NURISP - SP1

General Seminar

SP1- Overview
Core Physics subproject

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INTEGRATED PROJECT NURISP for Nuclear Reactor Integrated Simulations Project
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Summary

• Next generation of the best estimate tools for reactor safety and for the next generation reactor design has been completely developed.
• Implemented and tested against several numerical and experimental benchmarks for PWR, BWR and VVER.
• The NURESIM platform includes all the neutronics platform software: APOLLO2, TRIPOLI4, COBAYA3, CRONOS2, DYN3D
• Have been integrated in the SALOME platform, after implementation and improvement of the coupling between them.
• Methodology for XS and other neutronic parameters generation with feedback of local variable values.
• Spatial resolution to pin-wise. Advanced cell and assembly IDF for finite-difference corrected diffusion have been developed for cartesian and hexagonal geometry.
The NURESIM Core Physics Platform

- Advanced **Monte Carlo** Methods
  TRIPOLI4.7 (CEA) coupled to FLICA4 (CEA)
  by TU Delft and KIT.

- Advanced **Deterministic** Diffusion and Transport Methods:
  Lattice, Core and Lattice-Core scope
  APOLLO2.8.3 + CRONOS 2.10 (CEA)
  COBAYA3.2 cell-nodal + ANDES nodal solver (UPM)
  DYN3D (HZDR)

- Advanced **Few-group XS**
  APOLLO2.8.3 – Saphyb (CEA)
Reactor Physics codes NURESIM Platform (NURISP)
NURESIM Platform

Scope: PWR, VVER, BWR

Nuclear data (JEF2, JEFF3)

APOLLO2.8-2E
- Multigroup lattice calculation
  - 2D Heterogeneous cell MoC

COBAYA3
- 3D Nodal, pin/pin
- Monte Carlo

CRONOS2.9
- 3D Nodal, pin/pin

DYN3D
- Monte Carlo

TRIPOLI-4
- Pointwise calculation

K_{eff}, Power Distribution

Reference
- Deterministic
- Monte Carlo
Identified weaknesses in the analytical methods when performing plant analysis for reactor safety

**Deliverable D1.0 was released:**

“**Status and limits of current methods for plant analysis**”

- analysis of deterministic and Monte-Carlo core physics codes
- analysis of the methods and data
- limits of core physics codes for GEN IV reactors
T1.1.1 Method to obtain cross section data at specified temperatures (12m)

*Deliverable D1.1.1 has been released:*

“Linux binary of TRIPOLI-4, capable of producing point cross-sections at various temperatures”

- point XS generation from elementary nuclear data at each temperature vs. XS interpolation from tables at discrete temperatures analyse.
- for temperature interpolation in point XS, TU Delft & CEA found inelastic thermal scattering were most sensitive.
- interpolate the probability density functions for selecting the energy after scattering, seems a potential practice.
T1.1.2 Fission source from distribution, using power distribution obtained from a deterministic calculation to accelerate convergence (24m)

- CEA has implemented in TRIPOLI-4 an option allowing depict the fission source in a meshing independent of the geometry volume description in TRIPOLI-4 code.
- APOLLO2 gives multigroup XS to CRONOS2, to produce a deterministic solution to feed TRIPOLI-4 as initial guess.
- A CRONOS2-TRIPOLI-4 test of this new capability has been done on a PWR configuration type.

Deliverable D1.1.2 has been released:

“Optimal way to couple deterministic fission source convergence with TRIPOLI4 code - Monte Carlo Source Initialization by Deterministic Calculations”
Deterministic calculation (APOLLO2 – CRONOS2)

A fission source exchange between the deterministic transport code CRONOS2 and TRIPOLI-4 code starting from the TRIPOLI-4 geometry has been developed.

Initialisation Validation

- Isotopic composition
- Sources

(Module C2TRIPOLI of CRONOS2)

Monte-Carlo calculation (TRIPOLI4)
T1.1.3 Interface between a Monte Carlo code and a 1-D thermal-hydraulics code (24m)

• TUD has developed a calculation scheme allowing to couple:
  FLICA with MNCP-5
  FLICA with TRIPOLI-4
  SUBCHANFLOW with MCNP-5
  SUBCHANFLOW with TRIPOLI-4

• KIT has developed a calculation system allowing to couple:
  SUBCHANFLOW with KENO
  SUBCHANFLOW with MCNP

• Coupling demonstration cases have been produced for PWR pin cell, and BWR subassembly in particular.

Deliverable D1.1.3 has been released:
“Demonstration of the interface between Monte Carlo and a simplified thermal-hydraulics feedback code”
T1.1.4 Monte Carlo techniques for *kinetics* calculations (30m)

- Feasibility of long-time kinetics Monte Carlo has been demonstrated by TU Delft with CEA support on TRIPOLI-4
- Dynamic Monte Carlo method has been implemented in TRIPOLI-4 and tested for simple system
- Advanced variance reduction methods that increase figure of merit with a factor of 10 have been developed
- Power produced in a fuel assembly due to the movement of control rods has been simulated successfully.
- Next step is to couple the dynamic code to a TH code for transient simulation

*Deliverable D1.1.4 has been released:*

“*Possibilities and efficiency of long-time kinetic and dynamic Monte Carlo calculations* “
T1.1.5 **Geometry** preparation tool by McCad for Monte Carlo in the SALOME platform (24m)

- McCad uses Open CASCADE technology for geometry related computations
- Conversion capabilities of McCad have been validated for all surface types in TRIPOLI4, except for quadrics that is not supported by CAD kernel
- Comparison between volumes build from planes, cylindrical, conical and spherical surfaces shows good agreement
- McCad Code beta test version 0.1 have been released

*Deliverable D1.1.5 has been released:*

*Final report on the extension of McCad geometry preparation tool for the TRIPOLI Monte Carlo code*
T1.1.6 TRIPOLI4 numerical benchmark with TH feedback (36m)

- CEA provided benchmark specifications to a BWR pin fuel (axial dependence of enrichment, moderator density and temperature axial profiles have been introduced).
- CEA provided results of fuel temperature, coolant density, fuel power distributions from APOLLO-2 / FLICA-4 coupling.
- KIT and TU Delft provided solutions for the benchmark problem with the different coupling schemes in T1.1.3.
- Good agreement which gives a basis for future reference 3D-TH/NTR coupling.

**Deliverable 1.1.6 has been released:**

“Specifications and results of the Monte Carlo benchmarks problem with TH feedback”
T1.2.1 Definition of the SAPHYB Interface. (12m)

**Deliverable D1.2.1 was released:**

“*Definition of the SAPHYB API*”

- The document describes the content and organization of a SAPHYB file, which contains the XS obtained by APOLLO2 runs.
- A Saphyb-browser has been developed and proposed by CEA in order to read Saphyb files in HDF5 format.
- From this tool, one can convert a Saphyb binary file into the appropriate format readable by CRONOS, COBAYA and DYN3D.
APOLLO-CRONOS

APOLLO-2 - Cell and Lattice Scope (2-D Transport) ➔ CRONOS - Core (3-D) ➔

**Single Cell**
- UCX
- MOX-1
- MOX-2
- MOX-3
- Gd-UCX

**Pin Clusters**
- MOX Cells (M1 + M2 + Water Holes)
- UCX-Gd Cells (UCX+Gd+WH)

**Assembly**
- UCX
- MOX
- UCX-Gd

**Cluster of Assemblies**
- MOX surrounded by 8 UCX
- UCX-Gd surrounded by 8 UCX

**Full Core**
- UCX/MOX Core at HZP and HFP
- UCX/UCX-Gd Core at HZP and HFP
- Nodal vs Pin Level XS

SAPHYB
T1.2.2 Definition and tools for advanced XS libraries (15m)

- Interface Discontinuity Factors (IDF) at pin-by-pin and nodal levels have been defined, and parameterizations vs. neighborhood performed.

- Definition of the libraries and tools to be managed in order to generate advanced XS libraries for diffusion and SP3 calculations.

- UPM and HZDR provided a common data table with the data to be generated by APOLLO-2.8 (in SAPHYB file), to be used by COBAYA3 and DYN3D.

- IDF generation with APOLLO-2.8 and parameterization testing for PWR, and VVER.

*Deliverable D.1.2.2 has been joint with D1.2.3*
T1.2.3 Development of interface between APOLLO2.8 and DYN3D/COBAYA3 (15m)

- Definition of Multigroup XS libraries used in COBAYA3 and DYN3D
- Parametric space covering the operational conditions for PWR and VVER and required configurations to calculate.

Deliverables 1.2.2 & 1.2.3 have been released in a joint document:

- **D1.2.2** “Definition and tools for Advanced Cell and Nodal Cross Section Libraries”
- **D1.2.3** “Definition of the interface between APOLLO2 and DYN3D / COBAYA3”
**Pre-processing**

**APOLLO2 input files**

- Geometry
- Branching data points
- Composition
- Nodal/pin-by-pin
- PWR/VVER
- Infinite lattice/cluster

**APOLLO2 run**

**Parallel execution script**

- A2
- A2
- A2
- ...
- A2

**Concatenated SAPHYB**

**Post-processing**

**SAPHYB-BROWSER**

- NEMTAB library
- Data table for functional fitting

**COBAYA3 & DYN3D**
T1.2.4 Advanced APOLLO2.8 Lattice Code (18m)

Deliverable D1.2.4 was released:
“Release and documentation of APOLLO2.8”

- the tagged version APOLLO2.8-2.E
- the procedures APROC
- the neutronics libraries, the GUI SILENE1.2.2
- the software documentation
New version APOLLO2.8-3.E has been released with the following features:

- collecting isotopic compositions to input data for TRIPOLI-4
- consistent verification between APOLLO2 and TRIPOLI-4
- developments on Assembly Discontinuity Factors (ADF)
- capability to extract ADFs on internal surfaces of a MOC geometry or a multicell geometry
- various versions (1227.E, 1228.E & 1230.E) have been delivered following some bug fixing (concatenation of Saphybs, ADFs, Linear Surface TDT-MOC)
T1.2.5 Advanced Core Code CRONOS2.9 (12m)

Deliverable D1.2.5 was released:

“Release and documentation of CRONOS2.9”

- Tagged version CRONOS2.9.patch
- Procedures CPROC
- Software documentation

New deliverable of CRONOS2.10 with the following features:

- optimizing the storage of transfer cross sections
- improvements on interpolation in concentration of multigroup cross sections
- linked to SAPHTOOL 1.8 offering functionalities based on hexagonal MED geometries
T1.2.6 Development and integration of the advanced Core Code DYN3D-SP3(24m)

- DYN3D is working in hexagonal geometry
- SP3 on triangular geometry implemented in DYN3D
- Steady-state test calculation for a simplified VVER core done
- Testing vs. Monte Carlo
- Pin power reconstruction method in DYN3D
- API capabilities within SALOME are available
- the pin-wise results visualization and code coupling inside SALOME

Deliverables D1.2.6 (a & b) have been released:
“Development and Integration of the advanced DYN3D-SP3”
HEX-TRIANGULAR GEOMETRY

VVER-1000 Fuel Assembly

3 Alternate Dissections in Hexagonal 3D “Boxes”

VVER-1000 Color-Set 1

VVER-1000 Color-Set 2

Boundary Faces are recalculated 2 times as internal planes before use

3D Whole Core Nodal Solver in Triangular Nodes and MG

VVER-1000 Fuel Assembly
T1.2.7 Development and integration of the advanced Core Code COBAYA3.2 (24m)

- COBAYA3 compiled with latest versions of SALOME
- MED files in hexagonal geometry for nodal and pin by pin problems
- Hexagonal geometry pin-by-pin with irregular water gap has been tested
- Implementation of 3D boron distribution to run the boron dilution transient
- Computation of transients at pin-by-pin level in parallel
- Updates to use tabulated and functionalized cross sections libraries
- PWR and VVER benchmarks done with INRNE
- Perfect agreement with APOLLO2 solutions when using IDF

**Deliverable D1.2.7 was released:**

- **a:** “COBAYA3 input manual”
- **b:** “COBAYA3 developers manual”
- **c:** “ANDES quick guide”
COBAYA3: Multi-Scale 3D Lattice-Core

COBAYA3 (MG-3D)
3D MULTI-Scale MULTI-GROUP DIFFUSION SOLVER
DOMAIN DECOMPOSITION BY ALTERNATE DISSECTIONS

ANDES
MG 3D Diff. NODAL CORE SOLVER

2D MULTIGROUP TRANSPORT (MOC) LATTICE CODE APOLLO2 (DK)

Fine-Mesh (Cells) MG 3D Diffusion LATTICE SOLVER
CELL FLUXES + NODE INTERFACE FLUX + CURRENT + BOUNDARY CONDITIONS + HOMOGENEIZED NODAL XS
Domain Decomposition by Alternate Dissections
PARALELL SCHEME IN COBAYA3

1 BOX “SURFACE” = 4 x 17 x 304 CELL FACES x 8 GROUPS =
= 165e3 BOUNDARY CONDITIONS (J/φ)

1 BOX “VOLUME” = 17 x 17 x 304 CELLS x 8 GROUPS =
= 703e3 FLUXES PER CELL AND GROUP
T1.3.1 Development of **calculation schemes** and generation of XS libraries for PWR, BWR and VVER (18m)

- A reference and an industrial scheme for APOLLO2 calculations using two level MOC, to generate XS libraries have been developed and tested for PWR and VVER
- The first step uses a Pij collision probabilities multi-cell model, the second step uses Method of Characteristics MOC with 281 groups (reference) and 40 groups (industrial)
- The APOLLO2 simulations with the industrial scheme last minutes for each run making the generation of a XS library 10 times faster, than using the reference scheme
- Multi-processor (‘parallel’) calculations with APOLLO2 able to generate accurate parameterized XS libraries in an automatic way

**Deliverable 1.3.1 has been released:**

“Development of calculation schemes and generation of XS libraries with APOLLO2 at the nodal level for CRONOS2 and DYN3D diffusion and SP3 analyses of PWR and VVER”
Deliverable D1.3.1 annex has been released:

“Development and validation of the depletion calculation scheme of APOLLO2.8.3E solving VVER-440 mathematical benchmark with UO2 and GD2O3 pins” (KFKI)

- VVER.440 calculation with APOLLO2.8.3e MOC/JEFF-281g library
- Depletion evolution to 60 MWd/kgHM was considered
- The solutions for k-infinity, power distributions and U, Pu, Xe and Gd isotopic concentrations vs. burnup investigated
- The results were compared with CASMO4E, HELIOS, WIMS8, KARATE and TVS-M solutions
- Good agreement with other codes solutions is displayed
T1.3.2 Definition and development of automated pre and post-procedures and codes to generate advanced cell and nodal XS libraries for PWR, BWR & VVER(24m)

- Automatic procedures to generate multidimensional XS libraries using APOLLO2 for COBAYA3 and DYN3D, covering the full parameter space of operation, burn-up and transient conditions, taking into account historical effects.
- Modified SAPHYB-BROWSER to get libraries in NEMTAB format (including IDF for cartesian and hexagonal geometries). Developments in pre-processing of APOLLO2.8, and to launch it on multiprocessor machines (UPM & INRNE).
- Functional-fitting libraries for XS & IDF with local state variables have been developed. Optimization based on sensitivity analysis (UPM).
- Functional-fitting with respect to neighborhood effect has been developed (UPM & INRNE).
WP 1.3 Advanced few group XS libraries generation

- Parameterized and tabulated libraries tested with COBAYA3 for PWR and VVER (UPM & INRNE)
- Parameterized IDF for PWR pin-by-pin developed. Working on nodal IDF for PWR and VVER
- Polynomial fitting for XS parameterization and tested for BWR (Chalmers)
- History effects into DYN3D accounted by Pu239 concentration as a burnup-history indicator. Comparison with HELIOS 1.8 shows its effectiveness (HZDR)

Deliverable D1.3.2 has been released:

“Definition and development of the automated pre- and post-processing procedures and codes to generate advanced cell and nodal XS libraries for PWR, BWR and VVER, covering the full parameter space of operation, burn-up and transient conditions”
Condensation in different MG structures & homogenization at pin or nodal level

\[ \Sigma(Q, T_m, T_f, \rho, C_B) \]

\[ \Sigma(Q, T_m, T_f, \rho, C_B) = a_0 + a_1 \rho + a_2 \rho^2 + \ldots + b_1 C_B + \ldots + c_1 \rho \cdot C_B + \ldots \]

Tabulated X-section library

Functional-fitting X-section library

Fine mesh calculation

Coarse mesh calculation

APOLLO2 lattice code

-2 library types
- two levels
T1.4.1 Definition of the **generic strategy** for V&V (6m)

**Deliverable D 1.4.1 has been released:**

“**Generic Strategy of Benchmarking for the Validation of the NURESIM Core Physics Platform**”

Based on a step-by-step validation process from lattice to core calculations, with the objective of pin-by-pin neutronics fidelity for safety margin analysis.

Takes into account:

- A set of “numerical” problems with Monte-Carlo, and deterministic (MOC) reference solutions
- Well documented international experiments
T1.4.2 Synthetic analysis of benchmark results (36m)

**Deliverable 1.4.2 will be released in April 2012:**

“**Summary of the Synthetic analysis of the verification and validation benchmark process**”

- This is the final document of T1.4.3, T1.4.4, T1.4.5 and T1.4.6, with important conclusions of the V&V process for PWR, VVER and BWR lattices
- APOLLO2 demonstrates the capability to provide accurate solutions for LWR cells, lattices and cores with changing nuclide composition
- MOC based calculation schemes for cross-section library generation with APOLLO2 were implemented at the nodal and pin level, and validated vs. TRIPOLI4 reference solutions for different LWR applications
- The COBAYA3 pin-by-pin multi-group diffusion solver with IDF was tested vs. APOLLO2 and TRIPOLI4 reference solutions for PWR, VVER and BWR
- APOLLO2.8e/JEFF3.1.1 was experimentally validated vs. ZR-6 VVER critical assembly data
- DYN3D nodal calculations and pin power reconstruction were validated vs. V1000-LR0-STAT critical assembly data
T1.4.3: PWR benchmarking using APOLLO2 vs. TRIPOLI4 (24m)

Two computational benchmarks for PWR lattices, the first one devised to ensure 3D whole core calculation accuracy:

- **PWR lattice benchmark specifications (UPM)**
  - 3x3 cell clusters, UOX and MOX assemblies, and a color-set
  - APOLLO2 MOC vs. TRIPOLI4 solutions (INRNE)
  - APOLLO2 Linear Surface MOC vs. TRIPOLI4 solutions (INRNE)
  - APOLLO2 MOC industrial vs. ref calculation scheme solutions (INRNE)

- **PWR pin-cell depletion benchmark (PSI):**
  - UOX, MOX-1 and MOX3 models
  - APOLLO2.8e vs. CASMO5 & MCNPX/CINDER (PSI)

Demokritos (User’s group) calculated VENUS-2-MOX system with TRIPOLI4 and JEFF-3.1.1, ENDF/B-VI.4, ENDF/B-VII
PWR lattice benchmarking

- Specifications based on the PWR MOX/UO$_2$ CTB
- 2D lattice calculations at HZP
  - Clusters 3x3
  - Fuel assemblies
  - Colorset
Deliverable D 1.4.3a was released (INRNE):
“Report on PWR schemes and benchmark analysis results using APOLLO2 and TRIPOLI4”
• Good agreement APOLLO2 with TRIPOLI4 results is displayed (added Interface fluxes/currents)
• Tested industrial schemes with MOC calculations in APOLLO provide well converged solutions for XS and IDF generation at acceptable computation cost.

Deliverable D 1.4.3b was released (PSI):
“Report on PWR pin cell schemes and depletion benchmark analysis results using APOLLO2”
• Results provide confidence in the PSI APOLLO2 scheme.
• Confirm its applicability to PWR UO2 and MOX pin-cell.
The objective is to test the PWR lattice benchmark (UPM):

- Using 2g, 4g and 8g, XS and IDF from APOLLO2
- With the multi-group nodal and lattice-core solvers
- In 3D pin-by-pin core simulators COBAYA3 and DYN3D
- Compared to APOLLO2 and TRIPOLI reference solutions

Deliverable D1.4.4-Part1 has been released

“PWR Specifications and isotopic compositions”
+ Tables to be filled with PWR fuel assembly results
+ Tables to be filled with PWR cell and color-set results
Deliverable D1.4.4 was released:

“Report on the results of PWR benchmarks using COBAYA3 and DYN3D pin-by-pin”

- Pin-level XS & IDF generation with APOLLO2.8.3e (INRNE)
- Compute pin-by-pin solutions with COBAYA3 (UPM, INRNE) and DYN3D (HZDR)
- The COBAYA3 pin-by-pin solutions are nearly identical to those of APOLLO2, used to obtain the XS and IDF
- The COBAYA3 results are very close to TRIPOLI4 reference solutions
- Preliminary DYN3D pin-by-pin diffusion and SP3 solutions were obtained with HELIOS/ENDFB6 XS and IDF. Testing with APOLLO2 generated XS is ongoing
- The considered 2D benchmark cases illustrate the target accuracy of pin-by-pin few-group diffusion theory solutions when using advanced XS
COBAYA3: Full core pin-by-pin
T1.4.5: VVER benchmarking using APOLLO2, TRIPOLI4 and COBAYA3 pin-by-pin (33m)

The objective is to test the lattice-core solvers and calculation schemes. Numerical and experimental validation were performed.

**Part 1: Numerical validation (D1.4.5a)**
- MOC based calculation schemes in APOLLO2 were tested vs. TRIPOLI4 reference solutions (INRNE).
- COBAYA3 pin-by-pin multi-group diffusion vs. APOLLO2 vs. TRIPOLI4 solutions were analyzed. Close agreement of COBAYA vs. ref solutions is displayed (INRNE, UPM).

**Part 2: Experimental validation (D1.4.5b, D1.4.5c)**
- APOLLO2 MOC results vs. ZR-6 critical assembly measurements (KFKI).
- DYN3D nodal results vs. V1000-LR0-STAT data (NRI).
Part 1: Numerical validation

Deliverable D1.4.5a was released:

“Specifications and results of the VVER lattice benchmark using APOLLO2, TRIPOLI4 and COBAYA3 pin-by-pin” (INRNE)

- A VVER lattice benchmark including 19-cell clusters, assemblies and assembly cluster was defined and solved with APOLLO2, TRIPOLI4 and COBAYA3 pin-by-pin. The results show very good agreement.
- The performance of the higher-order Linear Surface MOC is found very promising.
- MOC based calculation schemes for nodal and pin-by-pin XS library generation with APOLLO2 were implemented and tested for tight hexagonal LWR lattices.
- At the pin level, the use of pin-cluster branch calculations that take into account the cell neighbourhood was investigated.
- Based on this study, MOC calculation options of the industrial calculation schemes for VVER lattices were recommended.
- The tested schemes in APOLLO2 were used to generate multi-parameter nodal and pin-by-pin few-group diffusion XS libraries for VVER transient analysis.
- COBAYA3 pin-by-pin vs. APOLLO2 vs. TRIPOLI4 reference solutions show very good agreement, both in structured and unstructured meshes.
- Specifications based on the VVER MSLB benchmark
- 2D lattice calculations at HZP
  - 19-pin clusters
  - Fuel assemblies
  - Color-set
Part 1: Numerical validation
Whole core benchmarks (V1000-2D-C1, V1000CT2-EXT1) were solved with APOLLO2 LS MOC and TRIPOLI4

V1000-2D-C1 benchmark, ARO.
APOLLO2 281/37g vs. TRIPOLI4 solution
$\Delta k = 62$pcm, max $|\Delta$ fis rates$| = 2.1\%$
Part 2: Experimental validation

Deliverable D1.4.5b has been released:
“Experimental validation of the APOLLO2.8-E.3 for VVER on ZR-6 experiments” (KFKI)

VVER mock-up measurements at KFKI were solved with APOLLO2.8E:

- Regular lattices of UO2 pins with different pitch/enrichments/boron density/temperature
- Macrocells containing different absorber rods in the center (especially different enrichments of \( \text{Gd}_2\text{O}_3 \) in \( \text{Al}_2\text{O}_3 \))
- 2D whole core configuration with point perturbations, fuel assembly imitators (macrocells surrounded by water gap)

APOLLO2.8E is in good agreement with the measured data:

- \( K_{\text{eff}} \) is slightly overestimated in 2D core calculations
- gadolinium rod efficiency and pin-by-pin distributions are well reproduced
MOC spatial mesh for K91 configuration
Deliverable D1.4.5c has been released:

“\textit{V1000-LR0-STAT experimental benchmark}” (NRI)

VVER-1000 mock-up in Rez (LR-0)

- 2 gr. XS library generated with HELIOS /ENDFB6.
- DYN3D solutions: nodal, reconstructed centre-of-node solution, and combination of reconstruction with pin-flux result from a lattice code.

DYN3D calculations against experiment provide:

- good agreement on $K_{\text{eff}}$: slight underestimation.
- significant discrepancies for the radial fission rate distribution: direct pin-by-pin calculations need to be tested.
VVER Mock-up: LR-O Reactor
LR0-Calculation vs. experimental results

Measurement 1 - calculation results
FA No. 1
11. axial layer
EC1 cluster

node-averaged flux = $1.421 \times 10^{25}$

reconstructed flux

reconstructed x pin-wise flux
T1.4.6 BWR benchmarking at HZP using APOLLO2, TRIPOLI4 and COBAYA3 pin-by-pin (33m)

The objective is to test the BWR lattice benchmark (UPM):
- OECD/NEA BWR MOX benchmark assembly
- With six different Pu enrichments
- Specified in 2D at HZP and at the BOL.
- Asymmetric water hole in the center of the array.
- Covering the different states of BWR operation: CZP, HZP, HP with 0%, 40% and 80% void fraction

Deliverable D1.4.6 Part1 was released:
“BWR Specifications and isotopic compositions
+ Tables to be filled with BWR fuel assembly results”
- Specifications based on the Physics of Plutonium fuels BWR MOX benchmark from NEA
  - Modern 10x10 fuel assembly
  - Different void fractions (cold and hot conditions)
  - Simplified cruciform control rod (reality much complex) + more geometrical simplifications
BWR lattice benchmarking

- APOLLO2 MOC geometries

un-rodded

rodded
Deliverable D1.4.6 was released:
“BWR benchmarking results using TRIPOLI4, APOLLO2 and COBAYA3”

- TRIPOLI4 reference solution was computed and documented (Chalmers)
- Calculation scheme for XS generation (PSI)
- The proper generation of XS & IDF libraries with APOLLO2 (PSI)
- Analysis of 2D pin-by-pin with COBAYA3 and CRONOS2 (UPM, PSI)
- APOLLO2.8E MOC-281g and COBAYA3 are compared to TRIPOLI4:
  - biases on Keff are significantly higher than those observed for PWR or VVER calculations, due to the strong heterogeneities of BWR assemblies
  - reactivity effects at HP including CR worth are well reproduced
- COBAYA3 pin-by-pin vs. APOLLO2 solutions shows close agreement
T1.5.1 For TRIPOLI4, APOLLO2 and CRONOS2 (24m)

In the second period:
CEA dedicated TRIPOLI support to TU Delft, INRNE, Demokritos.
two TU Delft stays in CEA/Saclay:
22th – 26th November 2010,
28th February-4th March 2011

Two APOLLO2 sessions held in CEA
April 12th -16th 2010
May 17th – 21st 2010
16 trainees from KFKI, NRI, KIT, INRNE, FZD, UPM, PSI
Hands-on-training in Nov. 2011: PSI, KFKI, KIT, INRNE

A CRONOS2 session held in CEA
May 31st - June 4th 2010
8 trainees from NRI, INRNE, PSI, KFKI, TU Delft
Two SALOME sessions were held in CEA:
• Training session on CAD modelling, meshing and visualization
  GEOM/MESH: 30\textsuperscript{th}-31\textsuperscript{th} August 2011
  VISU: 1\textsuperscript{st} September 2011
• Training session on code integration and code coupling
  12\textsuperscript{th}-13\textsuperscript{th} May 2011.

\textit{Deliverable D1.5.1 has been released:}

“\textit{Report on summary of Training for the APOLLO2, CRONOS2 and TRIPOLI4 codes}”
T1.5.2 For the DYN3D code (24m)

**Deliverables D1.5.2 have been released:**

D-1.5.2a: *Documentation on Training for the Use of the Code DYN3D*

D-1.5.2b: *Input Data Description DYN3D-MG-V2.0*

T1.5.3 For the COBAYA3 code (24m) hands-on training:

- 3 month I. Spasov (INRNE) at UPM
- 2 months M. Calleja (KIT) at UPM
- 3 months N. Petrov (INRNE) at UPM
- 1 month N. Zheleva (INRNE) at UPM

**Deliverable D1.5.3 has been released:**

“*Report on summary of Training for the COBAYA3 code and related tools of the NURESIM Core Physics platform*”
T1.5.4 General Seminar (36m)
New capabilities implemented in TRIPOLI4, CRONOS2, APOLLO2, COBAYA3, DYN3D.
Will be held in 2th-3th April 2012 in KIT.

Deliverable D1.5.4 will be released in April 2012:
“Report on summary of the General Education and Training Seminar for the codes and tools of the NURESIM Core Physics platform”
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SP1 Meetings

- Kick-of-meeting Paris (15 part.) April 2009
- WP1.1 meeting Paris Oct. 2009
- 2º SP1 meeting Dresden (26 part.) Dec. 2009
- WP1.2 Videoconf. HZDR-UPM April 2010
- WP1.1 meeting Paris July 2010
- 3º SP1 meeting Varna (27 part.) Sept. 2010
- WP1.1 meeting Paris Feb. 2011
- 4º SP1 meeting Karlsruhe (24 part.) Sept. 2011
- General Seminar Karlsruhe April 2012
Software Licenses, Deliveries and training

- INRNE/CEA: APOLLO2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10), FLICA-4
- UPM/CEA: APOLLO 2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10), FLICA-4
- Demokritos/CEA: TRIPOLI-4
- KIT/CEA: TRIPOLI-4, APOLLO2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10), FLICA-4
- TU Delft/CEA: TRIPOLI-4, FLICA-4
- NRI/CEA: APOLLO2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10)
- PSI/CEA: APOLLO2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10)
- Chalmers/CEA: APOLLO2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10), TRIPOLI-4
- HZDR/CEA: APOLLO2.8-2E (and 2.8-3.E), CRONOS2.9 (and 2.10)
- KIT/UPM: COBAYA3.2
- INRNE/UPM: COBAYA3.2
- KTH/HZDR: DYN3D
Papers in journals


Conferences

- 17th Int. Conference Nuclear Engineering (ICONE17), 2009
- ICAPP 2009
- 19th AER Conf. VVER reactor physics & safety, Varna, 2009
- SNA+MC2010, Tokio
- RPSD2010 Conference, Las Vegas, 2010
- 17th Pacific Basin Nuclear Conference, Cancún, 2010
- SNA+MC2010, Tokyo, 2010
- M&C-2011, Rio de Janeiro, 2011
- 21th AER Conf. VVER reactor physics & safety, Dresden, 2011
- Physor, Knoxville, 2012
Papers in Conferences

1. G. Bruna, A. Santamarina, A. Sargeni, “A 1st order formulation of a reaction rate variation for taking into account spatial and energy collapsing”, M&C 2009


3. P. Blaise, J-F. Vidal,”Validation of the REL2005 code package on poisoned PWR type assemblies through the CAMELEON Experimental Program”, ICAPP 2009


7. N.Petrov, G.Todorova, N.Kolev, F. Damian, ”Two-level MOC calculation scheme in APOLLO2 for cross-section libraries generation for LWR hexagonal assemblies”, M&C 2011


11. J. Dufek,”Complex models of nodal nuclear data”, M&C 2011


15. G.Hegyi, A.Keresztúri, A. Tota, “Qualification of the APOLLO2 lattice physics code of the NURESIM platform for VVER hexagonal lattices” AER 2011

16. N. Petrov, S.Sánchez-Cervera, J. J.Herrero “Steps ahead in the few-group cross-section library generation at the pin level”, AER 2011

17. Y.Bilodid, S.Mittag,HZDR “Influence of spectral history on PWR full core calculation results”, AER 2011
18. S. Duerigen, E. Fridman, HZDR “The simplified P3 approach on a trigonal geometry in the nodal reactor code DYN3D, AER 2011

19. B. Merk, S. Duerigen, HZDR “SP3 solution versus diffusion solution in nodal codes – which improvement can be expected,” Int. Conf. on Transport Theory, Portland, 2011


4. J.A. Lozano, "Development of an analytic nodal code for multigroup neutronic diffusion for reactors in 3D rectangular and hexagonal geometries“, UPM, 2010
6. B. L. Sjenitzer,”Transient Analysis of a Nuclear Reactor Using the Monte Carlo Method”, Delft University, 2013