

INGENIA NUCLEAR: UPM-CDIO Project in Nuclear Engineering Education

Pablo Mendivil et al. (Grupo INGENIA 2021-2022)

MASTER IN INDUSTRIAL ENGINEERING

E.T.S. de Ingenieros Industriales

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What ‘INGENIA’ course is?

- Course within in “**Master in Industrial Engineering Program at UPM**”
- 12 ECTS : 5hours/week – 2 semesters
- INGENIA is based on the CDIO (Conceive Design Implement Operate) initiative, which has been also adopted by other Universities: Delft, Politecnico di Milano, MIT, Stanford...
- See more information about CDIO at: www.cdio.org

Other INGENIA projects at UPM (in total 14):



PV facility



Videogame development



Design of Daily-life products



Automotive Engineers

Other INGENIA projects: Systems Engineering (to the construction of an intelligent technical system), Acoustic Engineering, Computer-aided Engineering (applied in material design), Thermal-Engine Design, Electric-System Design, Laser and Optics Design, Bioengineering,... , Beer Factory Project,...

What we do ?

- INGENIA-NUCLEAR is focused “on design & simulation of a Pressurized Water Reactor
- **Flow of information from nuclear data productions to 3D/core simulators of PWRs**
- **Main objective: to work with 3D/core simulators + keeping special attention to safety**

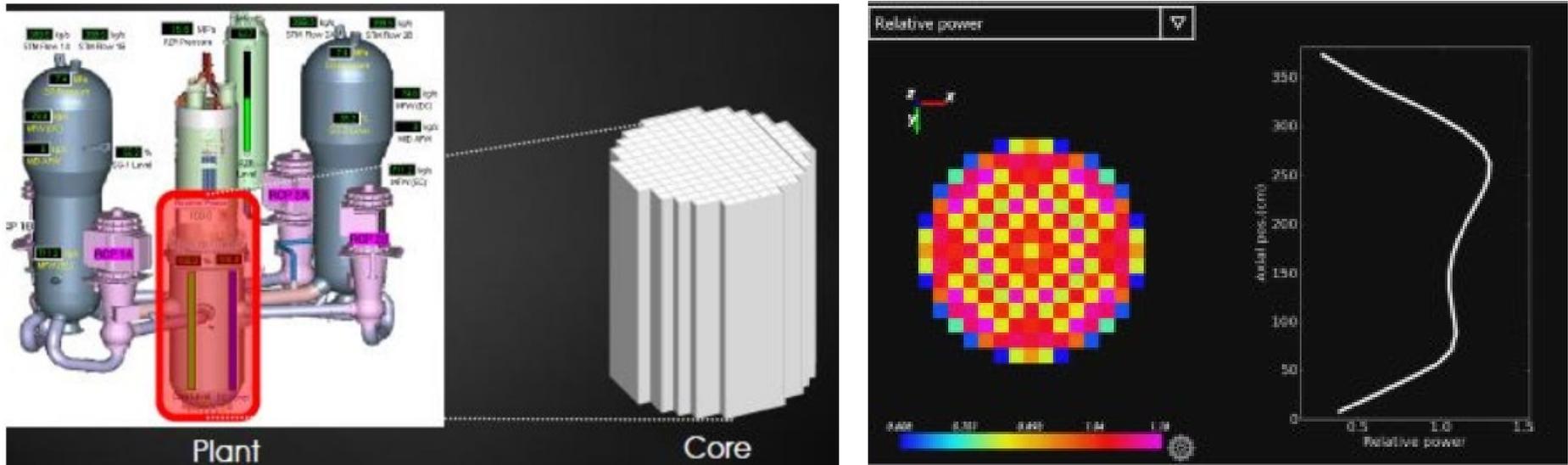


Figure: Pictures courtesy of NEL Software, Japan & IAEA

- ❑ Jose Cabrera – Zorita PWR - Interactive Graphic Simulator
[David Piedra \(October 2021\)](#)
- ❑ Experience in the use and development of simulators
[Isabel Parrado \(TECNATOM\)](#)
- ❑ BEACON Core Monitoring System (ENUSA)
[Jose Herrero \(ENUSA\), November, 29 2021](#)
- ❑ “The SEANAP System: Simulation of PWRs”
[Carolina Ahnert \(UPM\), December 13, 2021](#)
- ❑ “NuScale Simuation with COBAYA code”
[Luis Felipe Durán \(UPM\), December 21, 2021](#)
- ❑ Introduction to IAEA Nuclear Data Service and introduction to EXFOR Library-Mother of all libraries (IAEA)
[Naohiko Otsuka \(IAEA/NDS\), February 21, 2022](#)
- ❑ Evaluation of Nuclear Data: Practical Applications
[Luiz Leal \(IRSN\), April 2022](#)



Figure: Jose Cabrera - Zorita PWR - Interactive Graphic Simulator, October 2021



Figure: Group photo in the N. Otsuka's Conference, February 2022

- INGENIA/NUCLEAR-2021/22 is focused on:
 - **Neutronic Design of Small Modular Reactors PWR-type: NuScale – 160 MWth**
- Simulation PWR Core Analysis: **System “SEANAP”** ⇒ **“Updated” SEANAP to SMRs**

□ PWR Core Analysis System “SEANAP”

- **MARIA** system for lattice/assembly calculations (based on WIMSD5 code)
- **COBAYA** system for a detailed (pin-by-pin) core calculations
- **SIMULA** system for 3D/1-group corrected-nodal diffusion core simulation

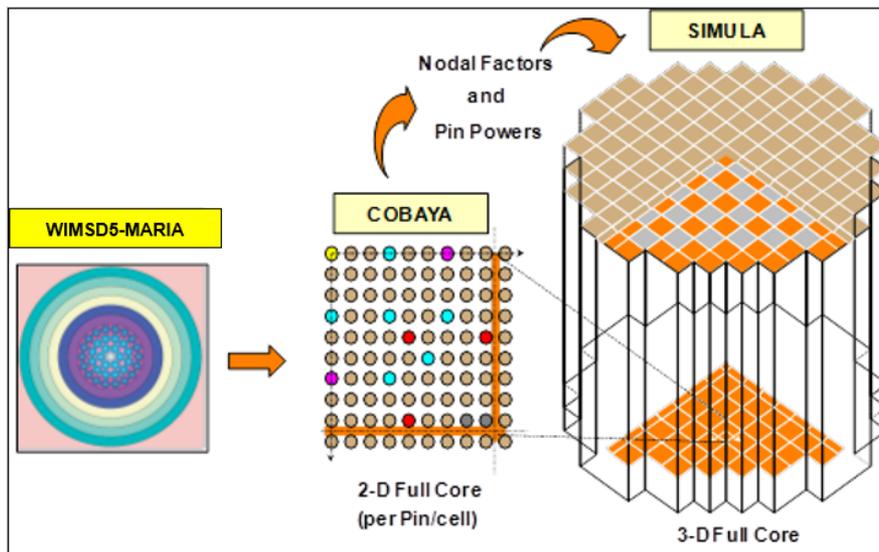


Figure. SEANAP: WIMS-D5 + COBAYA + SIMULA

References:

- “Validation of PWR Core Analysis system SEANAP-86 with measurements in test and operation”, C. Ahnert et al., M&C87

See also, “upgraded SEANAP” with WIMSD5 + recent nuclear data evaluations

- **JEFDOC-1917, April 2018**
- **JEFDOC-1968, April 2019**

SEANAP = Sistema Español de Análisis de Núcleos de Agua a Presión

- ❑ SEANAP system has been developed and applied for 3D PWR core analysis during near thirty years, as a close collaboration among the Polytechnical University of Madrid group of developers (J. M. Aragonés, C. Ahnert et al.) and the engineering groups of users at the several Spanish PWR units.
- ❑ SEANAP is a mature, demonstrated, complete and integrated system of computer codes and procedures that provide full and independent PWR core analysis capabilities.
 - Last 30 years for 7 Spanish PWR units: Almaraz I&II, Ascó I&II, Trillo, Vandellós II and Zorita
- Integrated /coupled codes in SEANAP
 - WIMSD4, MARIA, COBAYA, DELFOS, SIMULA, SIMTRAN, COBRA, RELAP-5
- SEANAP Applications:
 - Fuel Loading Pattern Evaluations
 - Nuclear Design Analysis: Start-up physic test at HZP and Nominal operation
 - Dynamic Core Analysis for Safety
 - On line 3D Simulations: Planning of Optimal Operational Maneuvers, Training Simulations

Reference: “Continuous Validation and Development for Extended Applications of the SEANAP Integrated 3D PWR Core Analysis System”, C. Ahnert, J.M. Aragonés, O. Cabellos, N. García-Herranz, M&C99 (1999)

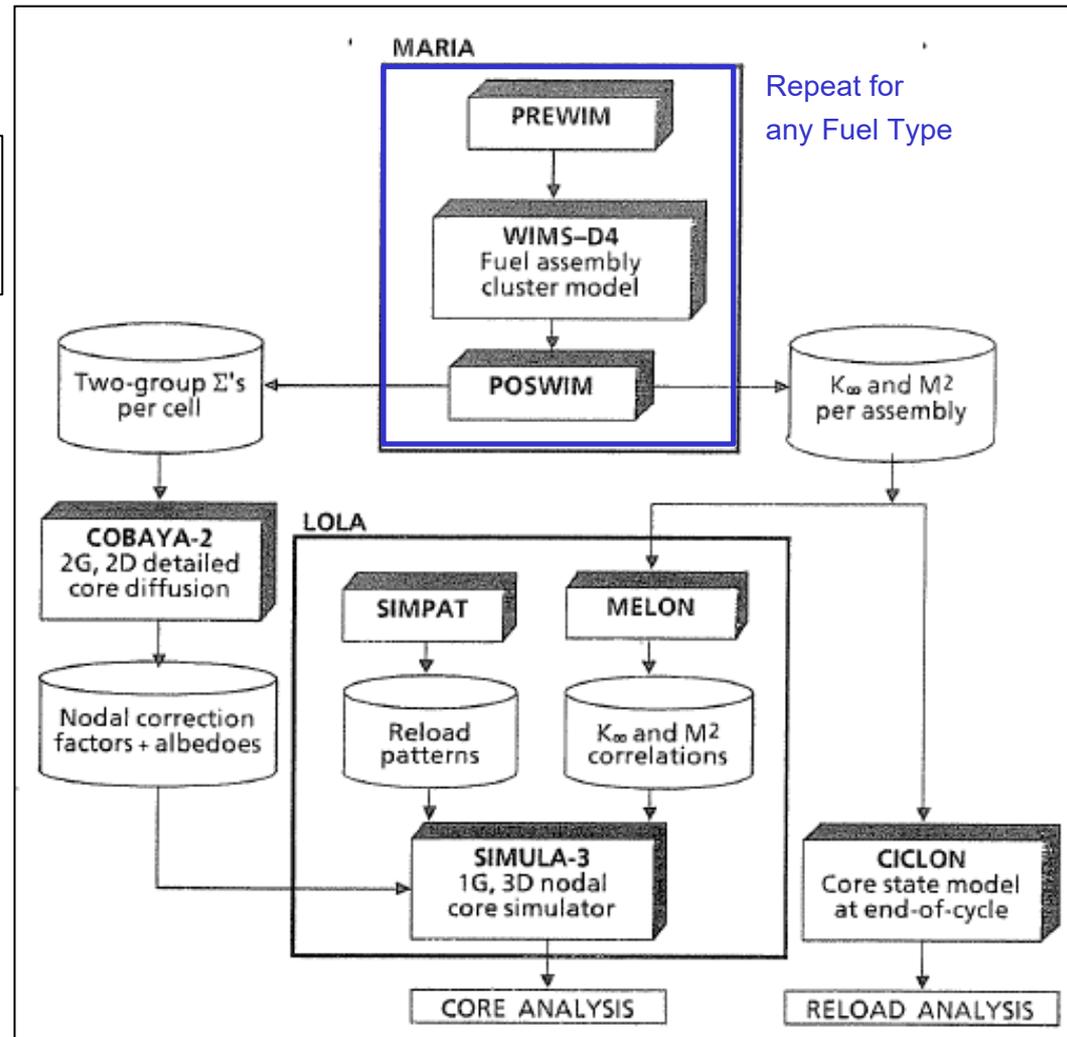
Figure. Scheme of the PWR Core Analysis System **SEANAP-86**

Ref.: "Validation of PWR Core Analysis system SEANAP-86 with measurements in test and operation", C. Ahnert et al., M&C87

SEANAP is integrated by 4 subsystems:

1. **MARIA** system for assembly calculations
2. **COBAYA** system for a detailed (pin-by-pin) core calculations at reference conditions
3. **SIMULA** system for 3D 1 group corrected-nodal core simulation

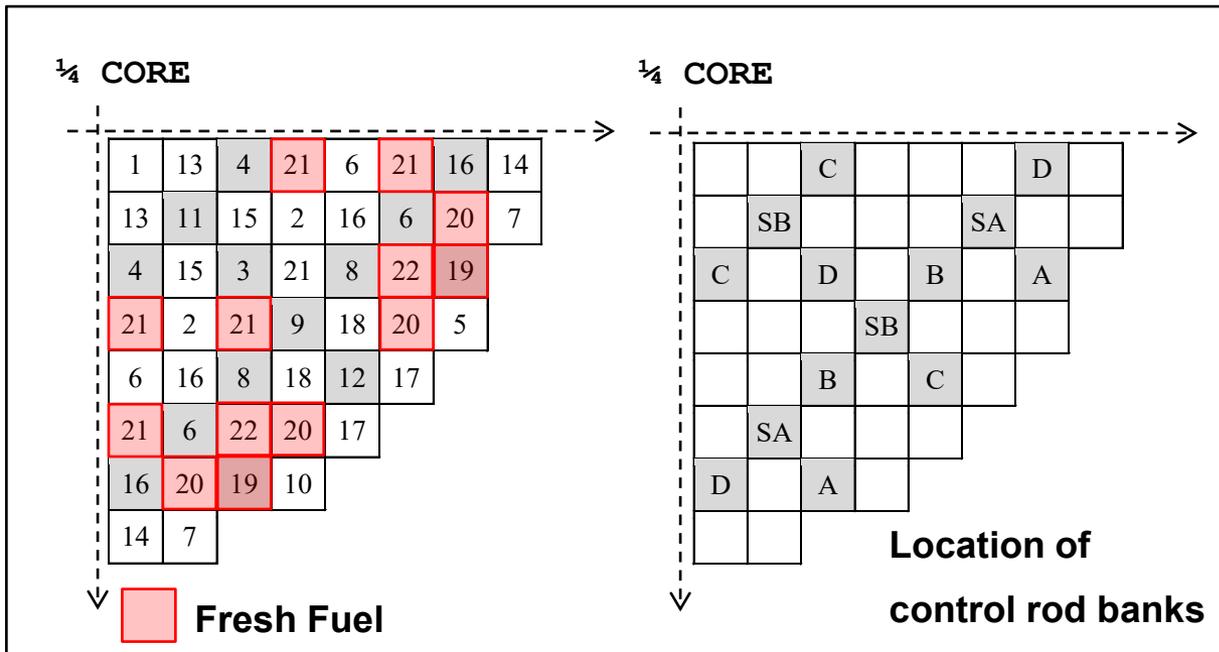
CPU Time/cycle ~ 5 min / i7 870@2.93GHz



❑ PWR (Westinghouse-type): 3 loops

- Power 2775 MWth
- 157 Fuel Assemblies (UO₂): 17x17 – 264 fuel rods, active height: 365.76 cm
 - UO₂/2.1-5.0%wo – clad/Zircaloy – Gadolinium/WABAs

Figure: Fueling of a typical PWR (Westinghouse-type) 2775 MWth - 3 loops



SEANAP system has been developed and implemented as an **on-line simulator** ~20 cycles of three PWRs (Vandellós-II, Ascó-I and Ascó-II)

- **Every 5 minutes, continuous operational surveillance:** boron concentration, reaction rates at the excore detectors, A.O., fluid temperatures at the location of thermocouples, temperatures at the hot legs...
- **Every month** incore flux maps: Incore/excore calibrations
- **Planning of Optimal Maneuvers, Dynamic Core Analysis** for safety and training for plant engineers and operators

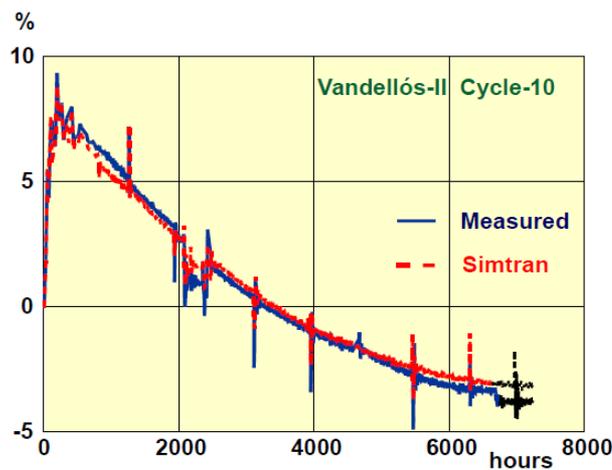


Figure: Delta-I of Incore Power as Measured and Calculated by SIMTRAN on-line

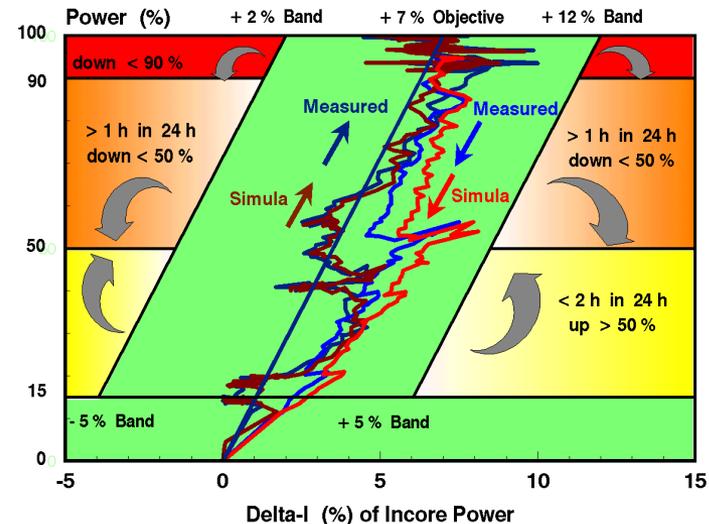


Figure: Measured and Simulated Power vs Delta-I in return to Power after a Short Shutdown

- ❑ **INGENIA/NUCLEAR** course is a CDIO-Based subject which contributes to nuclear engineering education.
- ❑ This year's objective is **focused on Neutronic Design of SMRs**
- ❑ The **SEANAP 3-D Core analysis** system has been used to carry out this work:
 - **NuSCALE Neutronic Design**
 - The impact of different **nuclear data libraries**
 - JEF-2.2, JEFF-3.1 and JEFF-3.3
 - ENDF/B-VII.1 and ENDF/B-VIII.0
 - Testing ATFs (Accident Tolerant Fuels) cladding materials
 - Cr- 20 μm coating
 - FeCrAl- clad with 300 μm thickness
 - Simulation of Maneuvers/Operation in NuScale with SEANAP system

Acknowledgments

*Special thanks to Prof. **Carolina Ahnert** for all her support and help with the SEANAP System through the challenging INGENIA Course 2021/2022.*

*Thanks also to Prof. **Nuria García-Herranz** for providing us with SEANAP inputs to perform simulation of key neutronic safety parameters.*