Nuclear Engineering Department
Capabilities and R&D activities

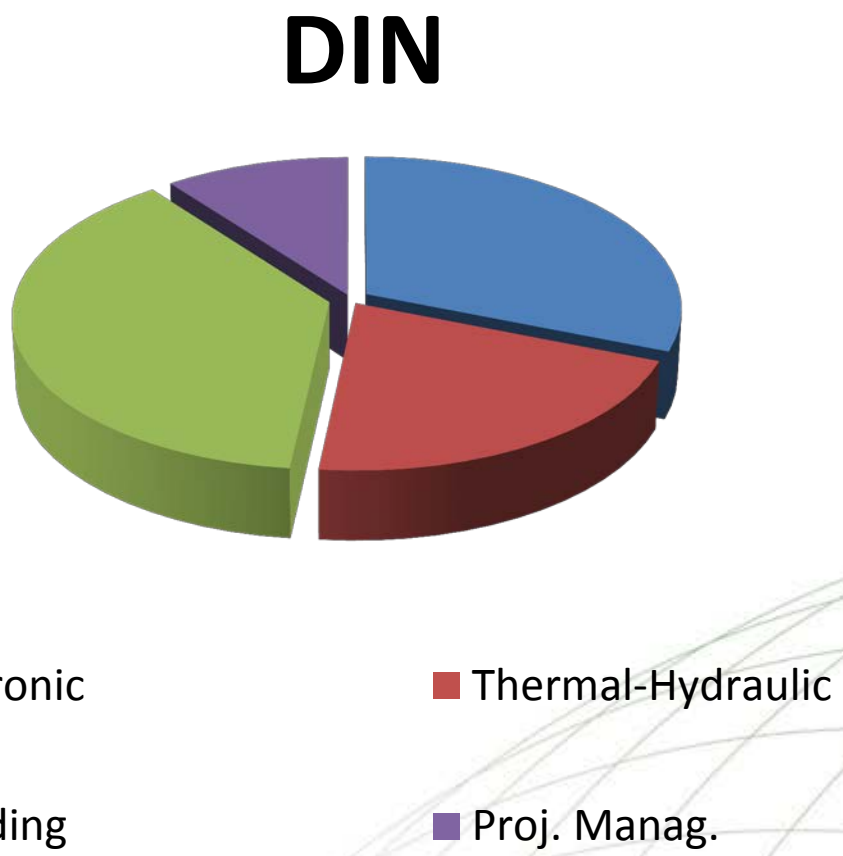
Resource Overview

Nuclear Deparment Expertise by Areas

- **Neutronics**
  Core Design
  Fuel Management
  Criticality

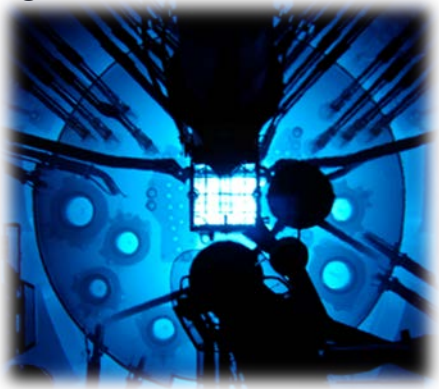
- **Shielding**
  Radiological Protection

- **Thermal-hydraulics**
  Core Design
  Safety Analysis



Activities

- Design and Analysis
- Safety Analysis
- OLC
- Commissioning
- Research & Development
- Nuclear Engineering Training
- Experimental Facilities
- Consultant Services

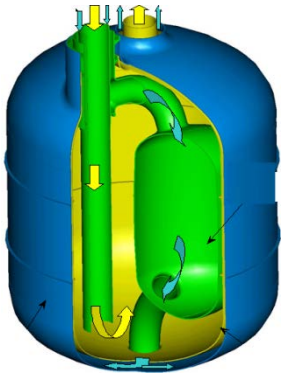


Expertise

- Expertise in different Reactor Types:
  - RR, HWR, SMR, PWR
    WEC qualified personnel
    (FM in more than 20 NPP in USA)

- Radioactive Installations
  - Radio Isotope Production
  - Criticality Analysis,
    Dry FA Storage
  - Radioactive Material Transportation
  - Medical Applications

- Research and Development
  - New concepts in NPP
  - CAREM Reactor



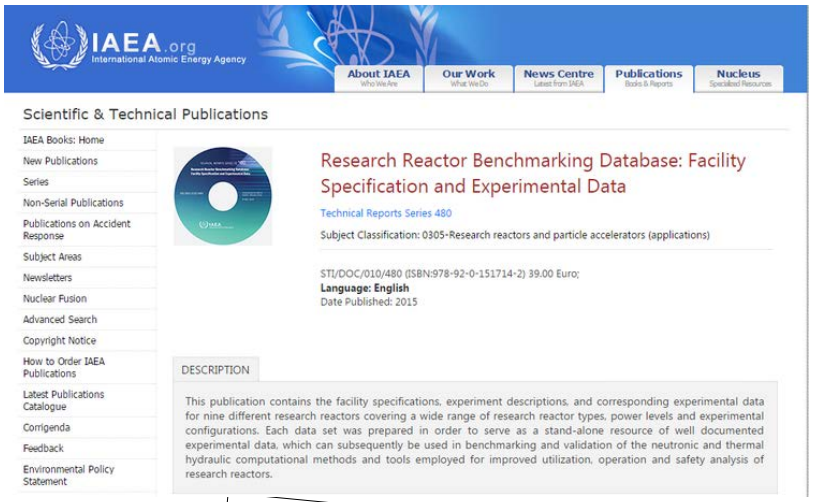
- New concepts in RR
  - Fuel and Material Analysis, Burnable Poisons
  - Fuel Element Types (Conversion)
  - Irradiation Facilities, Silicon Doping
  - Secondary Neutron Sources (Cold, Hot)
  - Medical Applications (BNCT)

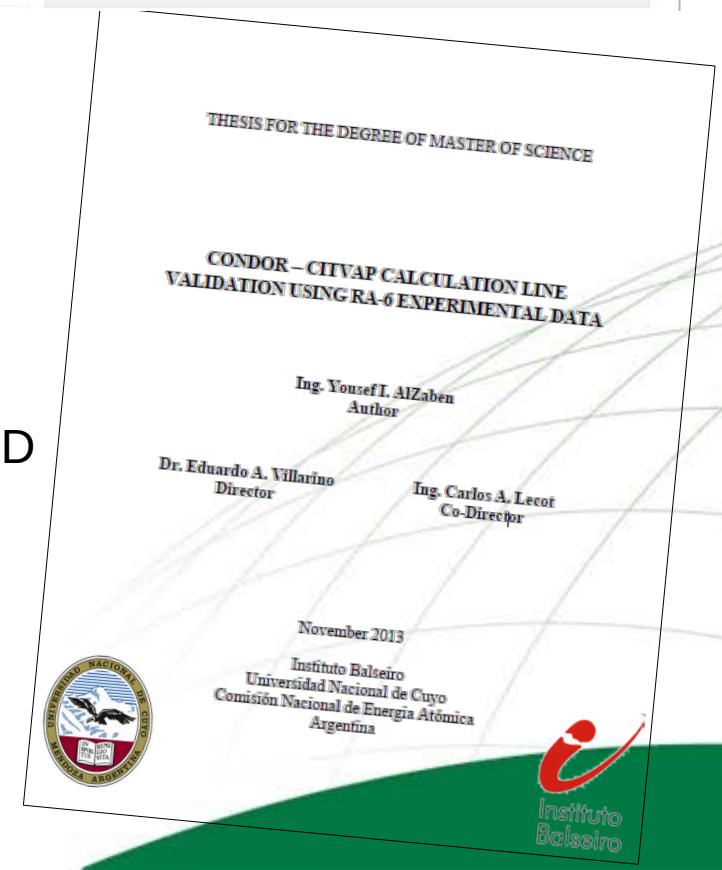
Expertise

- Participation in IAEA projects:
  - Advisory Group Meetings on SMR
  - NPP and desalinization plant coupling
  - Transient analysis in RR
  - Safety in RR
  - Nuclear data Libraries.
  - Innovative Methods in reactor calculation
  - IAEA Experts on Shielding, Neutronics and Thermal-hydraulics

- Balseiro Institute
  - Thesis for nuclear engineering, Master and PhD degree (> 50)
  - Professors

- Training of International Projects trainees and participants.





Expertise

Research and Multipurpose Nuclear Reactors

- Neutronic design of the reactor core, in-core and out-of-core facilities:
  - Steady state parameters
  - Neutronic parameters for transient analysis
- Experimental test design and planning
- Code validation & verification
- Neutronic data for Fuel Performance analysis.
- Commissioning tasks
- National and international training.
- IAEA projects participation (Nuclear desalination, Codes V&V, Experts missions)
- Consultant services (AECL, Babcock & Wilcox, WEC)

Nuclear Power Plants

- WEC Physics Method Accuracy Team participation.
  FM in more than 20 NPP in USA
  WEC Sweden:
  - Nuclear Data Lib. Generation.
  - New Resonant Method.
- CAREM: Core Design Pr. Eng.
- CNA 2: independent verifications

Projects

Research and Multipurpose Nuclear Reactors

- RP-0 (10 W, Peru)
- RP-10 (10 MW, Peru)
- RA-6 (500 kW, Argentina)
- NUR (1 MW, Algeria); **Power upgrade 3.5 MW**
- RA-8 (10 W, Argentina)
- ETRR-2 (22 MW, Egypt)
- OPAL (20 MW, Australia)
- **RA-10 (30 MW, Argentina)**
- **LPRR (30 kW, Saudi Arabia)**
- **RMB (30 MW, Brazil)**
- MIPF (10 MW, Puerto Rico)
- **PALLAS (Netherlands)**

Portfolio:
80 MW, 10 MW, 5 MW, Critical & Sub-Critical Fac.

Nuclear Power Plants

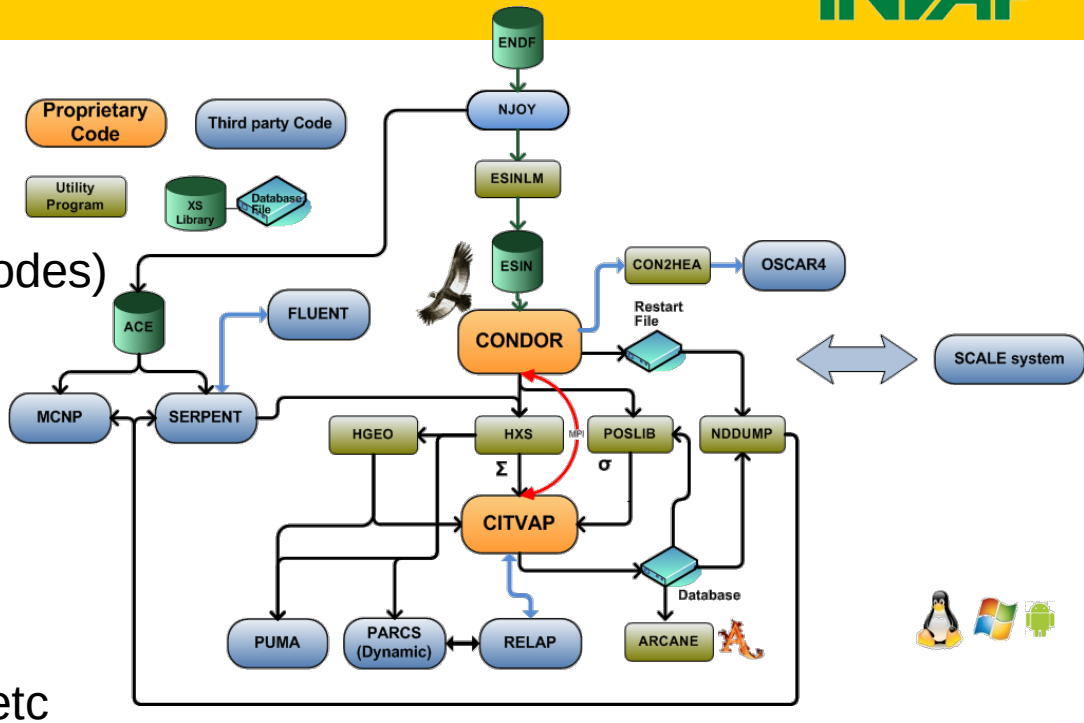
- CAREM25 (Argentina)
- CNA 2 (Argentina)
- > 20 PWR (in USA).

Accelerators

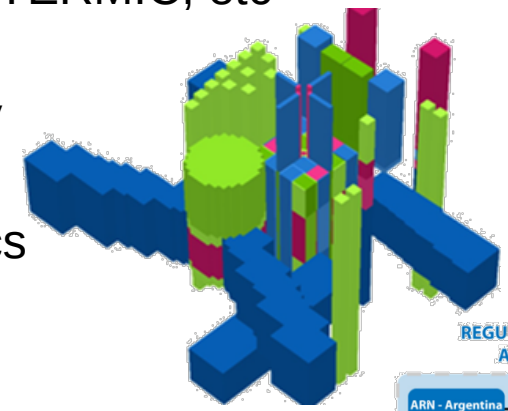
- Proton-Therapy IBA 230 MeV
  Versa HD < 25 MeV
  Cyclone IBA 18 MeV

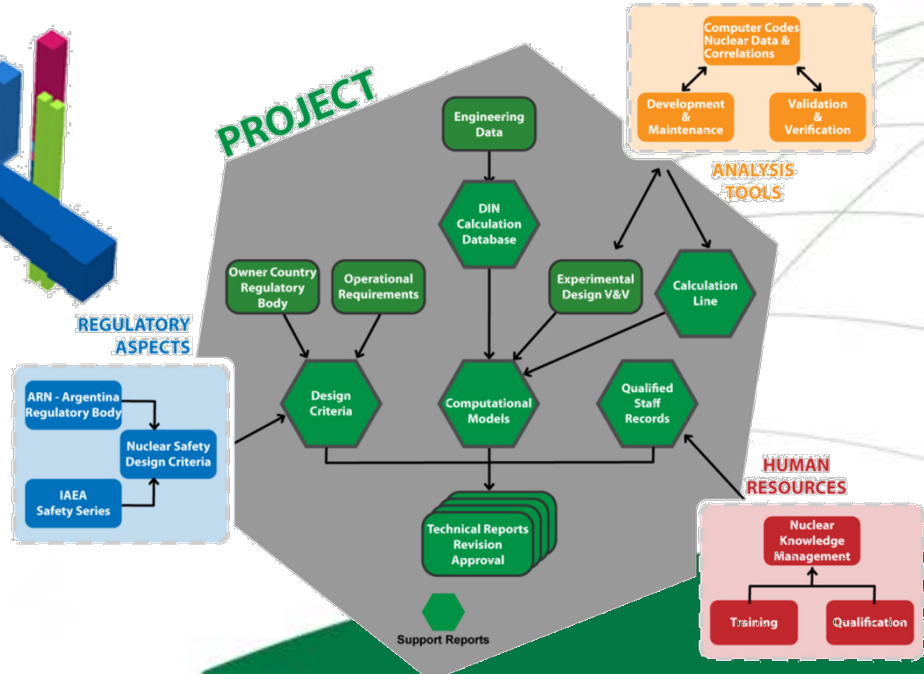
Methods and Tools

- Codes and System development (own developments and adapted codes)
  - Calculation System:
  - MTR_PC (RR, Neutronic, Shielding, Th-H)
  - Neutronic Codes:
    - CONDOR, CITVAP, RENO, etc.
  - Thermal-hydraulic Codes:
    - CAUDVAP, CONVEC, TERMIC, etc



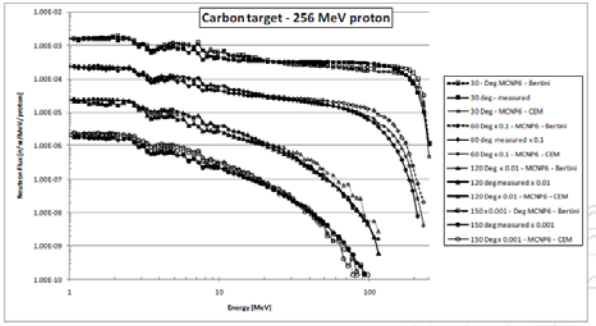
- Calculation methodology
- Tools and its Validation
- Innovative Characteristics
- Consultant Services:
  - WEC USA (PMAT team)
  - WEC Sweden (Nuclear Data and Methods)



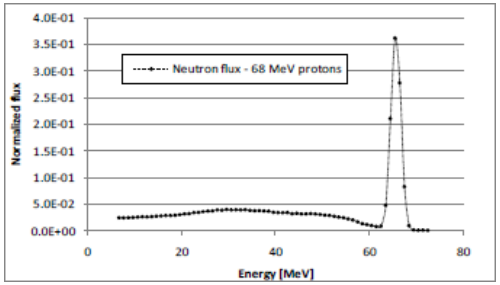


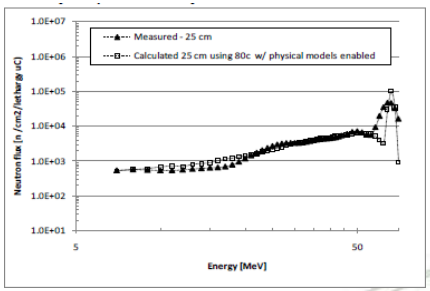
Methods and Tools: Accelerators

- Benchmarking of secondary particles generation.

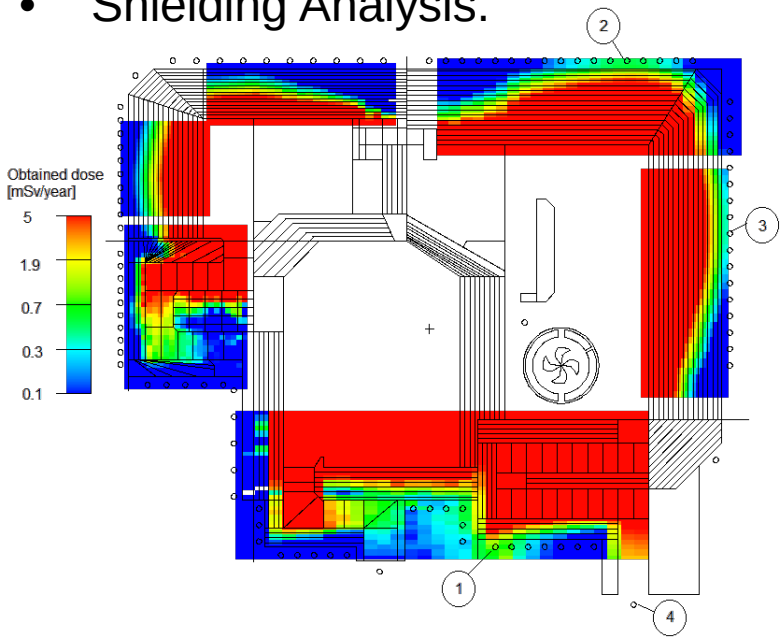


- Benchmarking of the high energy secondary particles



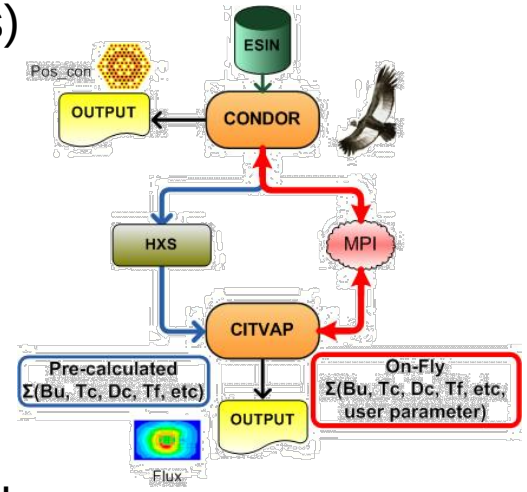


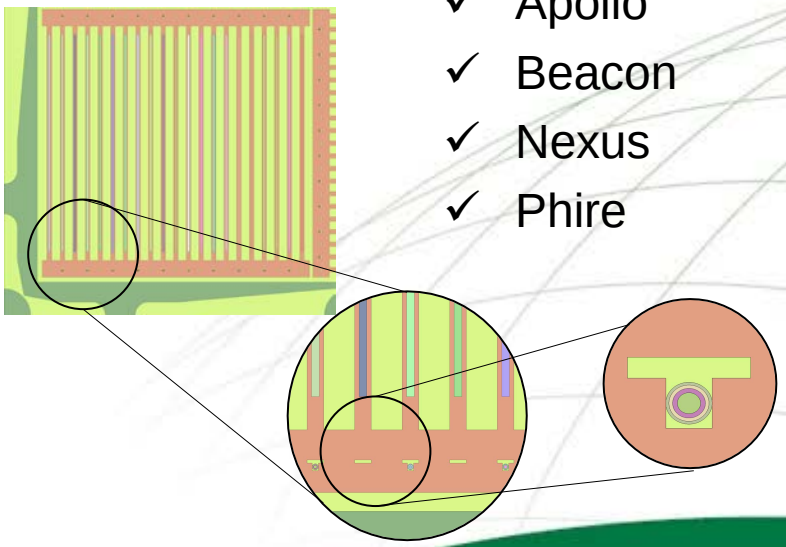
- Shielding Analysis.



Available Codes

- Codes (production & State of Art):
  - ✓ MCNP5 v1.6 (OMP & MPI compilations)
  - ✓ MCNP6 v1.0 (OMP compilation)
  - ✓ Scale 6.1 / KENO VI / Monaco 6.1
  - ✓ CITVAP (OMP Compilation)
  - ✓ CONDOR (OMP)
  - ✓ CONDOR-CITVAP (MPI)
  - ✓ Etc.
- INVAP is Beta Tester of Serpent VTT Code:
  - ✓ Serpent 1 v1.14 & Serpent 2 v1.29(OMP)
- Computation Resources:
  - ✓ All the OMP versions are available to run in a 64-bits linux-based cluster.
- Available Nuclear Data libraries:
  - ✓ MCNP 5 & 6: ENDFVII.0 and VII.1
  - ✓ Serpent 2: ENDF/B VI.8 & VII.0
  - ✓ NJOY processing capabilities





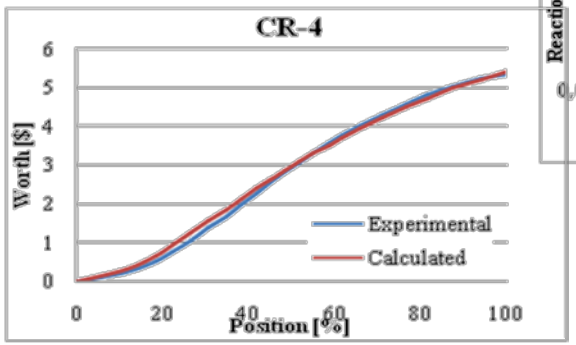
In WEC Projects:

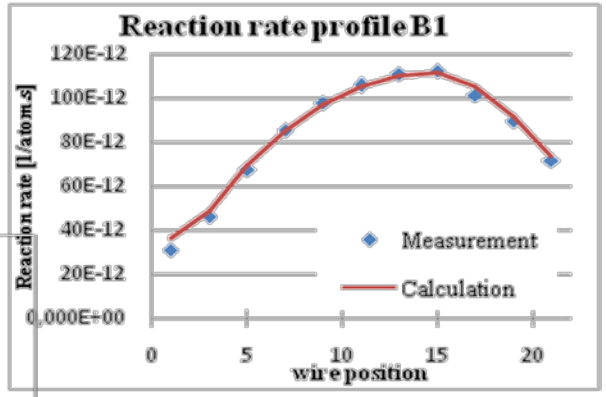
- ✓ Helios Code.
- ✓ Paragon
- ✓ ANC 8 & 9
- ✓ ALPHA
- ✓ VENUS
- ✓ Phoenix
- ✓ Apollo
- ✓ Beacon
- ✓ Nexus
- ✓ Phire

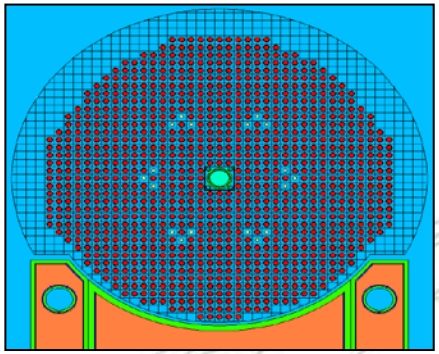
Benchmarking Philosophy

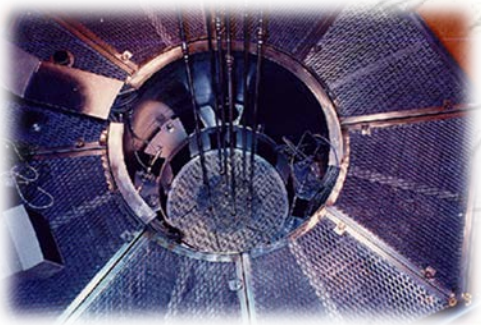
Different Types of Validation

- Verification against other codes.
  - Code developer
  - User cross checking.
- Theoretical benchmarks
  - Code developer
  - Inexperienced user.
  - More detailed benchmarks than available experimental data.
- Experimental benchmarks (real world).
  - A new reactor design.
  - User Training / Re-training.
  - Code developer
- Reactor measurements (real world). LPRR
  - These are experimental measurements carried out in similar reactor.
  - Verification of specific novel design.



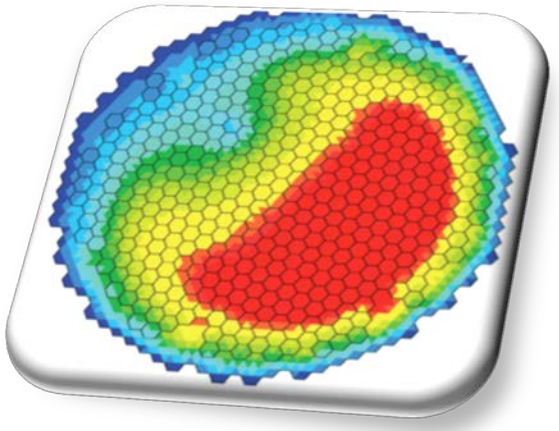






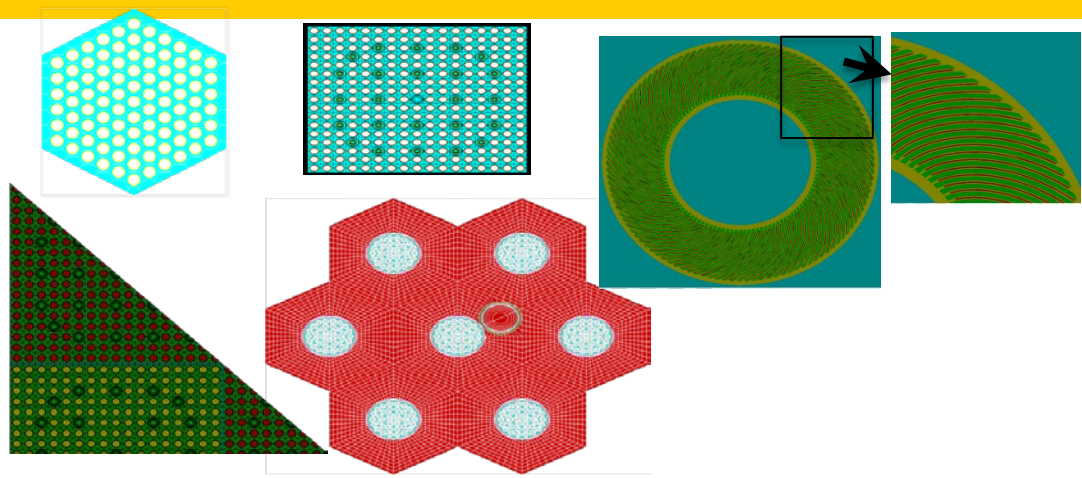
R&D Activities

- Method Development
  - Transport Methods :
    - HELIOS,
    - PHOENIX-H,
    - CONDOR
  - Collision probabilities 3D
  - Characteristic Methods + P_I
  - New resonant methods (subgroup for WEC, ultrafine).
  - Novel Method for XS generation.



- Innovative Methods
  - Core Thermal-Hydraulic Feedback (3D, natural convection)
  - Fuel Assembly Thermal-Hydraulic Feedback.
  - Fuel Performance analysis.
  - Oxide Layer growth in MTR FA.

R&D Activities



- Validation & Verification of Codes
  - PWR, BWR, SMR, PHWR, FBR.
  - MTR, ADS, TRIGA
  - Homogeneous Reactors

- Benchmarking.
  - Benchmark against Experimental Data on Neutronics and Thermalhydraulic Computational Methods and Tools for Operation and Safety Analysis of Research Reactors

IAEA

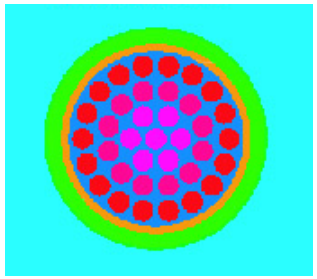
  - ICSBEP: International Criticality Safety Benchmark Evaluation Project
  - IFPE: International Fuel Performance Experiments
  - SINBAD: Shielding Integral Benchmark and Database
  - IRPhE: International Reactor Physics Experiments Project

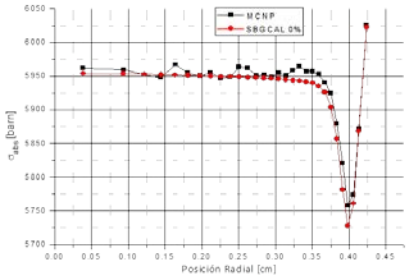
NEA Nuclear Energy Agency

R&D Thesis (Engineering, master of PhD)

$$\tilde{\sigma}_{\rho,g}(\sigma_e)\big|_T = \frac{\int_{u_{g-1}}^{u} du\, \sigma_\rho(u)\, \dfrac{\sigma_e}{\sigma_e + \sigma^*(u)}}{\int_{u_{g-1}}^{u} du\, \dfrac{\sigma_e}{\sigma_e + \sigma^*(u)}} = \frac{\sum_{k=1}^{K} \dfrac{\omega_k\, \sigma_{\rho_k}}{\sigma_k + \sigma_e}}{\sum_{k=1}^{K} \dfrac{\omega_k}{\sigma_k + \sigma_e}}$$

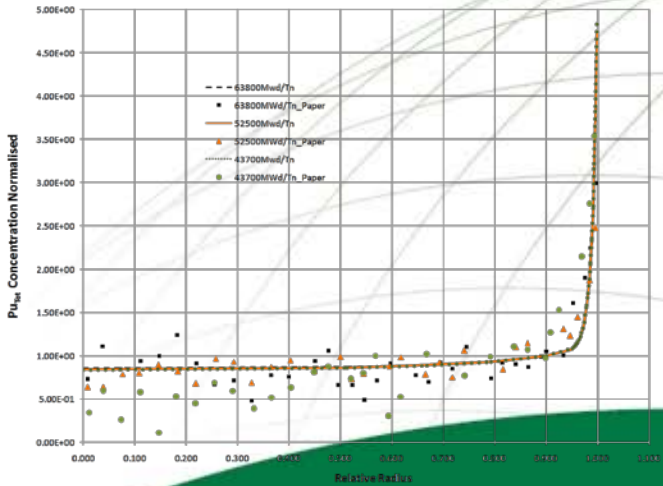
- Novel Method For XS generation.
- Subgroup resonant method
- Methods of Characteristic with Pl Scattering XS
- Detailed multigroup XS libraries for production codes.
- Molten Salt Reactors





- U-Th Fuel Assembly Validation
- Innovative Design of Miniature Reactors.
- Innovative method for Candu NPP modeling.
- Sub-channel thermal-hydraulic feedback for neutronic FA code.
- Non structured grid modeling in core codes.
- 3D transport core calculation.

- Innovative Method for Fuel performance analysis.

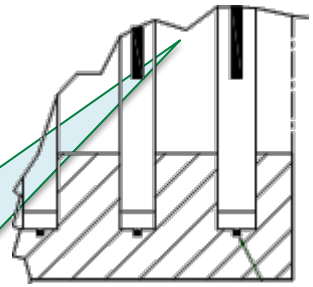


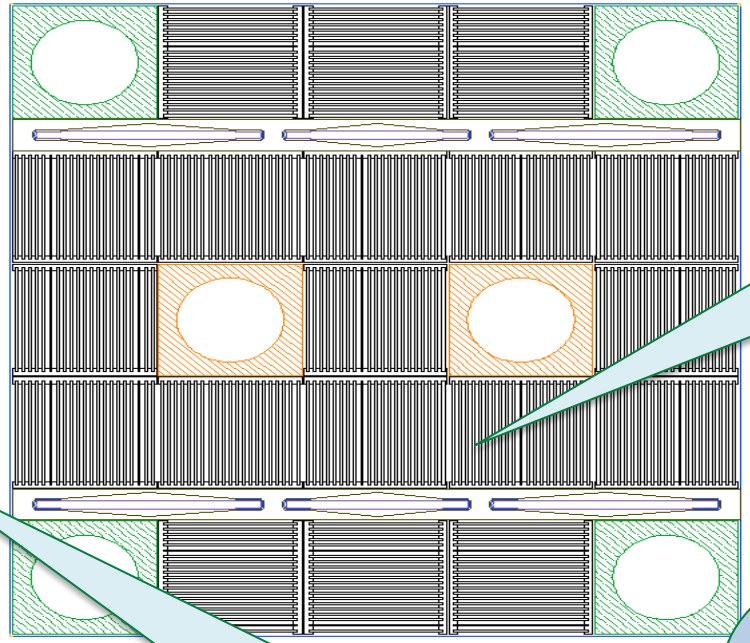
Multi-Physics

Chemical: Water properties

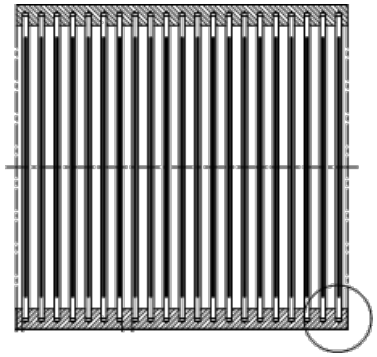
Neutronic: Power Densities, Irradiation History

Oxide Layer Analysis





Core Neutronic & Thermal-Hydraulic



Thermal-Hydraulic: Coolant & Moderator Temperatures & Densities

Thermal: Fuel & Cladding Temperatures

Fuel Plate Thermal Analysis

Multi-Physics

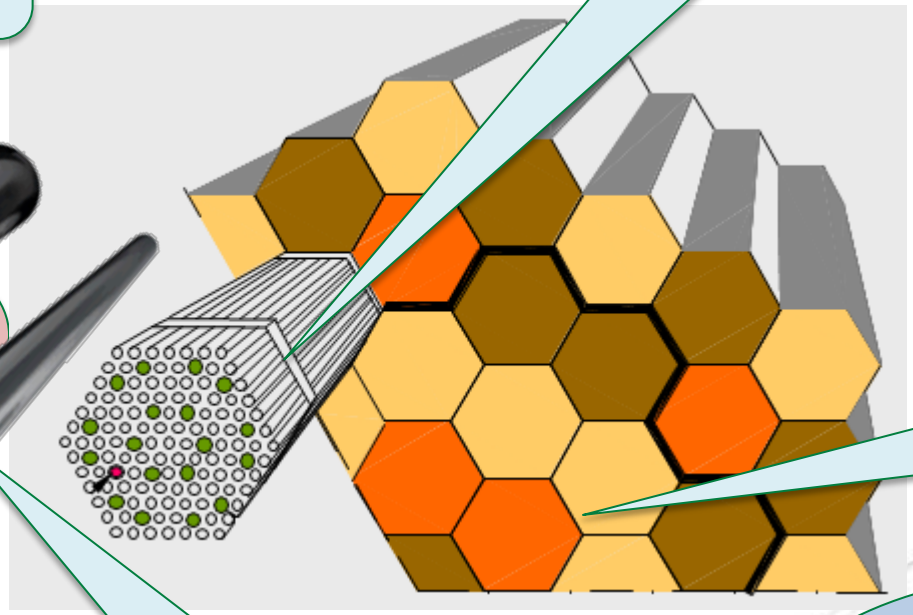
Neutronic:
Power Densities,
Fission Densities,
Fast Flux

Neutronic &
Sub-Channel
Thermal-Hydraulic

Fuel Performance
Analysis

Analysis tool

Physics
Area output



Mechanical:
Fuel / Clad Gap

Neutronic &
Thermal-Hydraulic
3D

Thermal:
Fuel & Cladding
Temperatures

Fuel Rod Thermal
Analysis

Thermal-Hydraulic:
Coolant & Moderator
Temperatures &
Densities

Conclusions

- Nuclear Engineering Department Design Capabilities were shown.

- Nuclear Engineering Department Calculation Capabilities were described:
  - Methods
  - Tools (Production and state-of-art),
  - Research and Developments & Academic Activities.

- Summarizing: INVAP has a software package designed to provide:
  - Design capabilities.
  - Research & Development capabilities
  - Training and re-training to the users.
  - Academic Activities: Engineering, Master and PhD Thesis.
  - Innovative methods.