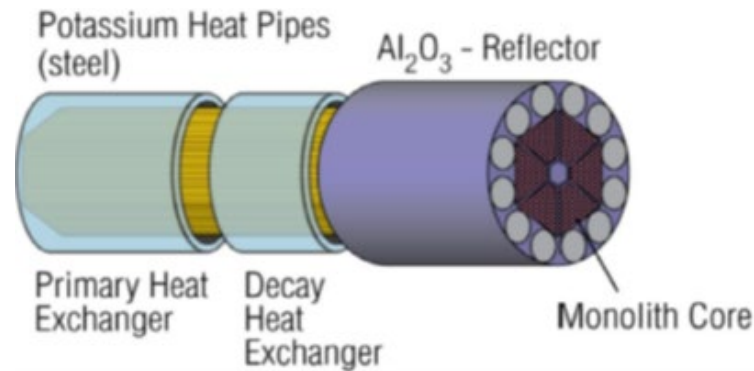


Motivation for the Development of AC² (1)

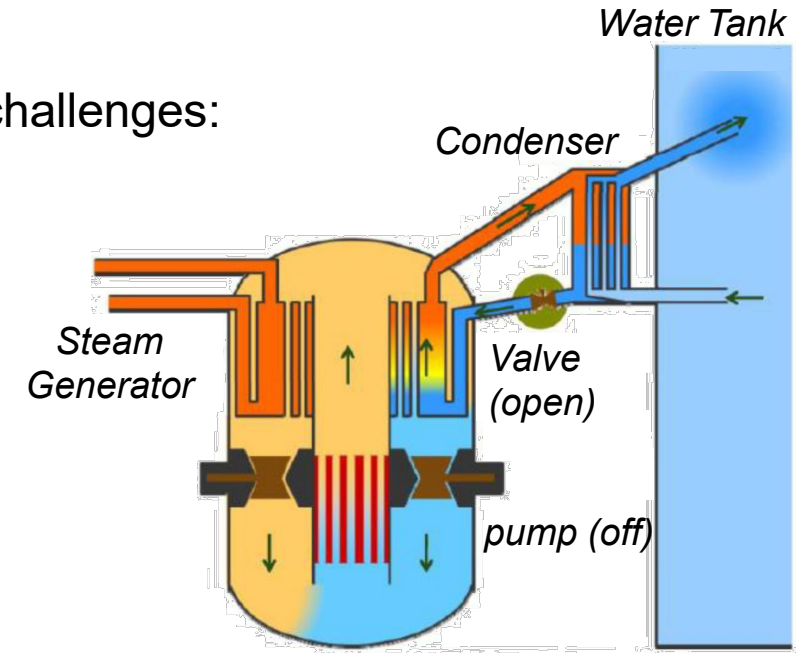
- New reactor concepts (Gen III, III+, SMRs, MMRs,...) impose special challenges:
 - Passive safety systems
 - Innovative components (e.g. compact heat exchanger, heat pipes)
 - New working fluids (e.g. Molten Salt, He, sodium, potassium,)
 - New containment concepts
 - Large water pools



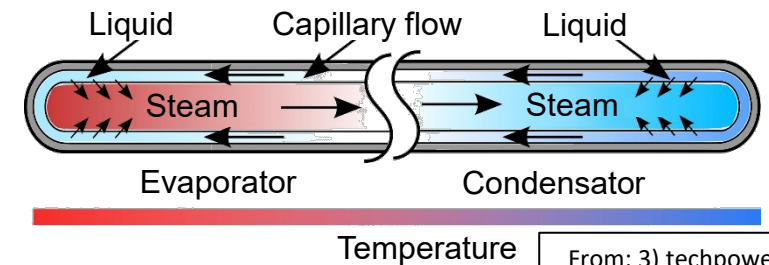
Adapted from: 6) M. Niemi 2017



From: 4) W. Sterbentz 2017



From: 2) J. Chénais, 2018



From: 3) techpowerup.com

Motivation for the Development of AC² (2)

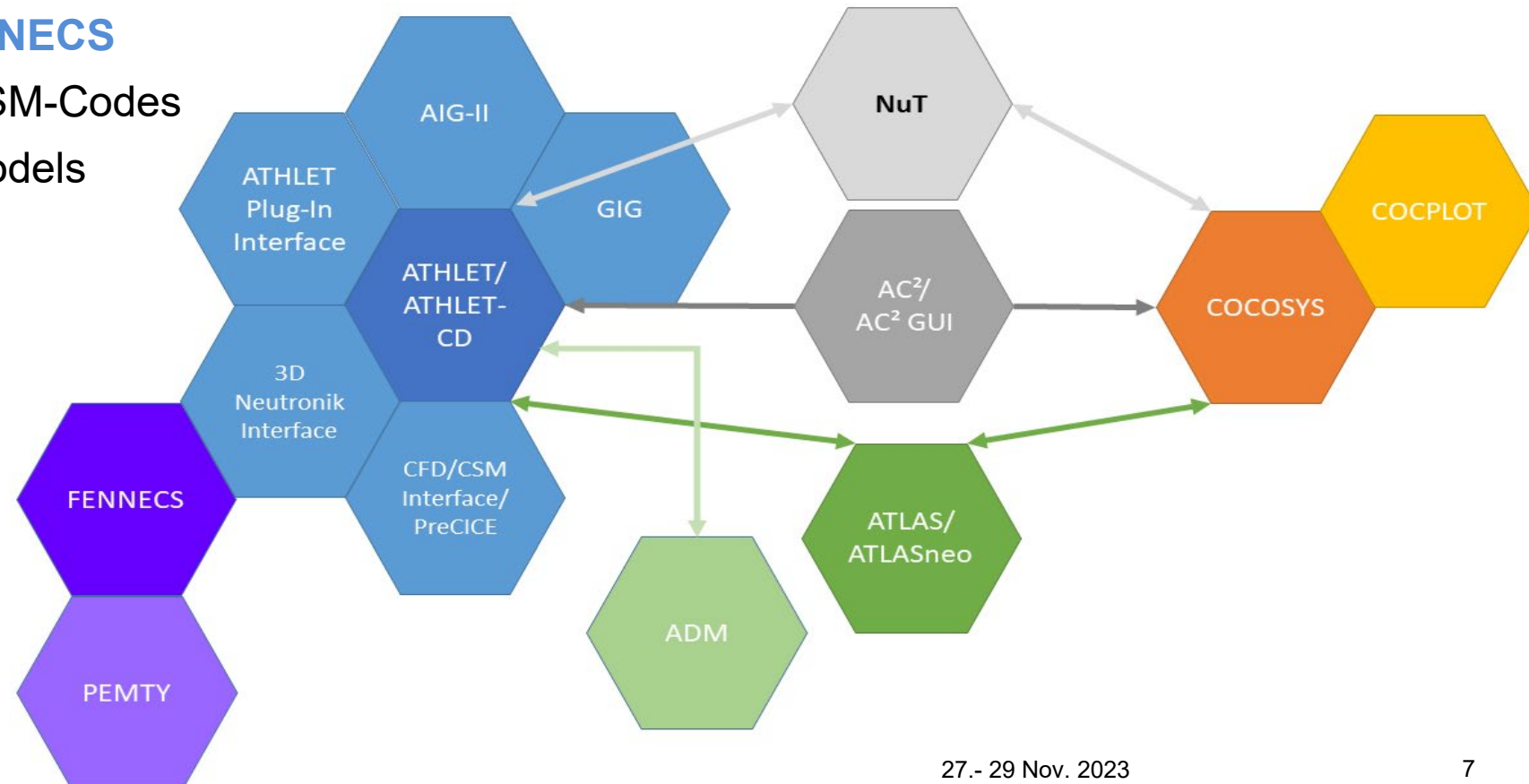
- **Advanced reactor concepts** require partially coupled (**multi-physics**) simulations of phenomena in the core, cooling circuit, containment and fuel pool

- **AC²** approaches this challenge by:
 - Further development of the specific models for **passive safety systems** and **innovative components**
 - **Coupling** ATHLET/ATHLET-CD und COCOSYS for the simulation of flow phenomena in cooling circuit and containment
 - Coupling thermo-hydraulics and neutron kinetics with **ATHLET and FENNECS**
 - **Simplifying input creation** for integral analysis
 - Improved compatibility of the **phenomenological models**
 - Extension to **new working media** and **homogenization** of material values
 - **Integral validation** of the overall system
 - Uniform programming standards and **QA requirements**

AC² 2023: Content of the Distribution

In addition to the AC² ([ATHLET](#), [ATHLET-CD](#), [COCOSYS](#)) code, **AC² 2023** package will also contain:

- **ATLASneo/ATLAS** for the visualisation of the simulation results and interactive control of plant simulators
- **ADM** (ATHLET Input Modeller) for graphical generation of thermo-hydraulic- und BOP models for [ATHLET/CD](#)
- **FENNECS**: 3D-Neutronic-Diffusion Code for compact cores
- **PEMTY**: Grid generator for [FENNECS](#)
- **Coupling Interfaces** to CFD/CSM-Codes
- **Plug-Ins templates** for User-models
- Tools für [ATHLET](#) und [COCOSYS](#)
- Documentation
- Sample inputs



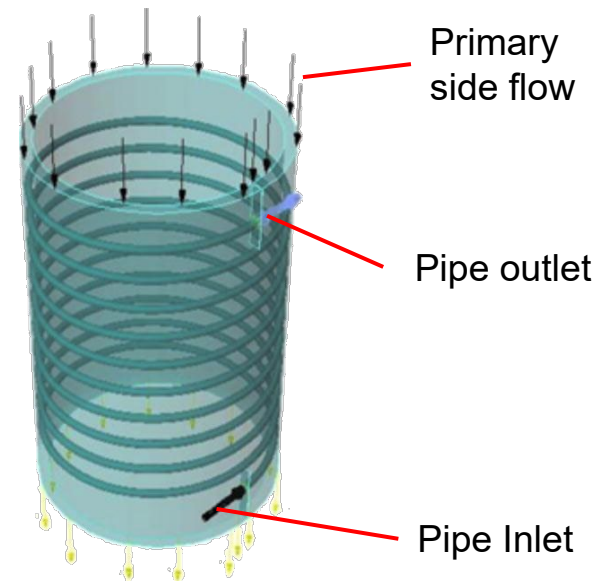
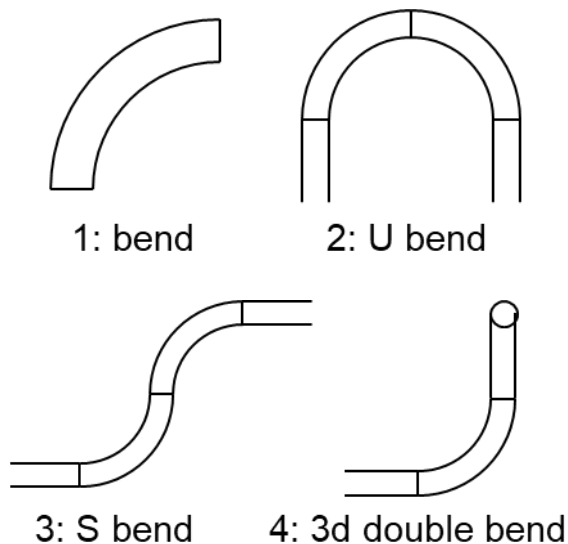
ATHLET 3.4

■ Numerous new and improved models

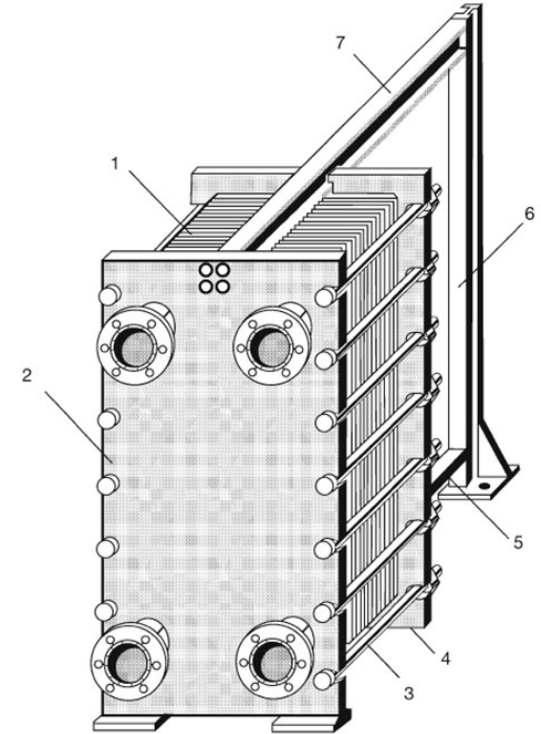
- Heat transfer and pressure loss correlations for **compact heat exchangers** in SMRs
- Improved consideration of **form losses**
- Widely updated **fuel rod model** for DBA analyses
- **New two-phase working fluids** and NC gas components
- Divers model updates, e.g. T-junction model, oxidation model



Fuel swelling
and relocation



From: 6), Niemi 2017

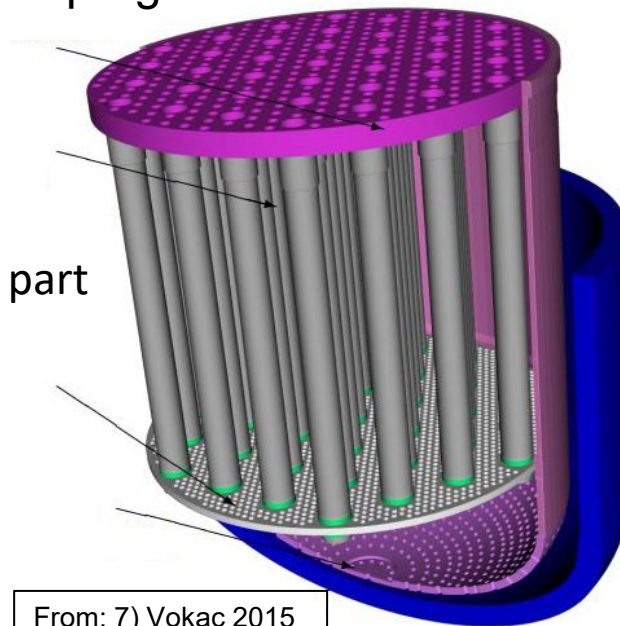


From: 5) VDI 2013

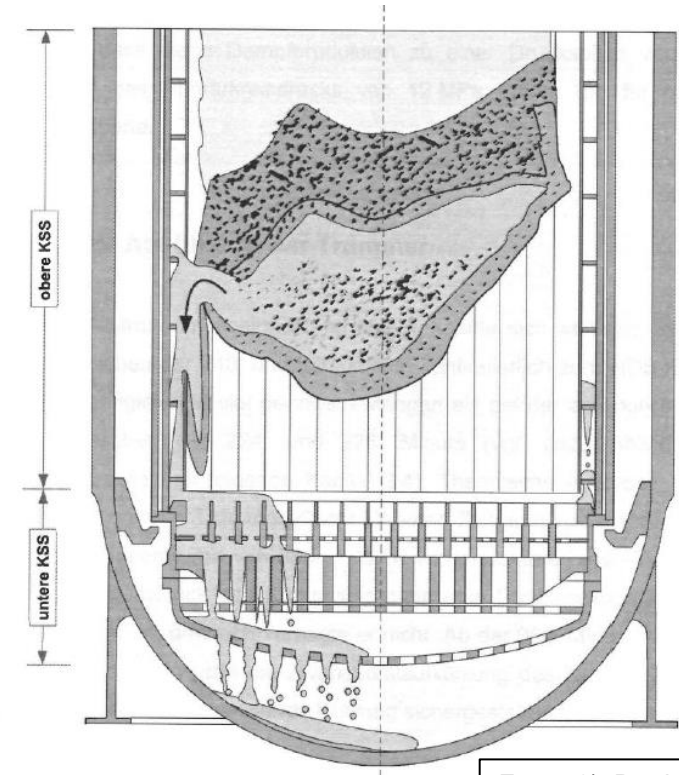
ATHLET-CD 3.4

- Melt **relocation** through the core bypass channel
- **VVER-440** specific model capabilities
 - Axial configurable core composition
- **Harmonization** between ATHLET-CD and ATHLET
 - Heat transfer correlations
 - ATHLET water properties used in AIDA
 - Further harmonization under progress

VVER-440 lower core part



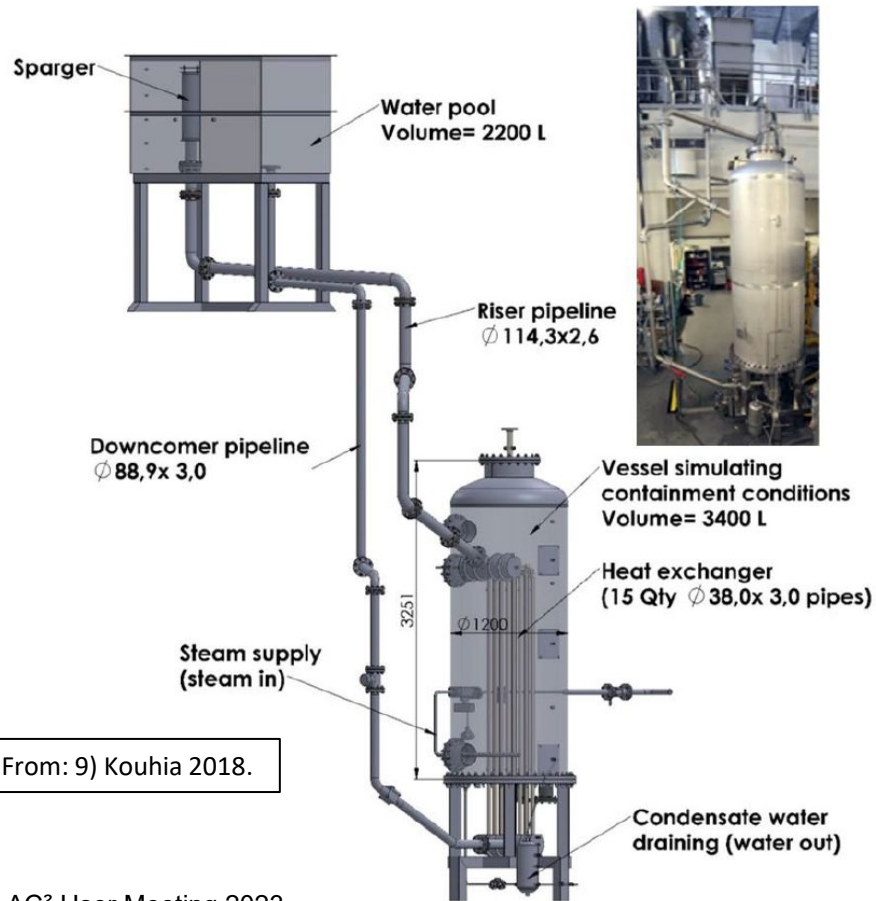
From: 7) Vokac 2015



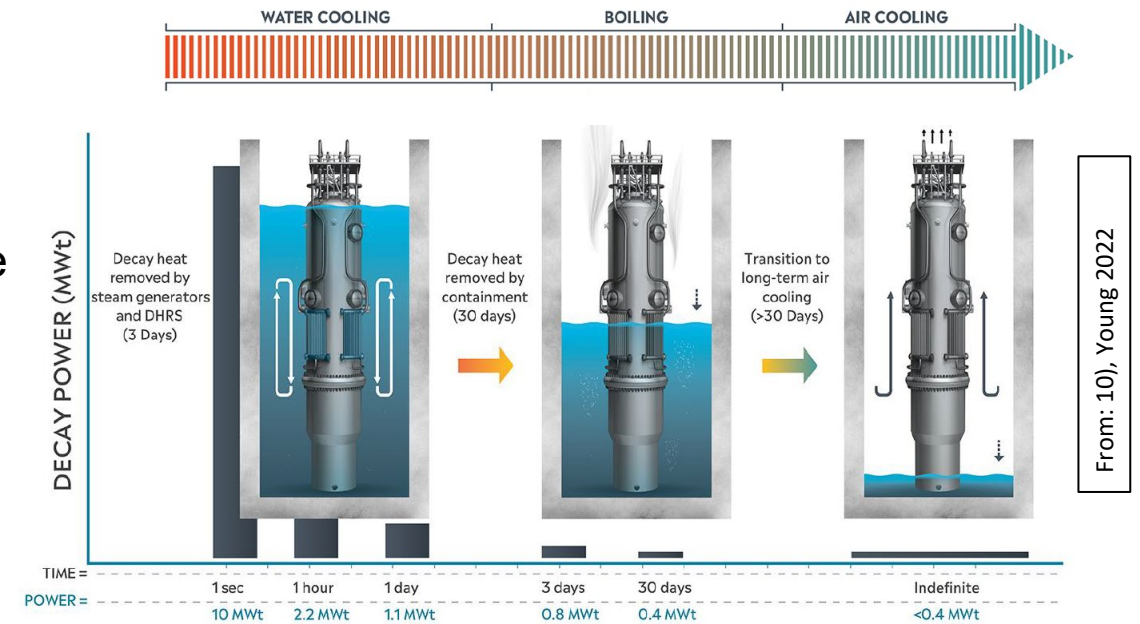
From: 8), Drath 2004

COCOSYS 3.2

- Improved **pool simulation** (heat transfer, boiling, level)
- Improved **building condenser** model (stability two-phase flow, non-condensable gases, pressure loss)

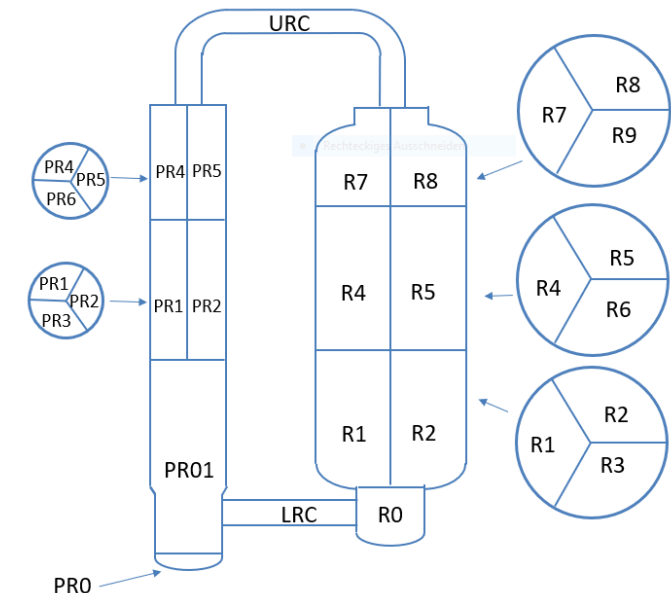


From: 9) Kouhia 2018.



AFP2:

- NewAFP** becomes **AFP2**
- Consideration of **FP and aerosol transport in ATM_FULL**
- pH model** is now available in **NewAFP**



FENNECS – Deterministic Neutron Kinetics Code for Irregular Geometries

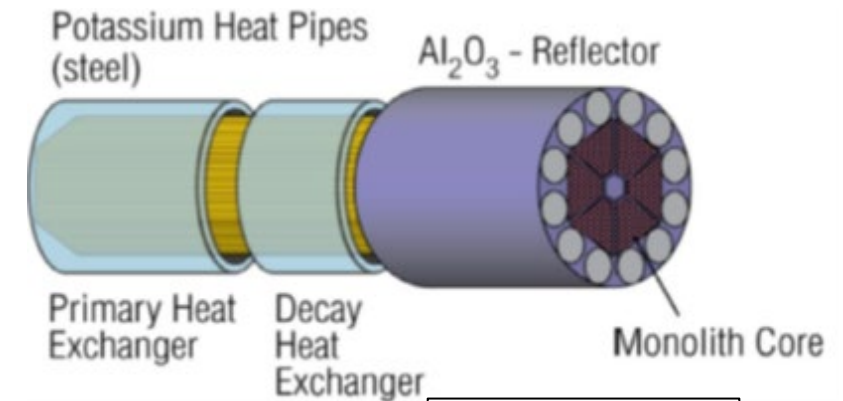


■ Finite Element Neutronics

- Time-dependent 3-d few-group **finite element**-based **diffusion** and **SP₃ transport** (steady state) code
- Geometrical flexibility to model **complex** and **irregular geometries** of **SMRs** and **MMRs**
- Also applicable to **Generation IV** reactor concepts and **LWRs**

■ Features:

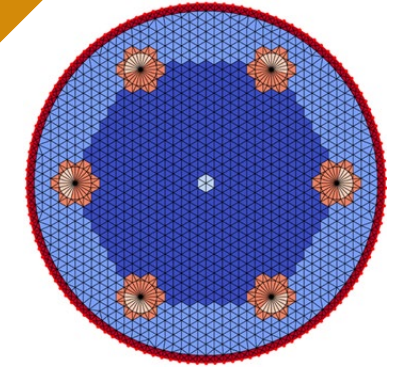
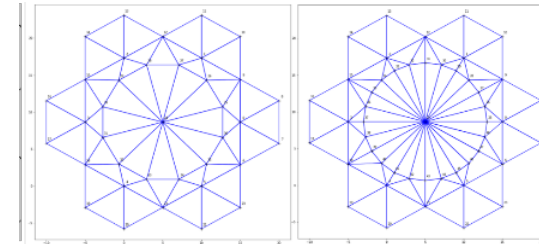
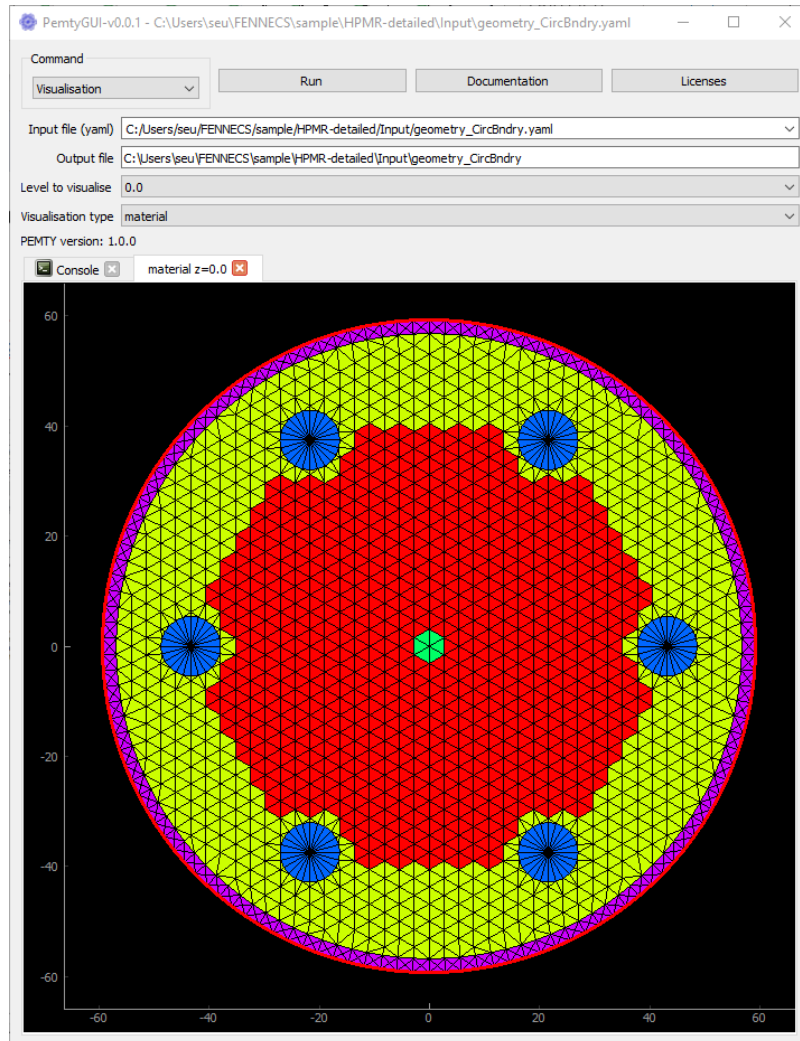
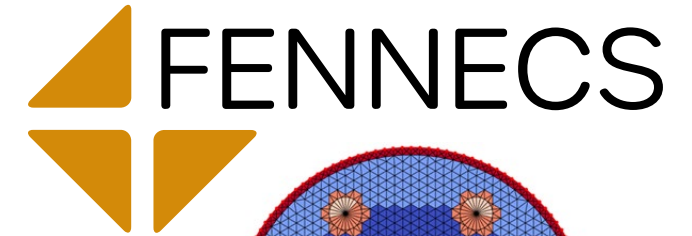
- **Coupled** with the GRS thermal-hydraulic system code **ATHLET**
- **Coupling with CTF in progress**
- **Core radial thermal expansion model** for SFR simulations
- **Control rods:**
 - **Axial** movements, different axial material zones,
 - in-plane **rotation** of **control drums**.
- Critical **boron search**.
- **Iodine/Xenon** and **Promethium/Samarium** dynamics
- **Visualization:** geometry, material, power density, neutron flux distribution, thermal-hydraulic parameters



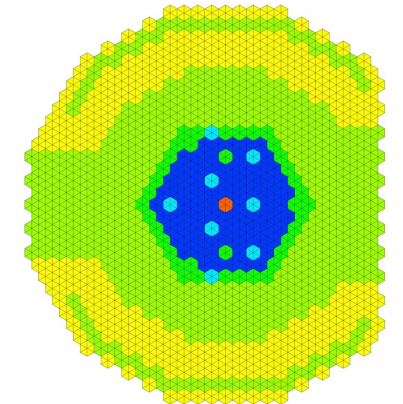
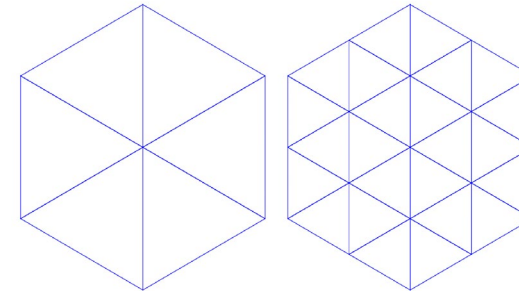
From: 4), Sterbentz 2017

PEMTY – Software for Meshing Irregular Geometries for FENNECS

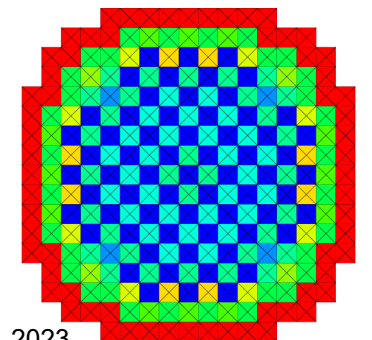
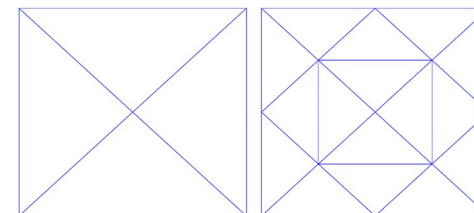
Python External Meshing Tool with Yaml input



MMR



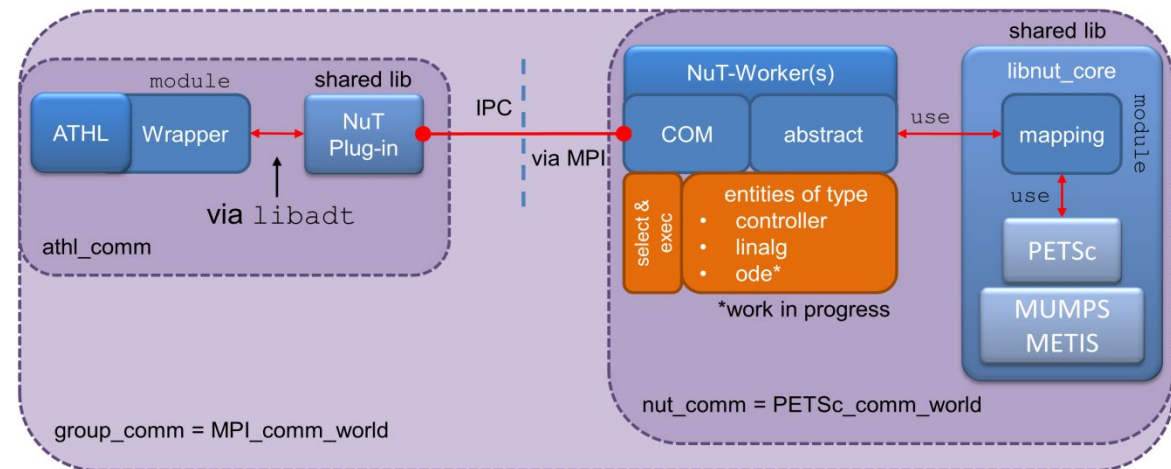
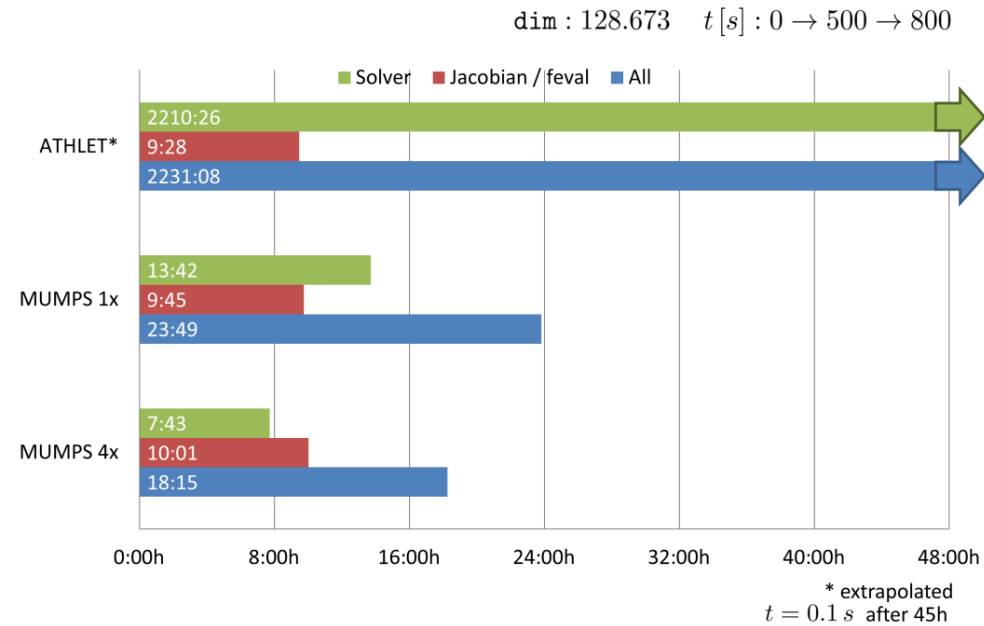
SFR



LWR

Numerical Toolkit (NuT) v2.0.2

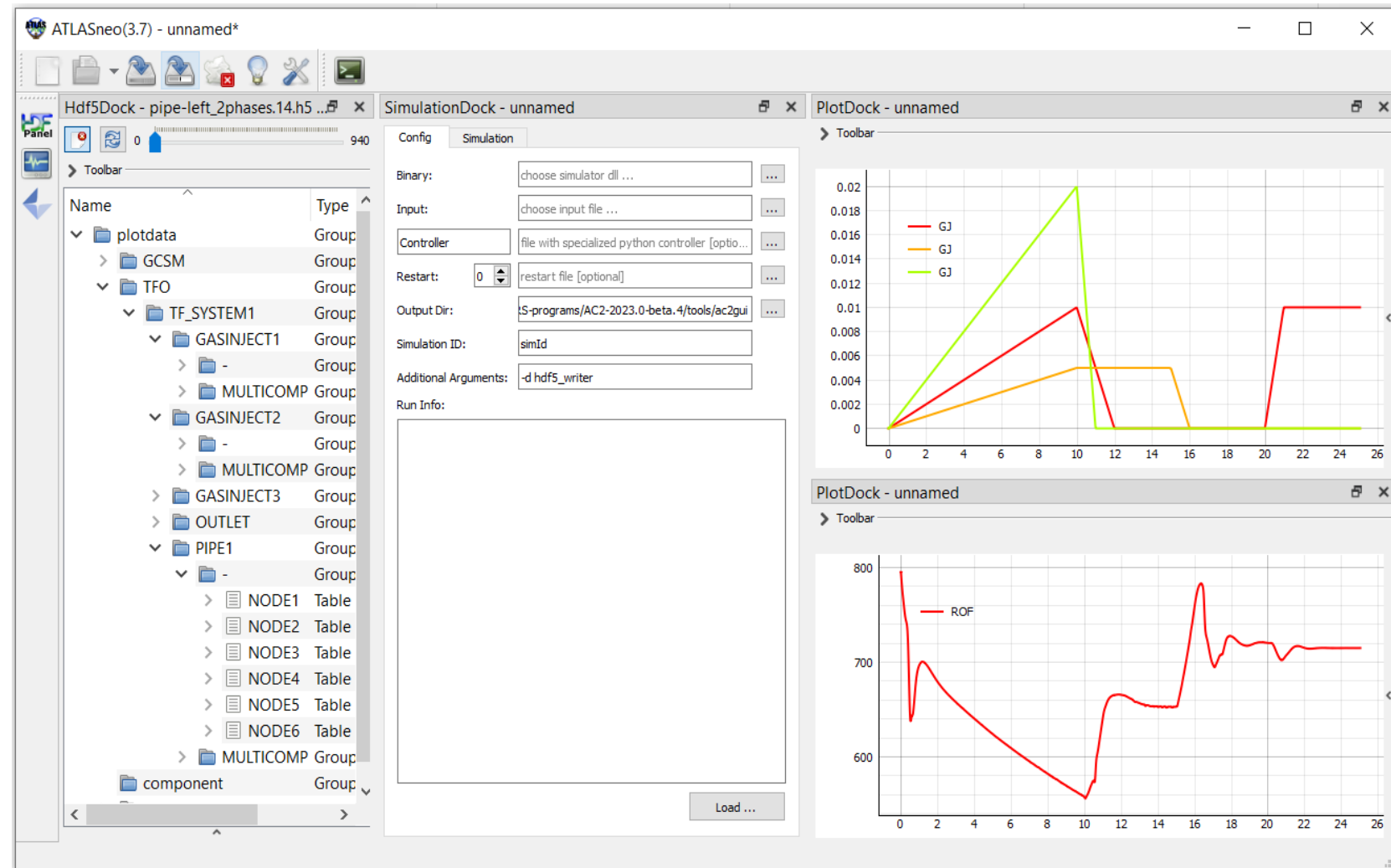
- Numerical Toolkit (**NuT**)
 - Based on PETSc Library (open source)
 - Coupled via MPI-Interface
 - Multithreading
- Significant performance gain for **ATHLET**
- New feature:
 - Support of **COCOSYS THY-module RAMAIN**
- Current development work:
 - Support **coupled calculations** of ATHLET/CD and COCOSYS with common equation system



```
mpiexec -n 1 ./athlet : -n 4 ./nut
```

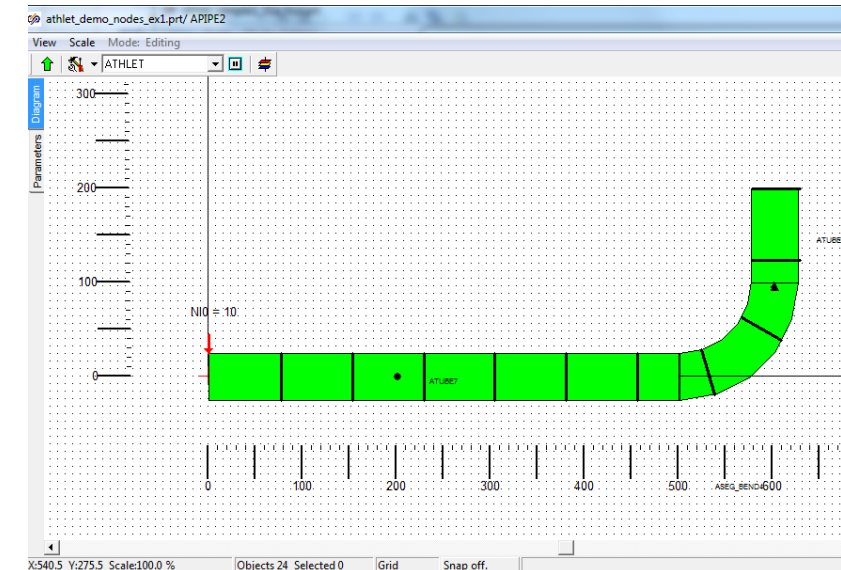
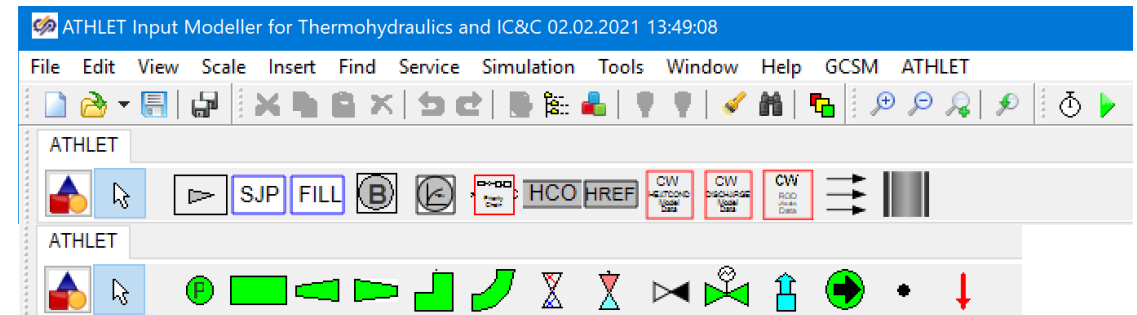
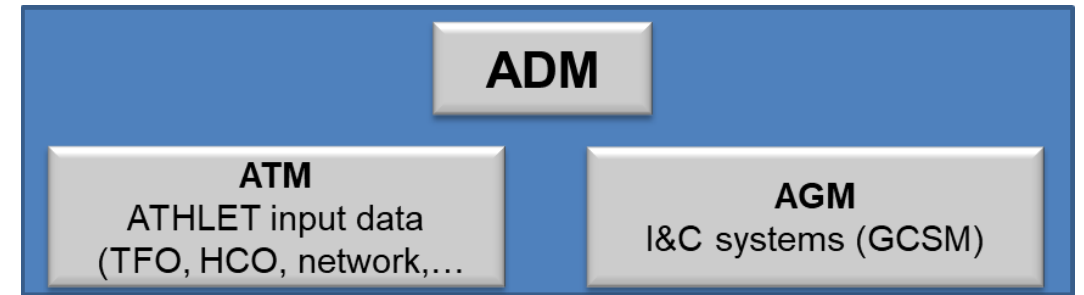
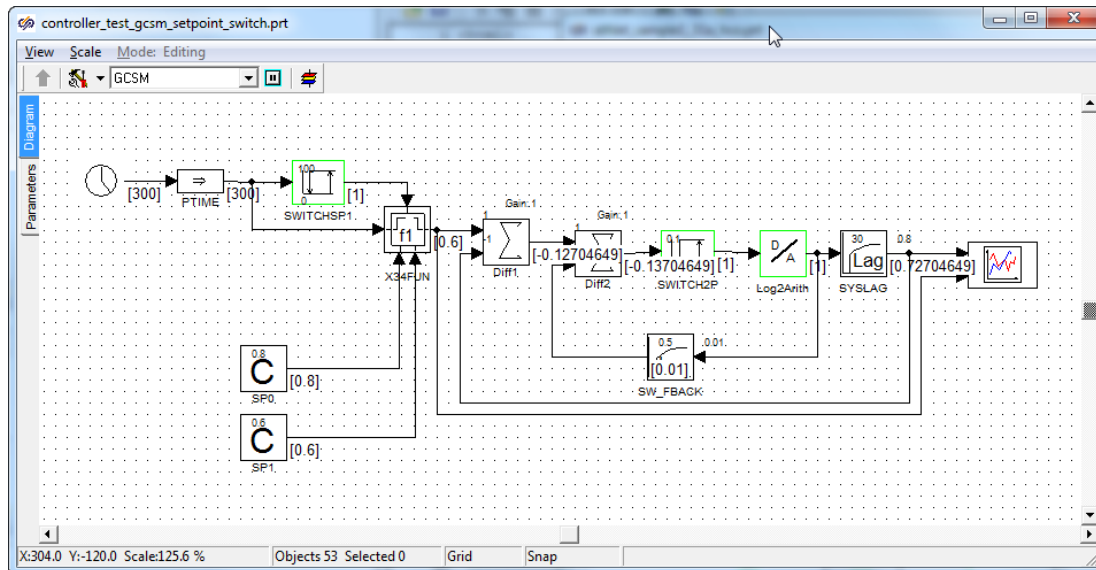
ATLASneo

- Dynamic simulation control
- Postprocessing
- Runs under Windows and Linux
- Dataformat: **HDF5**
- pdf2HDF converter
- 2D-visualization in development



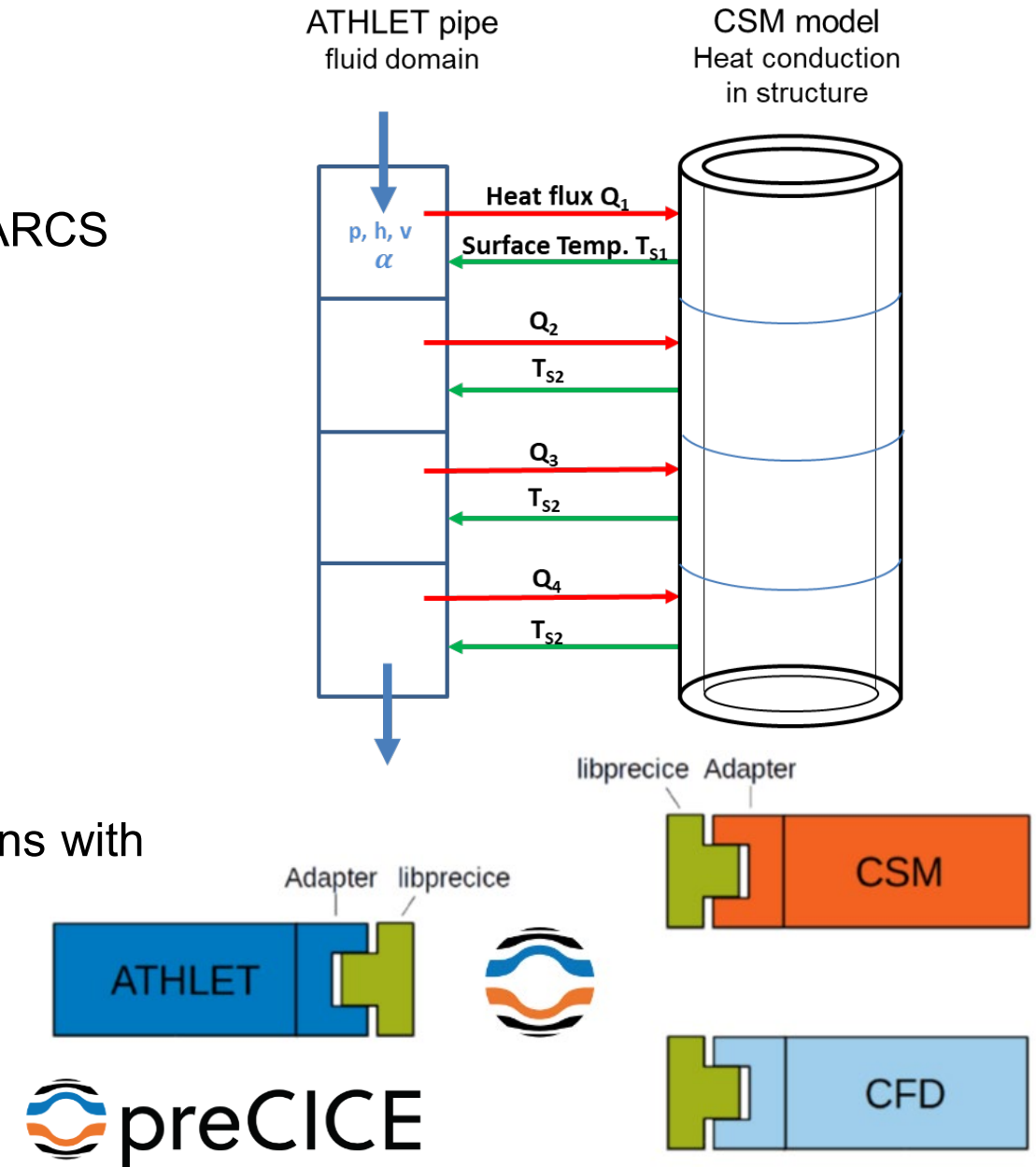
AC² Design Modeller (ADM)

- Interactive application for graphical modeling and input generation for ATHLET
 - ATHLET GCSM Modeller (AGM)
 - Used for system simulation in several plant simulators
 - ATHLET Thermohydraulic Modeller (ATM)
 - Supports many models (TFO, HCO, ROD,...)



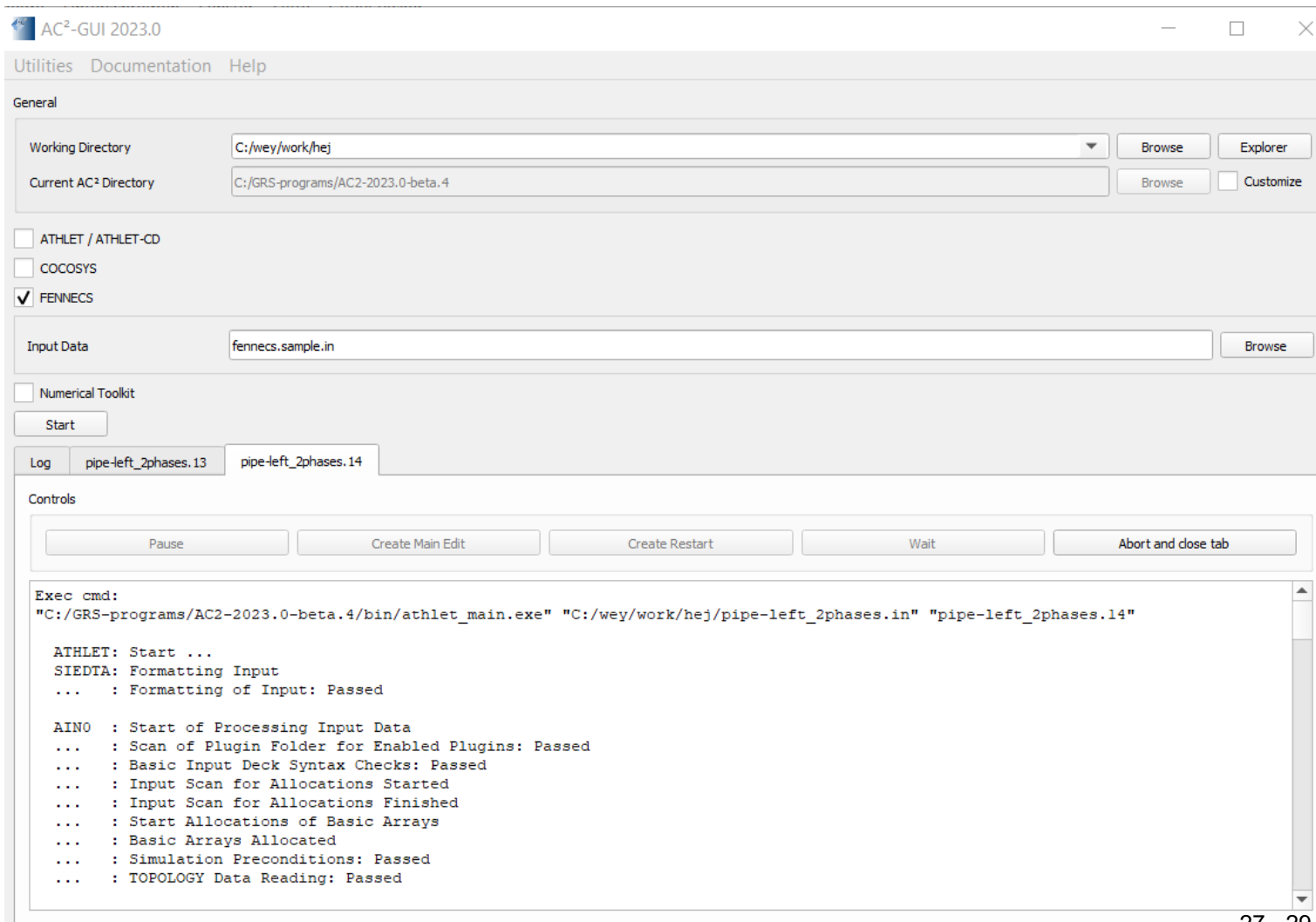
Coupling Capabilities of AC²

- Neutronic-Codes
 - **FENNECS**, QUABOX/CUBBOX, DYN3D (HZDR), PARCS
 - BIPR, KIKO3D (KFKI, HU), **TORT-TD**, **KMACS**
- Subchannel-Codes
 - COBRA-TF (NC State Univ., USA)
- CFD-Codes
 - ANSYS CFX, OpenFOAM
- Structure Mechanics Codes
 - ASTOR, WinLeck, **CalculiX**
- **Plugin-Interface** to couple user-defined models/functions with **ATHLET/ATHLET-CD**
- **New**: Interface to coupling library **preCICE**



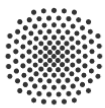
AC² - GUI

- AC² GUI to start ATHLET/CD, COCOSYS and FENNECS stand-alone and coupled calculations



AC² 2023: Development and Validation

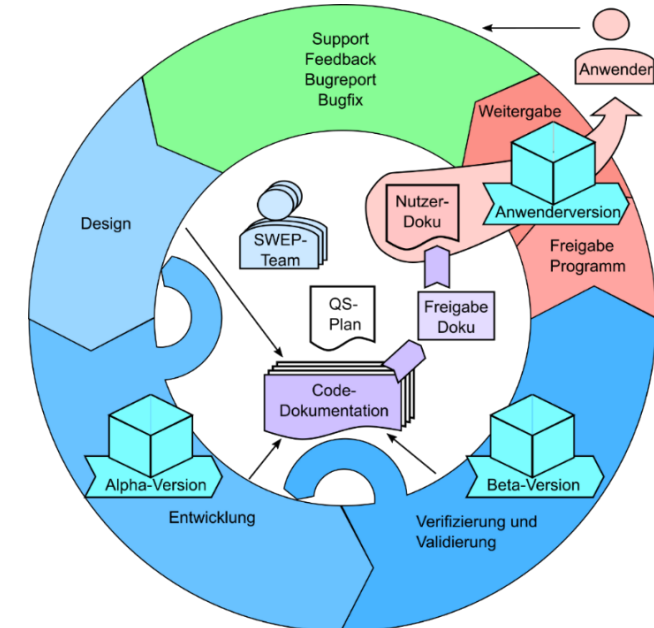
- All **AC²** Codes are developed and validated under strong quality assurance.
- The goal is a program that is validated in accordance with **regulatory requirements** (**SiAnf, SSG-2**) and can be used in nuclear regulatory procedures. The continuous validation of the AC² programs for 46 years establishes their value for research, development and application
- In addition to **GRS**, **AC²** programs are validated and partly developed by **long-standing partners** of GRS. These are particularly **German research institutions**.



Universität
Stuttgart



AC²-Development Process



CPU Affinity

- Intel CPUs processors (12th Gen and later) feature Performance-cores (p-core) and Efficient-cores (e-core)
 - p-core provide 2 logical high-performance processors
 - e-core provide 1 logical processor efficient, but not a fast
- **.Problem:** Windows 10 confines every background process to the slower e-cores



As soon as the AC²-GUI is in the background your simulation slows down (about 50%)

Our Solution: Environment variable `AC2_CPU_AFFINITY`

- Specify CPUs to be used for AC²-Simulation: Set `AC2_CPU_AFFINITY` to
 - individual CPUs, e.g. `AC2_CPU_AFFINITY = '0,2,3'`
 - CPU ranges, e.g. `AC2_CPU_AFFINITY = '0-3,10-12'`

Detailed Instruction in the **AC²-User Manual** (determine CPU type, setting environmental variable)

Summary and Outlook

- New Release AC²-2023
 - New neutronic physics code **FENNECS** and Analysis tool **ATLASneo**
 - Lots of new features in **ATHLET, ATHLET-CD, COCOSYS, NuT** available

- Lots of interesting talks in the next three days
 - Presentations on the new versions of **ATHLET, ATHLET-CD, COCOSYS, NuT, FENNECS, ATLASneo**
 - Talks on **special new features**, e.g. new working fluids, AFP2-module,...
 - Information on **current projects**
 - Presentations of our **Users** on their **applications** of AC²

Literature:

- 1) F. Weyermann, D. Eschricht, A. Wielenberg, T. Steinhoff, Ph. Schöffel, C. Spengler, L. Lovasz: AC² User Manual, GRS gGmbH, 2023
- 2) J. Chénais: SMR Technology, The French Approach, IAEA TWG SMR Vienna April 23-26 2018
- 3) <https://www.techpowerup.com/forums/threads/heatpipes-do-yo-really-know-them.210048/>
- 4) J. W. Sterbentz, J. E. Werner, M. G. McKellar, A. J. Hummel, J. C. Kennedy, R. N. Wright, J. M. Biersdorf: Special Purpose Nuclear Reactor (5 MW) for Reliable Power at Remote Sites Assessment, INL/EXT-16-40741, Revision 1, April 2017.
- 5) Verein Deutscher Ingenieure (VDI), VDI-Gesellschaft Verfahrenstechnik und Chemieingenieurwesen (GVC): VDI-Wärmeatlas, VDI-Buch, 11. Aufl., Springer Vieweg: Berlin, 2013.
- 6) M. Niemi: Simulation and safety features of NuScale small modular reactor, 2017, <https://api.semanticscholar.org/CorpusID:139154191>
- 7) P. Vokac: VVER-440/213 Melcor Core Model for Gd2M Fuel, 7th EMUG, UJV Rez, 2015
- 8) T. Drath, M. Dapper, I.-D. Kleinhietpaß, H. Unger, M. K. Koch: Simulation des TMI-2-Unfalls mit dem Programmsystem ATHLET-CD (Teil 1), 7. Technischer Fachbericht zum Vorhaben BMWA 150 1241, Ruhr-Universität Bochum, LEE-24, Dezember 2004.
- 9) V. Kouhia, et al.: General description of the PASI test facility, second edition, INTEGRA 5/2018, Lappeenranta-Lahti University of Technology, 05.12.2018.
- 10) E. Young:, NuScale Power Overview Future Vision of Nuclear R&D Webinar – SMR, February 15, 2022
- 11) https://en.wikipedia.org/wiki/Three_Mile_Island_accident#/media/File:Graphic_TMI-2_Core_End-State_Configuration.png, 12.12.2023

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