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# The BEPU Evaluation Model with RELAP5-3D© for the Licensing of Atucha-II NPP

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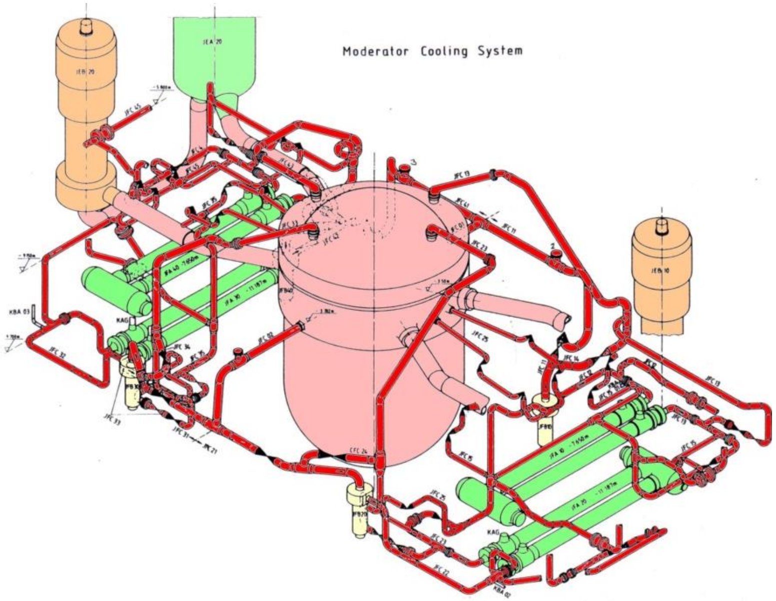
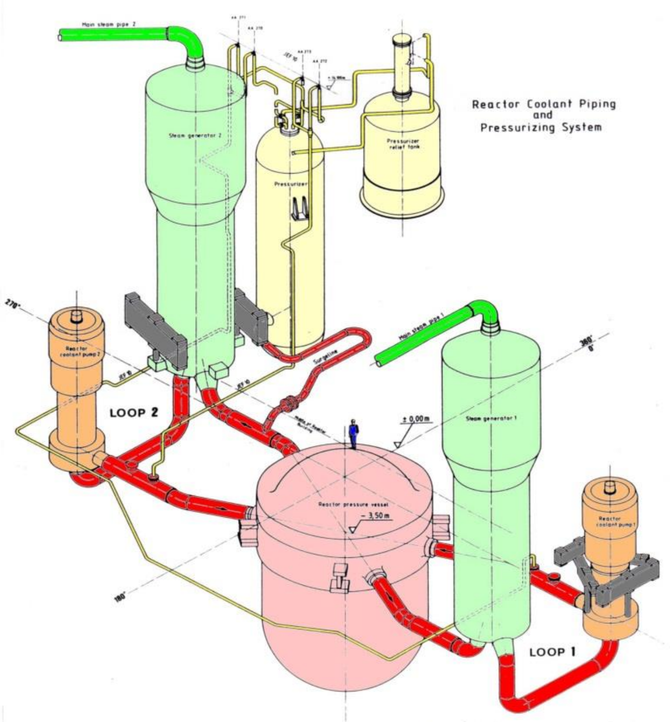
# Contents

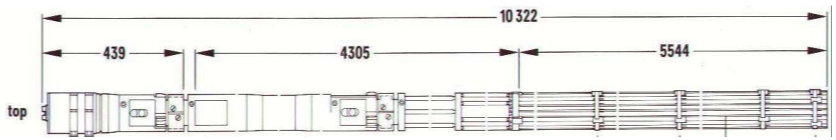
# Atucha-II NPP: short description

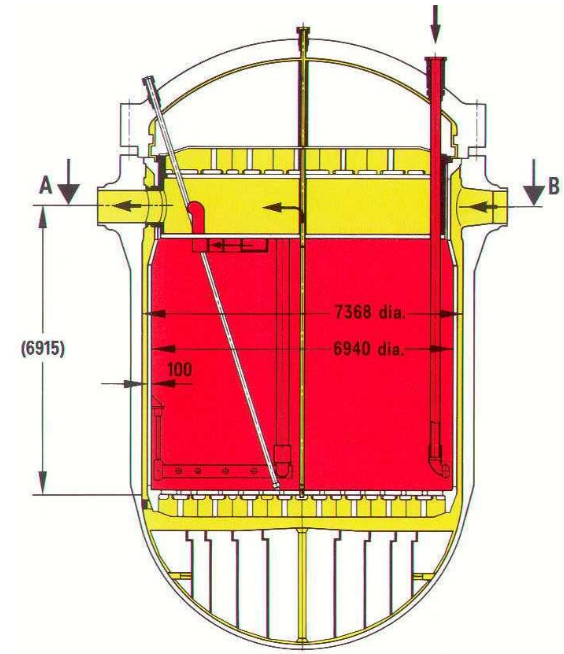
- Primary circuit characteristics (D2O cooled and moderated)
  - 2 U-Tubes SG, 2 MCP
  - Primary side pressure: 11.5 MPa
  - Primary side temperatures: 278 °C at RPV inlet, 313.3°C at RPV outlet
  - Thermal power: 2161 MW
- Moderator circuit (Normal operation and RHR\ECC)
  - Same pressure of the Primary circuit
  - AVG Moderator Temperature: 170-220 °C
  - 4 U-Tubes HX for Moderator cooling / FW pre-heating



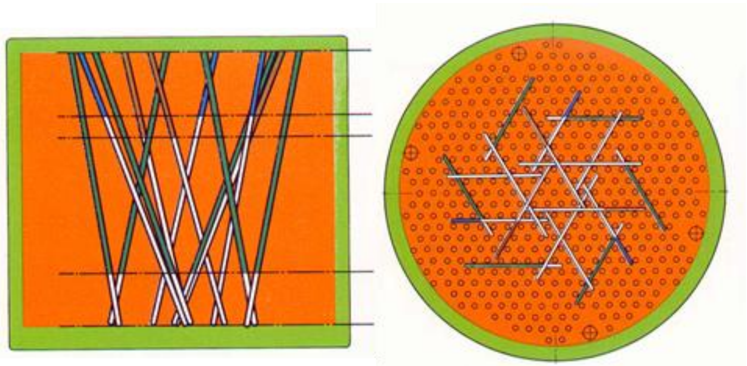



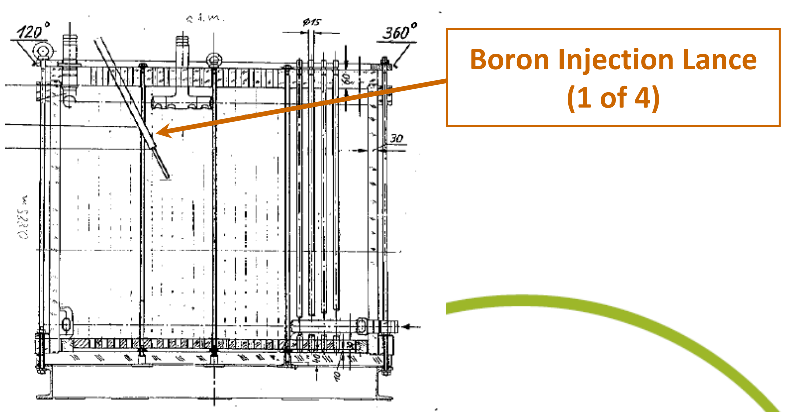
- RPV characteristics
  - 451 fuel channels vertically oriented
  - 37 fuel rods per channel (UO2 nat)
  - On-line refueling
  - Active core length: 5,3m
  - Oblique Control Cods




- Reactivity control system
  - Moderator temperature
  - Oblique Control Rods
  - Emergency Boron Injection System (JDJ) → during RIA (e.g. LB-LOCA)



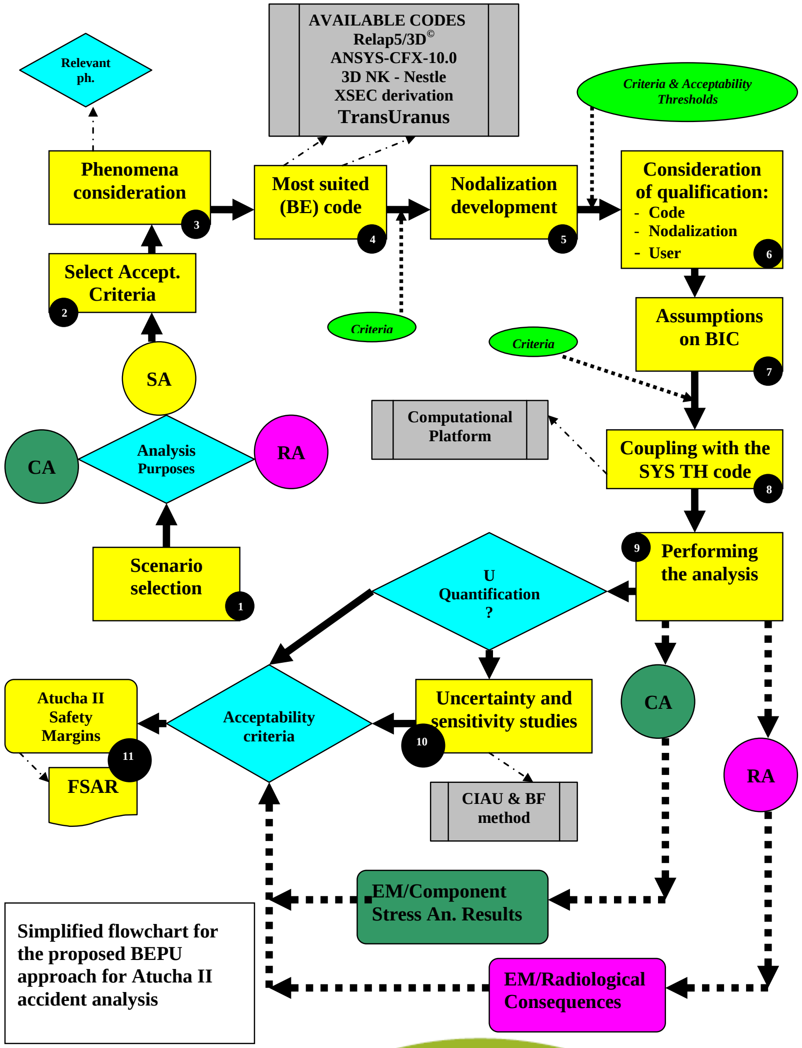


# The BEPU approach

- Methodology for accident analysis in NPP licensing
  - Comply with the established Regulatory requirements
  - Adequate and complete spectrum of events
    - ✓ deterministic and probabilistic methods
  - Availability of qualified tools and procedure for accident analysis
    - ✓ Conservative, BEPU

- Atucha-II Accident analysis for FSAR → "The BEPU description document"
  1. Evaluation of the possibility to use a BEPU approach within the context of the current national Regulatory Authority requirements
  2. Review of the experiences acquired in the use of Best Estimate analyses for licensing
  3. Structure of the BEPU
     a) Categorization of PIE
     b) Grouping of events
     c) identification of analysis purposes
     d) identification of applicable acceptance criteria
     e) 'General scope' Evaluation Model (EM) and of related requirements (from expected phenomena)
     f) Selection of the qualified computational tools + BIC
     g) Characterization of assumptions for the Design Basis Spectrum
     h) Performing the analyses
     i) Adopting a suitable uncertainty method

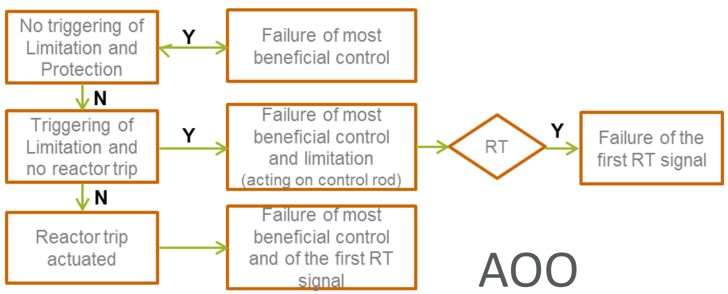
- "The BEPU description document" focuses on:
  - The roadmap pursued for the analysis foresaw the use of nominal conditions for the NPP parameters and the failure of the most influential system
    - ✓ Preparatory code run per each scenario modelling all the NPP system (full I&C) to identify the worst failures
  - The Selection of the codes and the interconnection among them
  - Qualification of the computational tools (development of the SCCRED)
    - ✓ Best estimate computer code
    - ✓ Nodalization (procedure for development and qualification)
    - ✓ Uncertainty methodology (procedure for the qualification)
    - ✓ Computational platform (coupling and interfacing)
  - The adopted methodology for Uncertainty Evaluation (CIAU)




Simplified flowchart for the proposed BEPU approach for Atucha II accident analysis

# The BEPU approach

- Initial condition in Atucha-II safety analyses
  - "normal operation shall be assumed as the **initial plant condition** for the analysis of chain of events. In each case, the **most probable operating condition** of the plant shall be chosen in view of the effects of an event"
    - ✓ Take credit of the **acceptable** limitation system
- Boundary condition (for I&C) based on full BE calculation (Case A, Case B)




AOO

Failure of the most beneficial control and of the first RT signal, EPM at TT

DBA

No failure of controls and limitations (Case A only)

SBDBA

- Three categories of PIE (PSA supported)
  - AOO: f > 10e-2/year
  - DBA : 10e-5/year< f > 10e-2/year
  - SBDBA : f < 10e-5/year

} 2A-LOCA is a SBDBA

- 83 scenarios subdivided in 9 families identified.
  - Three evaluation purposes for each scenario (RCA, CSA, CBA)

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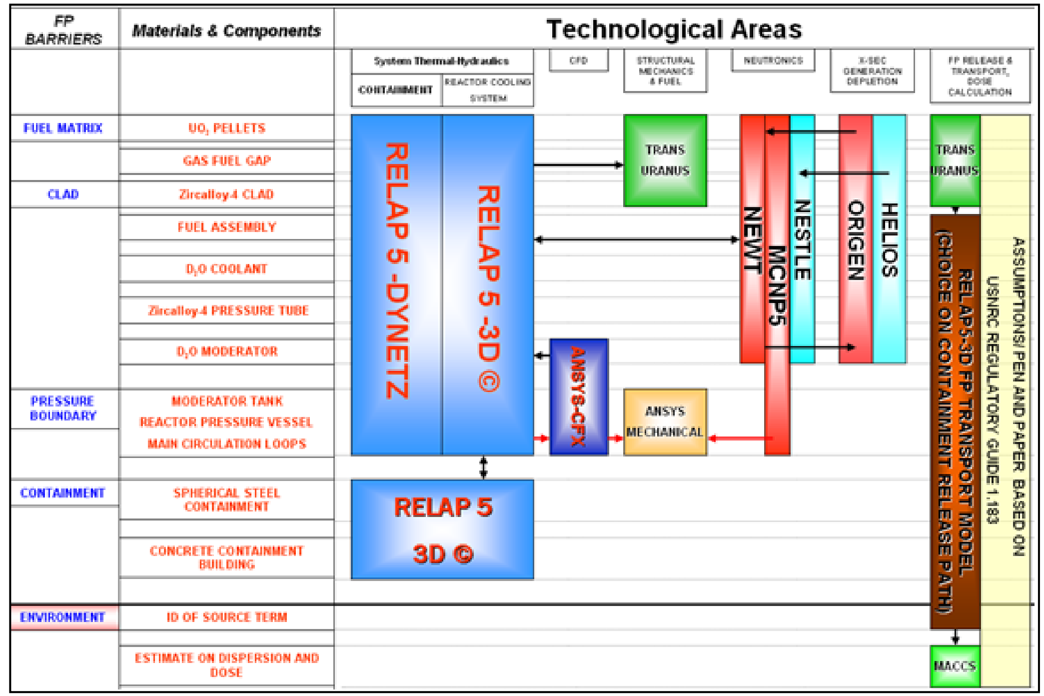
# The BEPU approach

| No | Transient | Section FSAR | Adopted Evaluation Model | Class of Accident |
|---|---|---|---|---|
| | **Increase in Heat Removal by the Secondary System** | **15.1** | | |
| **1** | Feed-Heater Train System Malfunctions that result in a Decrease in FW Temperature (Loss of low Pressure Feed Heater Trains) | 15.1.1 | CSA | AOO |
| **2** | FW System Malfunctions that result in an Increase in FW Flow (Stuck Open FW Control Valve) | 15.1.2 | CSA | AOO |
| **3** | Steam Pressure Regulator Malfunction or Failure that results in Increasing Steam Flow | 15.1.3 | CSA | AOO |
| **4** | Inadvertent Opening of a SG-RV or Safety Valve (Stuck Open Isolation of Safety Valve as a Single Failure) | 15.1.4 | CSA | DBA |
| | Spectrum of Steam System Piping Failures inside and outside of Containment (MSLB) | 15.1.5 | - | |
| **5** | Leak of MS Line inside the Containment | 15.1.5.1 | CSA/RCA/CBA | DBA |
| **6** | 2A MS Line Rupture Downstream Isolation Valve | 15.1.5.2 | CSA/CBA | DBA |
| **7** | 2A MS Line Rupture Outside Containment | 15.1.5.3 | CSA/RCA | DBA |
| **8** | Inadvertent Connection of the DHRS to the FW System | 15.1.6 | QA | AOO |
| **9** | Inadvertent Closing of the Moderator Cooler Bypass CV | 15.1.7 | CSA | AOO |
| | **Decrease in Heat Removal by the Secondary System (part 1 of 2)** | **15.2** | | |
| **10** | Steam Pressure Regulator Malfunction or Failure that results in Decreasing Steam Flow | 15.2.1 | CSA | AOO |
| **11** | Loss of Electric Load | 15.2.2 | CSA | AOO |
| **12** | Turbine Trip (*Closure of Stop Valve*) | 15.2.3 | CSA | AOO |
| | MSIV Malfunction | 15.2.4 | - | |
| **13** | Inadvertent Closing one MSIV | 15.2.4.1 | CSA | AOO |
| **14** | Inadvertent Closing all MSIV | 15.2.4.2 | CSA | DBA |
| **15** | Loss of Condenser Vacuum | 15.2.5 | CSA | AOO |
| | Emergency Power Mode (EPM) | 15.2.6 | - | |
| **16** | Coincident Loss of Onsite and External (Offsite) AC Power to the Station (Short-term EPM) | 15.2.6.1 | CSA | AOO |
| **17** | Coincident Loss of Onsite and External (Offsite) AC Power to the Station (Long-term EPM) | 15.2.6.2 | RCA | DBA |

| No | Transient | Section FSAR | Adopted Evaluation Model | Class of Accident |
|---|---|---|---|---|
| | **Decrease in Reactor Coolant System Inventory (part 2 of 2)** | **15.6** | | |
| | Spectrum of LOCA | 15.6.5 | - | |
| | Primary Coolant System LOCA | 15.6.5.1 | - | |
| | Small Break LOCA | 15.6.5.1.1 | - | |
| **50** | 30 cm2 LOCA cold | 15.6.5.1.1.1 | CSA | DBA |
| **51** | 100 cm2 LOCA cold | 15.6.5.1.1.2 | CSA | DBA |
| **52** | Break of the Refueling Nipple | 15.6.5.1.1.3 | CSA | DBA |
| | Intermediate Break LOCA | 15.6.5.1.2 | - | |
| **53** | 200 cm2 LOCA cold | 15.6.5.1.2.1 | CSA/CBA | DBA |
| **54** | LOCA in PRZ Surge-Line | 15.6.5.1.2.2 | CSA | DBA |
| **55** | 0.1A LOCA cold ■ | 15.6.5.1.2.3 | CSA/RCA/ CBA | DBA |
| **56** | 0.1A LOCA cold with Sump Swell Operation | 15.6.5.1.2.4 | QA | DBA |
| | Large Break LOCA | 15.6.5.1.3 | - | |
| **57** | 2A LOCA cold (*DEGB. Different Break Sizes and Positions are investigated*) ■ | 15.6.5.1.3.1 | CSA/RCA/ CBA | SBDBA |
| **58** | 2A LOCA hot ■ | 15.6.5.1.3.2 | CSA/CBA | SBDBA |
| | Moderator Loop LOCA | 15.6.5.2 | - | |
| **59** | 50 cm2 Small Leak in Moderator Suction Line | 15.6.5.2.1 | CSA | DBA |
| **60** | 0.1A Leak in Moderator Injection Line | 15.6.5.2.2 | CSA | DBA |
| **61** | 2A Break in the Moderator Line at Pump Suction (*DEGB*) | 15.6.5.2.3 | CSA | SBDBA |
| **62** | Break in the Largest Pipe connected with the Moderator Lines | 15.6.5.2.4 | CSA | DBA |
| **63** | Break in the Moderator Line at RPV Connection (*DEGB*) | 15.6.5.2.5 | CSA | SBDBA |
| **64** | CVCS Malfunction that decreases RCS mass Inventory | 15.6.6 | CSA | AOO |
| | **Radioactive Release from a Sub-system** | **15.7** | | |
| **65** | Radioactive Gas Waste System Leak or Failure | 15.7.1 | RCA | DBA |
| **66** | Radioactive Liquid Waste System Leak or Failure | 15.7.2 | RCA | DBA |
| **67** | Radioactive Release due to Liquid Tank Failure | 15.7.3 | RCA | DBA |
| **68** | Design Bases Fuel Handling Accidents | 15.7.4 | - (2) | DBA |
| **69** | Spent Fuel Cask Drop Accident | 15.7.5 | QA | DBA |
| **70** | Failure During Tritium Extraction Operation and Storage | 15.7.6 | RCA | DBA |

- Qualified computational tools adopted in the BEPU FSAR of Atucha-II
  - More than ten computer codes with several interaction **(TH-SYS code is the central process)**
  - More than 20 nodalization developed
  - Suitable qualification process
  - Uncertainty evaluation (CIAU)

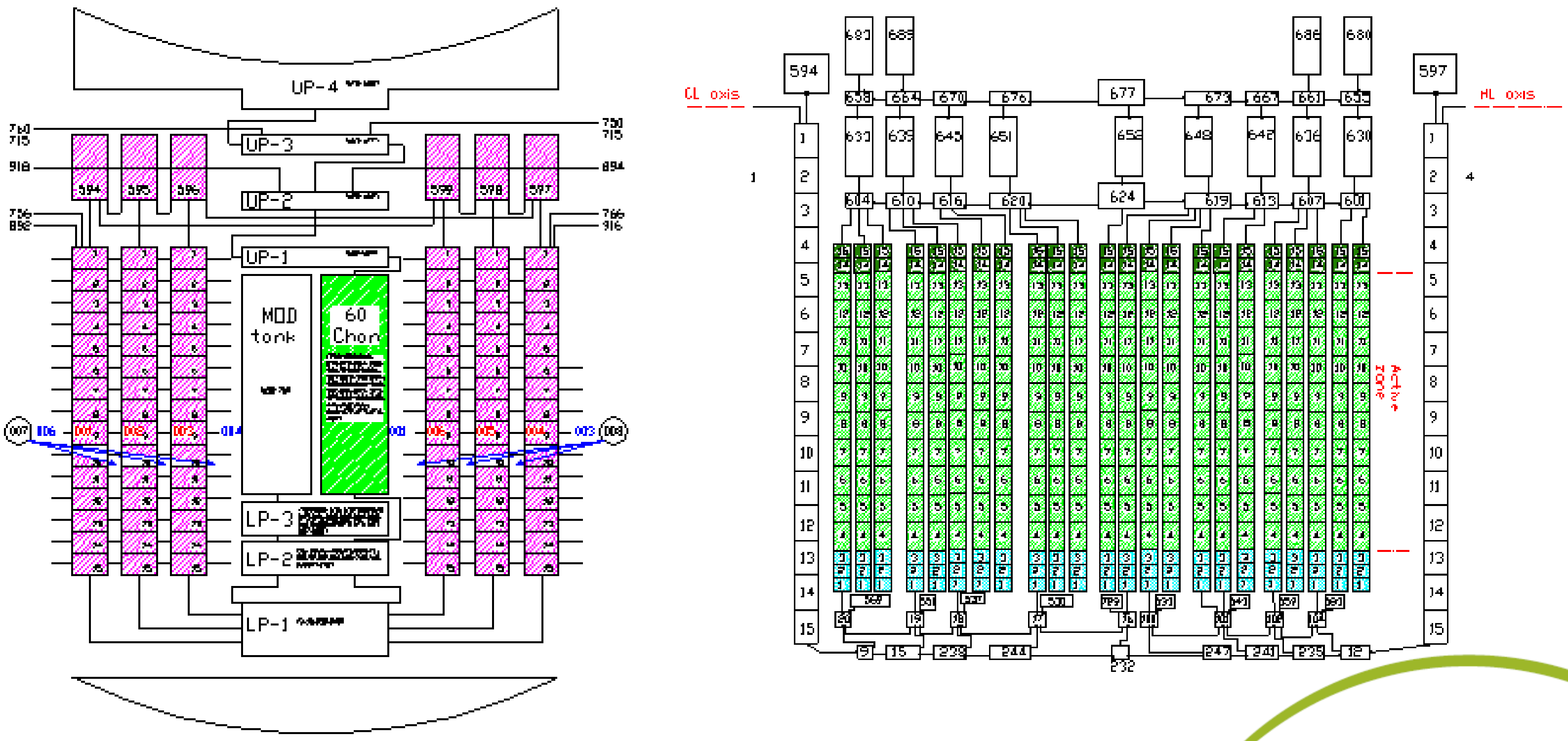
6 different R5-3D nodalization



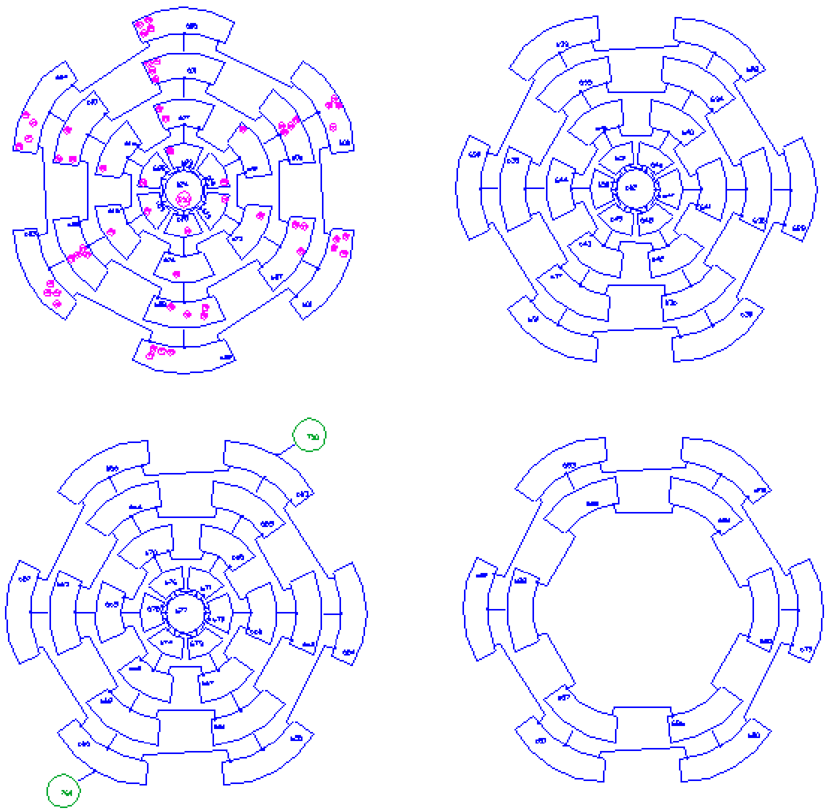

| # | CODE | NODALIZATION | OBJECTIVE | # | CODE | NODALIZATION | OBJECTIVE |
|---|---|---|---|---|---|---|---|
| 1-1 | RELAP5-3D© (only TH Model) | 60-ch | D | 13-3 | ANSYS-CFX | Boron Lances | S |
| 2-1 | | 280-ch | D | 14-4 | ANSYS | RPV-w | D |
| 3-1 | | 451-ch | S | 15-5 | TRANSURANUS | Fpin | D |
| 4-1 | | DNBR | D | 16-6 | NESTLE | 451-10nk | D |
| 5-1 | | CONT-R | D | 20-8 | MCNP | Core-M | S |
| 6-2 | DYNETZ | I&C-AT2 | D | 21-9 | NEWT-ORIGEN | FCell-S | D |
| 7-3 | ANSYS-CFX | MOD-T | D | 24-13 | DRAGON | FCell-D | S |
| 8-3 | | DC-LP | D (PTS) | 25-13 | MCNP-ORIGEN | FCell-M | D |
| 9-3 | | UP | S | 26-14 | RELAP5-3D© (Rad Model) | 60ch-3D | D |
| 10-3 | | FC Inlet | S | 27-15 | MELCOR-MACCS | ENV-M | D |
| 11-3 | | FC outlet | S | 28-15 | | CONT-M | S |
| 12-3 | | Grid Spacer | S | 30-17 | RODOS | ENV-R | S |

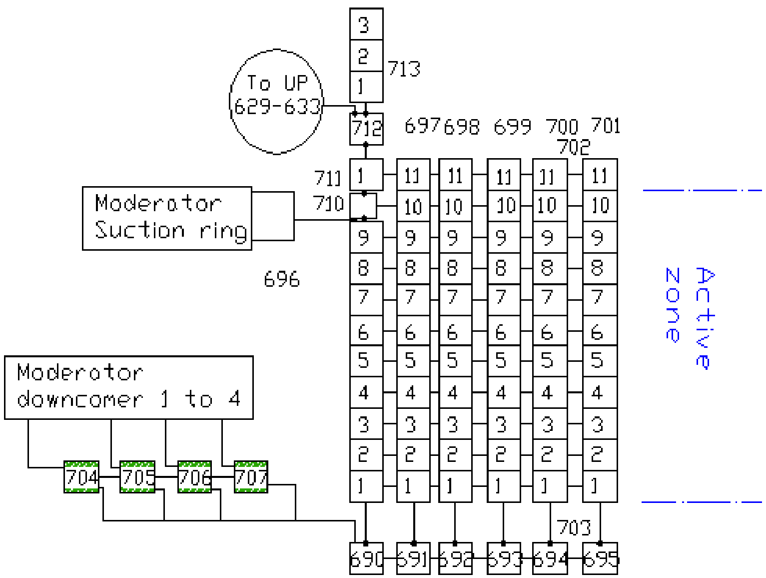
- The RELAP5-3D© 60-Channels Nodalization
  - Main nodalization adopted in the safety analyses of Atucha-II FSAR
  - Fictitious 3D approach
  - Two different coupling developed for I&C modelling (Dynetz)
    - ✓ Detailed description of the Secondary Side, Moderator System and auxiliary system (e.g. CVCS)

| Code resources | Number |
|---|---|
| Volumes | 2609 |
| Junctions | 3139 |
| Heat Structures | 2861 |
| Mesh Points | 22195 |
| Trips | 45 |
| Control Variables | 4316 |

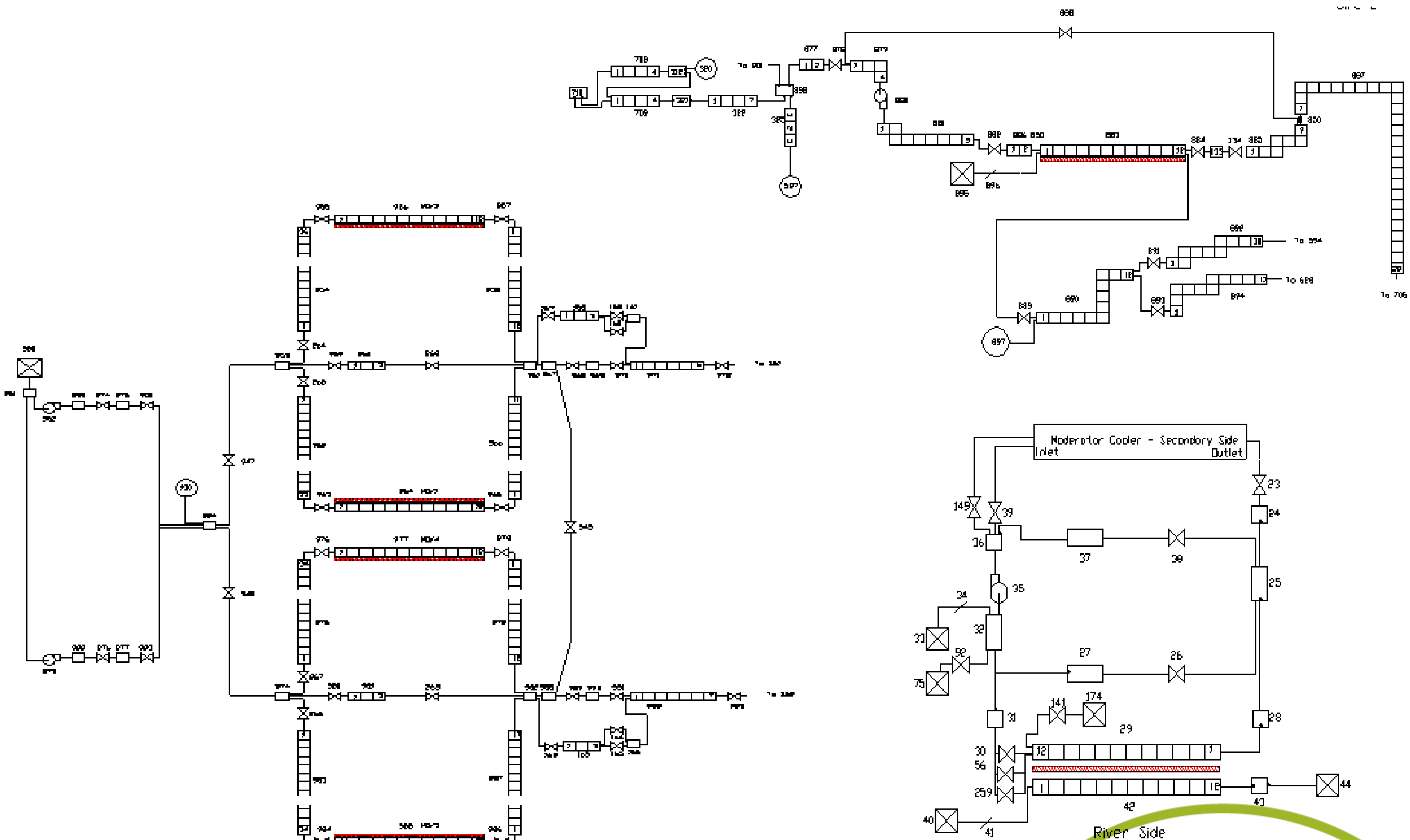


- Sample of the Fictitious 3D developed with CFD support calculations
  - Adopted in the BEMUSE project (Zion NPP) and UPTF calculations





- Sample of the nodalization of the SS and ML systems

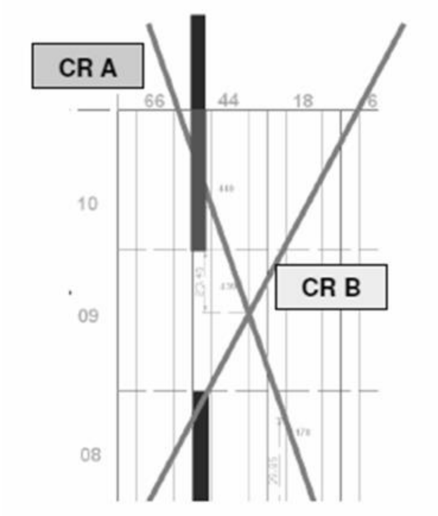


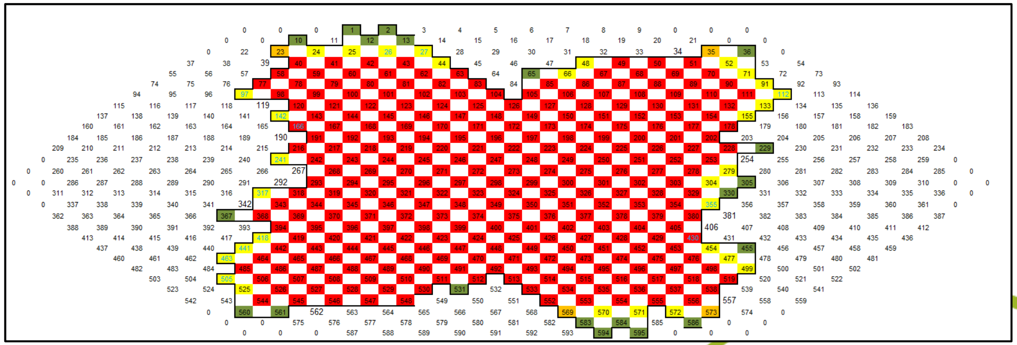
# RELAP5-3D©: 280 channels

- The RELAP5-3D© 280-Channels Nodalization
  - 3D-NK NESTLE model
    - ✓ Special technique to a take into account the Control Rod inclination (XS corrected with MCNP calc.)
  - MULTID components to model the Moderator Tank
  - 2 different techniques for CFD interfacing (boron injection)

- Inclined control rods (17°-25°) constituted by 2 different material (axially)
- “fictitious moderator tank” approach for boron feedback
  - Boron dilution (CFD) → boron concentration at 3D-NK resolution level

| Code resources | Number | Code resources | Number |
|---|---|---|---|
| 3D components | 3 | Geometry | hexagonal |
| Volumes | 9770 | Axial layer | 12 |
| Junctions | 12864 | Number of rings | 14 |
| Heat Structures | 8157 | Zones | 4164 |
| Mesh Points | 52895 | Regions (vol\HS) | 2\1 |
| Trips | 45 | Compositions | 1670 |
| Control Variables | 40 | Control rod groups | 281 |

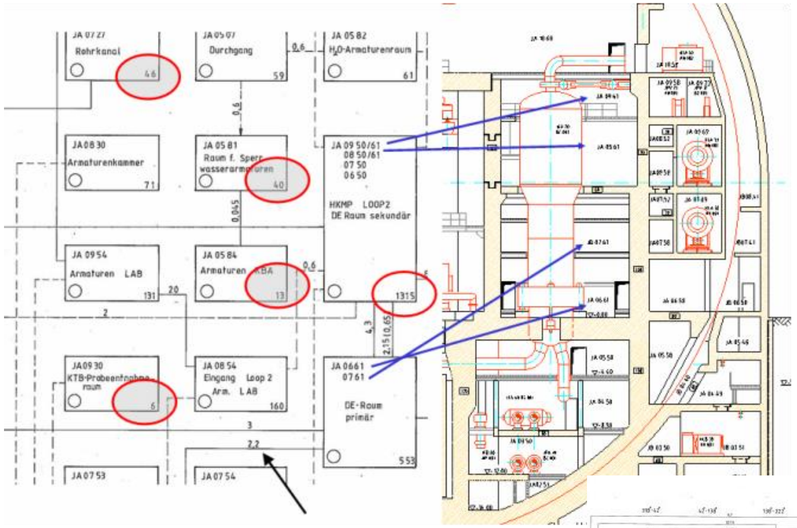


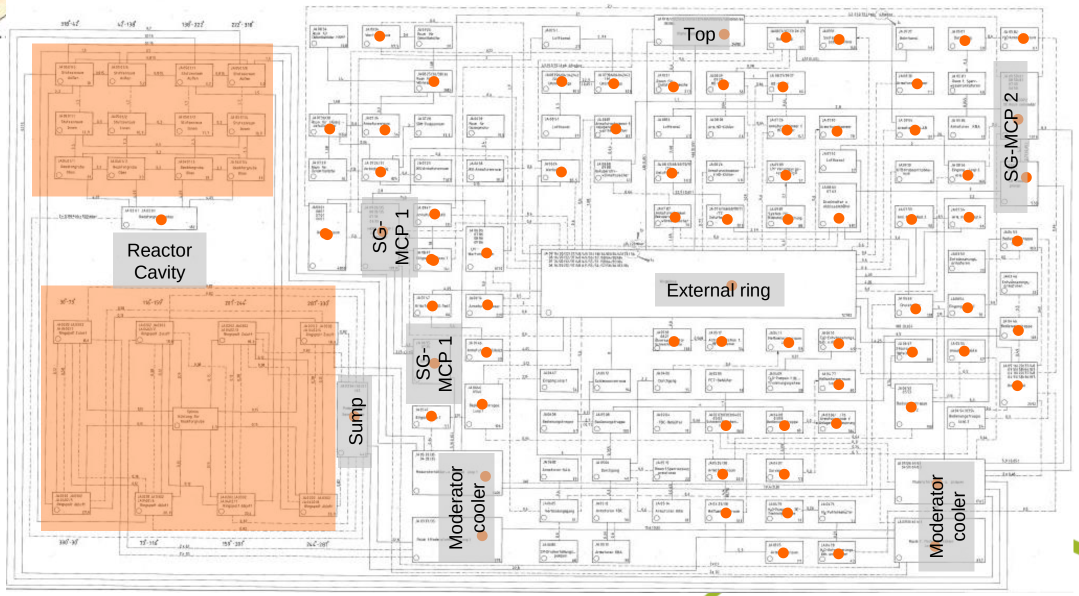
- The RELAP5-3D© Containment nodalization → pressure peak (e.g. 2A LOCA)
  - Careful investigation of the code capability
    - ✓ No Severe Accident, steam explosion, hydrogen combustion phenomena
    - ✓ Fission product distribution only in liquid phase
    - ✓ Limited data for mechanical loads on structures and components
  - Relevant phenomena can be investigated with **proper nodalization techniques**
    - ✓ Discharge of water and steam in the containment
    - ✓ Expansion of the steam in the containment rooms
    - ✓ Max pressure peak occurrence in short term
    - ✓ Heat exchange between the discharge water and containment environment and thermal structures
    - ✓ Condensation of the steam
    - ✓ Collection of the water from the break and condensing water
    - ✓ Injection of the collected water in the primary system
  - Specific care in modeling the obstacles (water on the floor and pool formation), rupture disks and fuse doors

| Accident Group | Mass sources | Energy sources | Radioactivity sources | Mechanical and thermal loads on structures/components |
|---|---|---|---|---|
| Group I (PS break) | Relevant | Relevant | Relevant | Relevant |
| Group II (SS break or isolable PS break) | Not Relevant | Relevant | Negligible | Relevant |
| RELAP5-3D capability | Full | Full | Partial | Partial |

- Sample of the nodalization scheme and adopted code resources

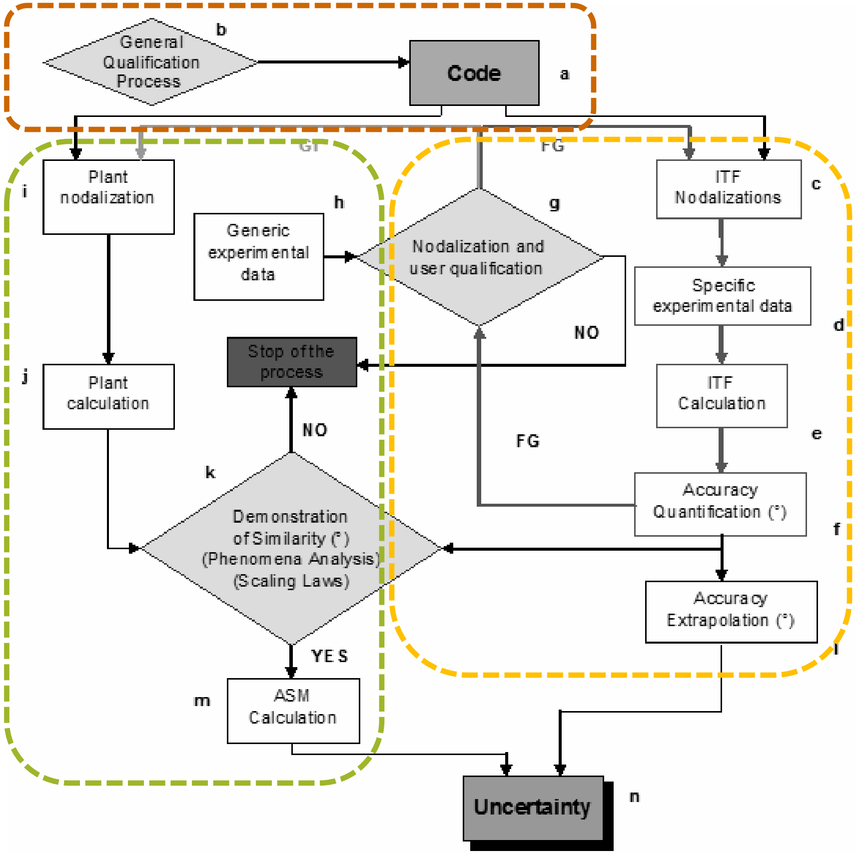


| Code Resources | Number |
|---|---|
| Volumes | 572 |
| Junctions | 1031 |
| Heat Structures | 558 |
| Mesh Points | 4120 |



# Qualification of the R5-3D EM

- The SCCRED methodology was rigorously adopted (Qualification of the developed computational tools)
- The Features of Atucha-II NPP require a specific approach for the Kv scaling analyses for the assessment of the Evaluation Model
  - Demonstration of Code Phenomena Coverage
  - Code validation
    - ✓ Computer code
    - ✓ Nodalization Techniques
    - ✓ Accuracy evaluation
    - ✓ User qualification
  - **Qualification of the Atucha-II nodalization**
    - ✓ **Identification of the system/sub-system**
    - ✓ **Nodalization techniques @ system/sub-system level**
    - ✓ **"Kv+CT" analyses @ system/sub-system level**
    - ✓ **Verification of the I&C simulator (code-to-code)**



- Nine different tests performed on five ITF selected for the "on transient" qualification of the Atucha-II nodalization (No prototypical ITF exists)
  - 9 qualified calculations ( SCCRED)
  - Multiple similarity analyses at **full system** and **system/subsystem level**

- The presence of the moderator system requires proper Kv scaling approach
  - "Correction" of the power-to volume scaling factor (power and volume)
  - Sensitivity calculation considering the moderator tank

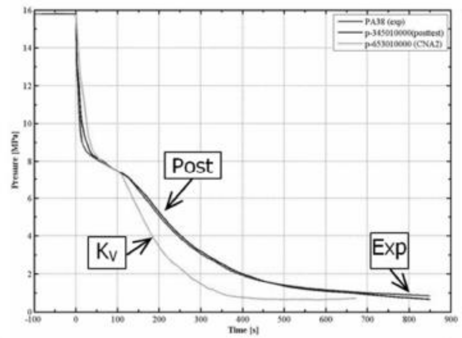
- The verification of the I&C simulator consider 10 NON-LOCA scenarios
  - Consider the actuation of the different I&C systems
  - Consider different plant status
  - Qualitative and quantitative analyses performed

## Scaling factors and selected test

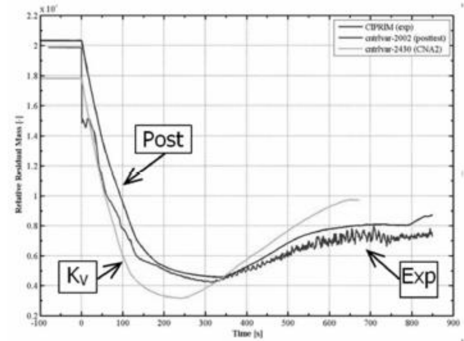
| No | Parameter | Reference CNA-II scaled model (w/o Moderator) | Sensitivity with Moderator |
|---|---|---|---|
| | | **Steady-State Setup** | |
| 1 | Power, $W$ | $f \cdot W_{CNA2}^{0.9}$ | $f \cdot W_{CNA2}$ |
| 2 | Pump velocity, $v$ | $f \cdot v_{CNA2}$ | |
| 3 | PS pressure, $P$ | $P_{ITF}$ | |
| 4 | CL temperature, $T_{CL}$ | ${T_{CL}}^{ITF}$<br>adjust SS conditions (pressure, FW temp, FW flow) to achieve | |
| 5 | Linear heat rate, $LHR$ | $LHR_{CNA2}$ + sample with $LHR_{ITF}^{max}$ | |
| 6 | PRZ volume, $V_{PRZ}$ | $V_{PRZ}^{CNA2} \cdot \frac{V_{CNA2}^{PS}}{V_{CNA2}}$ | $V_{PRZ}^{CNA2}$ |
| | | **Transient Setup** | |
| 7 | Break area, $A_{brk}$ | $A_{brk}^{ITF} \cdot K_T$ | |
| 8 | Accumulator:<br>a) height<br>b) total volume<br>c) liquid volume<br>d) inj. line pressure loss<br>e) initial pressure<br>f) liquid temperature | a) $H = H^{ITF}$<br>b) $V_{tot} = V_{tot}^{ITF} \cdot K_T$<br>c) $V_{liq} = V_{liq}^{ITF} \cdot K_T$<br>d) $K_{loss}^{ITF} / A_{ITF}^2$<br>e) $P = P^{ITF}$<br>f) $T = T^{ITF}$ | |
| 9 | HPIS/LPIS:<br>a) supplied flow<br>b) liquid temperature<br>c) setpoint | a) $\dot{m} = \dot{m}^{ITF} \cdot K_T$<br>b) $T = T^{ITF}$<br>c) as in experiment | |
| 10 | Power<br>a) scram setpoint<br>b) decay curve | a) as in experiment<br>b) experimental relative curve | |
| 11 | Secondary side pressure | As in experiment (imposed cooldown in LOCA) | |
| 12 | FW system<br>a) flow<br>b) temperature | a) procedure as in experiment<br>b) $T = T^{ITF}$ | |

| # | Facility | Test | Type | CNA-II Phenomena | CNA-II System/Sub-System |
|---|---|---|---|---|---|
| 1 | LOBI MOD1 | A1-06 | 2A CL LOCA | PRZ pressurization/depressurization<br>Mass inventory variation<br>PRZ discharge | PRZ and Surgeline |
| | | | | Core heat exchange related phenomena | Core |
| | | | | PS mass distribution and depressurization | RCS |
| | | | | Core related phenomena (refilling, flooding, quenching,...) | Core |
| 2 | LOBI MOD2 | A2-81 | CL SBLOCA | SG pressurization/depressurization<br>Mass inventory variation | SG SS |
| | | | | PS-SS heat exchange | SG SS and PS interface |
| | | | | Core heat exchange related phenomena | Core |
| | | | | Natural circulation occurrence | RCS (Core, RPV, U-tubes, Legs) |
| 3 | | A1-83 | 0.1 A CL LOCA | Core heat exchange related phenomena | Core |
| | | | | PS mass distribution and depressurization | RCS |
| | | | | Core related phenomena (refilling, flooding, quenching,...) | Core |
| 4 | | BT-15-16 | Loss of one MFW pump | SG pressurization/depressurization<br>Mass inventory variation | SG SS |
| | | | | PS-SS heat exchange | SG SS and PS interface |
| | | | | PRZ pressurization/depressurization<br>Mass inventory variation<br>PRZ discharge | PRZ and Surgeline |
| | | | | Core heat exchange related phenomena | Core (high pressure conditions) |
| 5 | PSB-VVER | Test #03 | Stuck open PRZSV | PS-SS heat exchange | SG SS and PS interface |
| | | | | PRZ pressurization/depressurization<br>Mass inventory variation<br>PRZ discharge | PRZ and Surgeline |
| | | | | Natural circulation occurrence | RCS (Core, RPV, U-tubes, Legs) |
| 6 | | Test #05 | MSLB and SGTR | SG pressurization/depressurization<br>Mass inventory variation | SG SS |
| | | | | PS-SS heat exchange | SG SS and PS interface |
| | | | | PRZ pressurization/depressurization<br>Mass inventory variation<br>PRZ discharge | PRZ and Surgeline |
| | | | | PS mass distribution and depressurization | Reactor Coolant System |
| | | | | Natural circulation occurrence | RCS (Core, RPV, U-tubes, Legs) |
| 7 | UPTF | Test 05 run63 | End of blowdown and refill phases following a LOCA with CL break | PS mass distribution and depressurization | Reactor Coolant System |
| | | | | Core related phenomena (refilling, flooding, quenching,...) | Core |
| 8 | LOFT | L2-5 | 2A CL LOCA | Core heat exchange related phenomena | Core and fuel rods |
| | | | | PS mass distribution and depressurization | Reactor Coolant System |
| | | | | Core related phenomena (refilling, flooding, quenching,...) | Core |
| 9 | SPES | SB-04 | 200 cm² CL LOCA | PS-SS heat exchange | SG SS and PS interface |
| | | | | Core heat exchange related phenomena | Core |
| | | | | PS mass distribution and depressurization | Reactor Coolant System |
| | | | | Core related phenomena (refilling, flooding, quenching,...) | Core |
| | | | | Natural circulation occurrence | RCS (Core, RPV, U-tubes, Legs) |

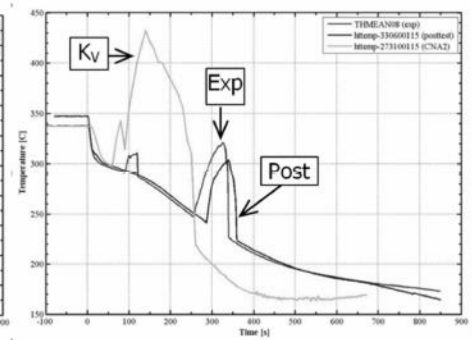
- LOBI MOD2 Test A1.83 – Atucha-II Kv Scaled Calculation



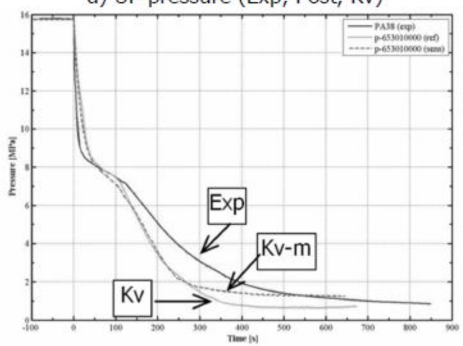

a) UP pressure (Exp, Post, Kv)



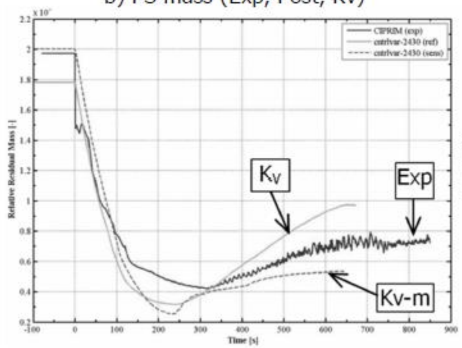

b) PS mass (Exp, Post, Kv)



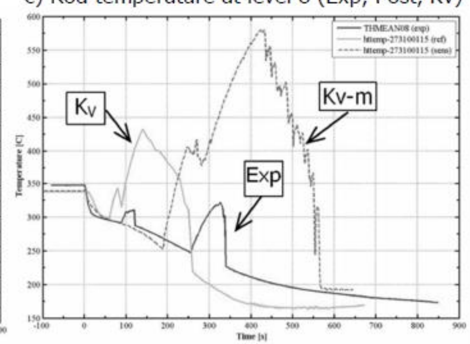

c) Rod temperature at level 8 (Exp, Post, Kv)



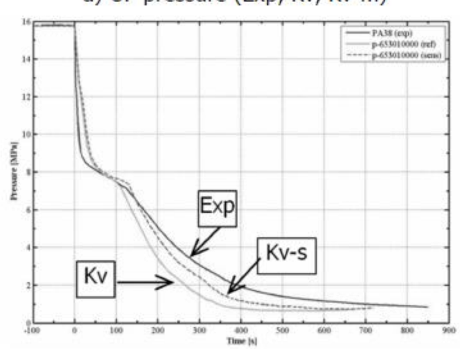

d) UP pressure (Exp, Kv, Kv-m)



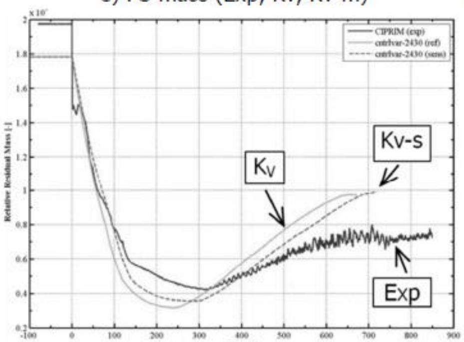

e) PS mass (Exp, Kv, Kv-m)



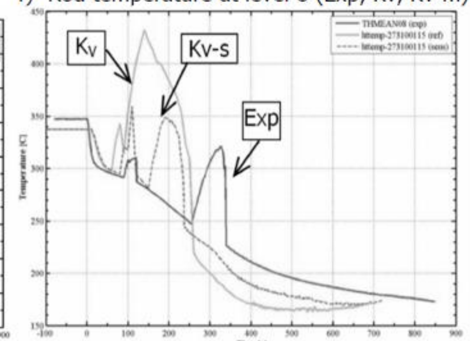

f) Rod temperature at level 8 (Exp, Kv, Kv-m)




g) UP pressure (Exp, Kv, Kv-s)




h) PS mass (Exp, Kv, Kv-s)




i) Rod temperature at level 8 (Exp, Kv, Kv-m)

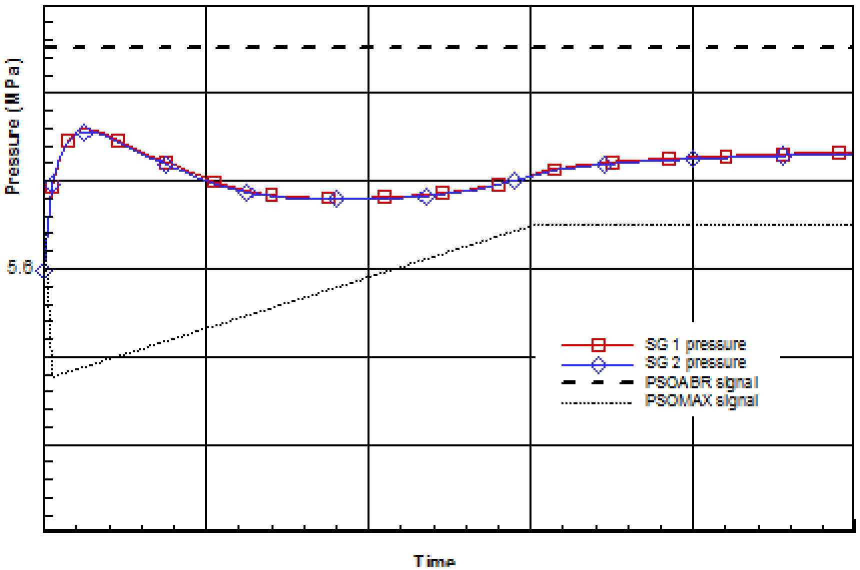
# AOO: Turbine Trip Scenario

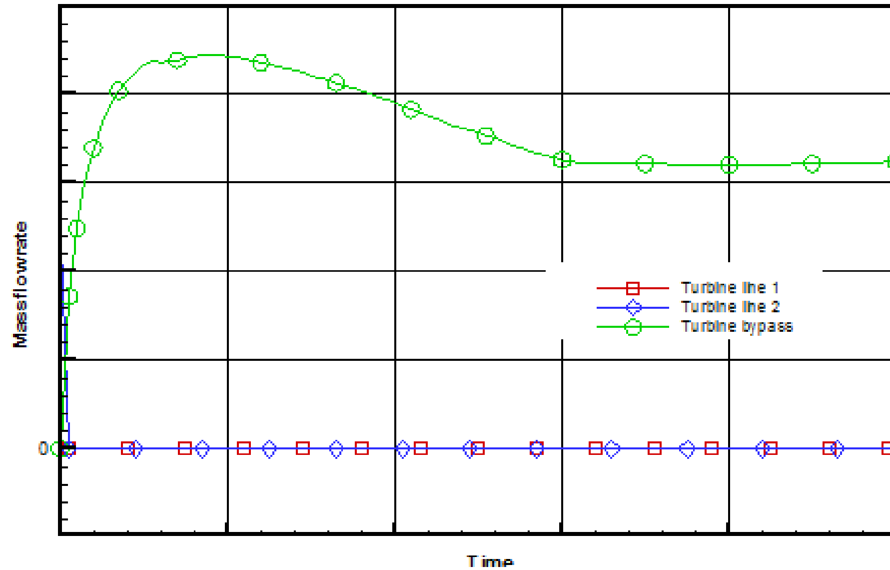
- The Turbine Trip - Closure of Stop Valve - Scenario (AOO, CSA, FSAR Ch. 15.2.3)
  - 60 channels Relap5/3D © nodalization coupled with I&C-AT2 Dynetz nodalization

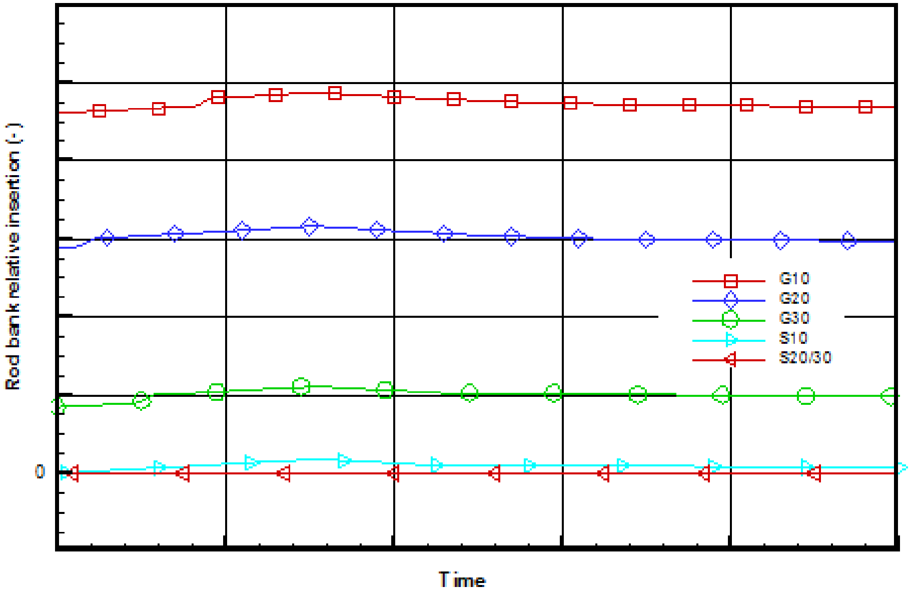
- Acceptance criteria
  - No fuel melting is acceptable
  - No departure from nucleate boiling can occur in the fuel channels or cladding
  - temperature can not stay above 600°C longer than 120 seconds
  - RCS pressure shall stay below 110% of design pressure (pressurizer safety valves can not be challenged)
  - Secondary side pressure shall stay below 110% of design pressure

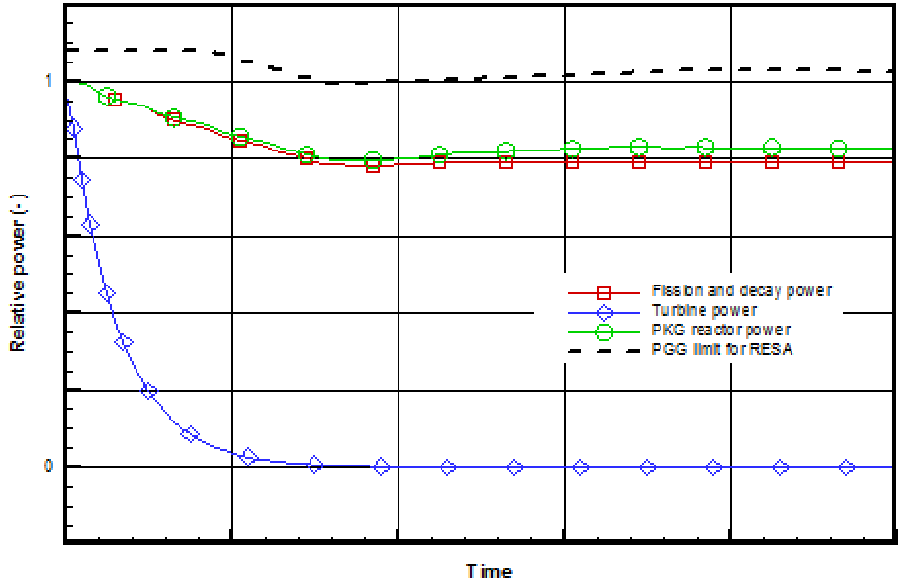
| Reactor Status | | Case A and Case B |
|---|---|---|
| Power | | 100% |
| Moderator tank average temperature | | Nominal (170°C) |
| Core condition | | Equilibrium (BEQ) |
| **I&C Status** | **Case A** | **Case B** |
| Single Failure | all systems in working order | Not Relevant |
| Repair Case | | Not Relevant |
| Emergency Power Mode | | No |
| Consequential Failure | | No |
| Control System Failure | | MS max pressure control |
| Limitation System Failure | | No |
| Reactor Trip | First signal | First signal if it does not occur in Case A and second signal if occurs in Case A |
| Operator action demanded | - | No, until plant is stabilized in a safe condition |

# Turbine Trip - Case A

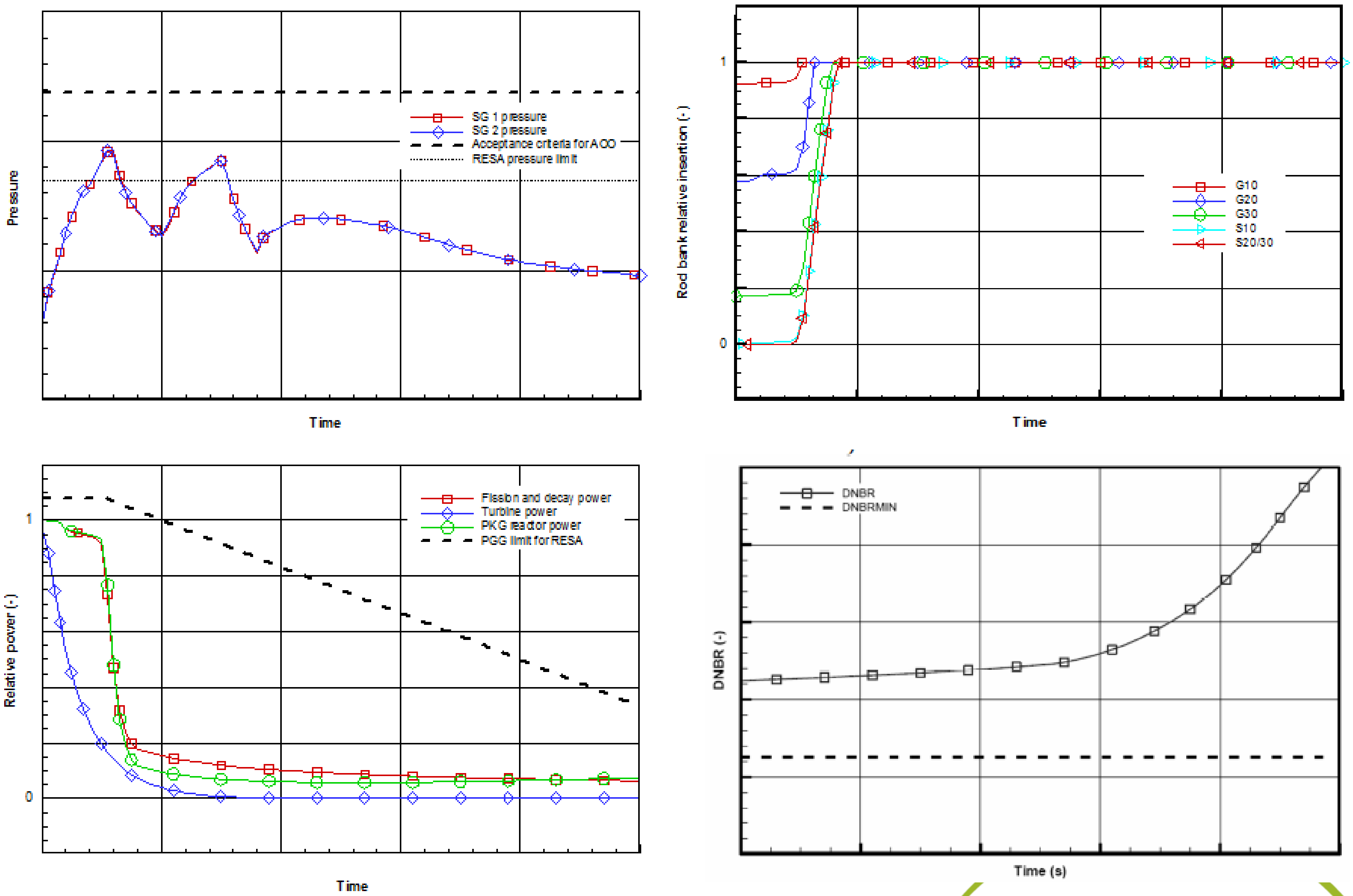


# Turbine Trip - Case B

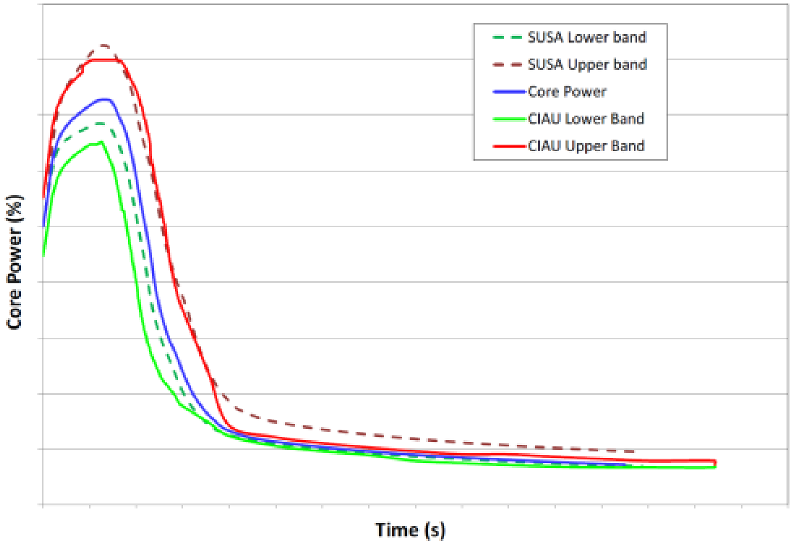


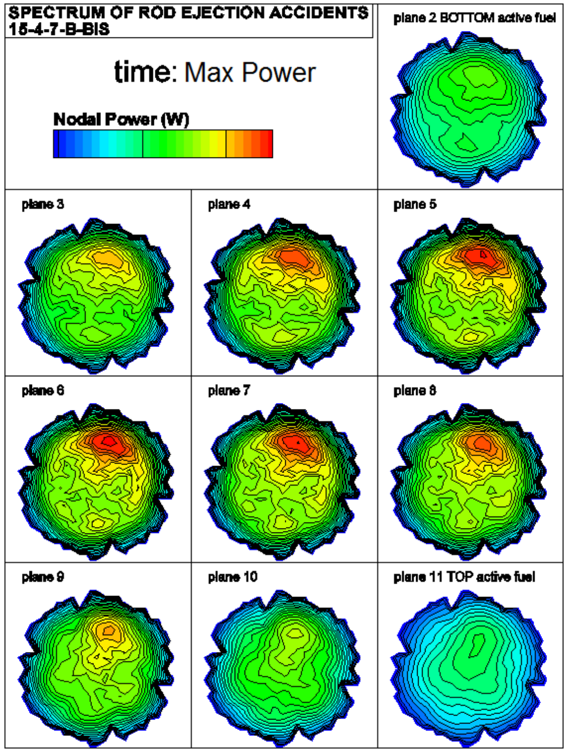
# DBA: Control Rod Ejection Scenario

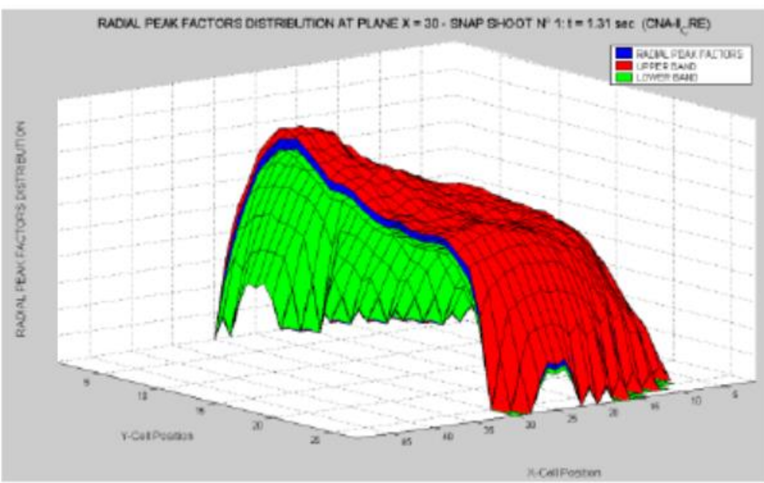
- The Control Rod Ejection Scenario (DBA, CSA, FSAR Ch. 15.4.7)
  - 280 channels Relap5/3D © nodalization coupled NESTLE
  - Case A: turbine bypass system behavior from 60 channels/Dynetz coupled nodalization
  - Two different Uncertainty evaluation Approaches (CIAU-TN & GRS-SUSA)
- Acceptance criteria
  - Average fuel hot spot enthalpy should be less than 230 cal/g for irradiated fuel
  - Cladding Temperature < 1200 °C
  - RCS pressure shall stay below 120% of design pressure
  - Secondary side pressure shall stay below 120% of design pressure

| **Reactor Status** | **Case A and Case B** | |
|---|---|---|
| Power | 100% | |
| Moderator tank average temperature | Nominal (170°C) | |
| Core condition | Equilibrium (BEQ) | |
| **I&C Status** | **Case A** | **Case B** |
| Single Failure | Not relevant | Two way valve of KBA-40 spraying |
| Repair Case | Not relevant | One KBA-80 Pump |
| Emergency Power Mode | No | Yes |
| Consequential Failure | No | Stuck rod No 6 |
| Control System Failure | No | No |
| Limitation System Failure | No | No |
| Reactor Trip | No failure of the first signal | Failure of the first signal |
| Operator action demanded | No, until plant is stabilized in a safe condition | |

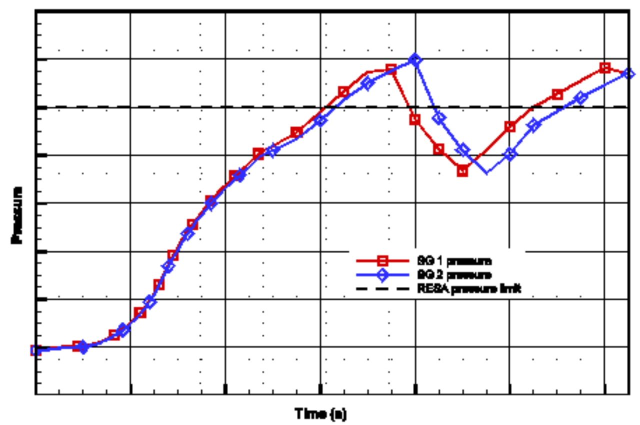
# Control Rod Ejection - Case B




d) Radial peaking factors at power peak instant (half surface).

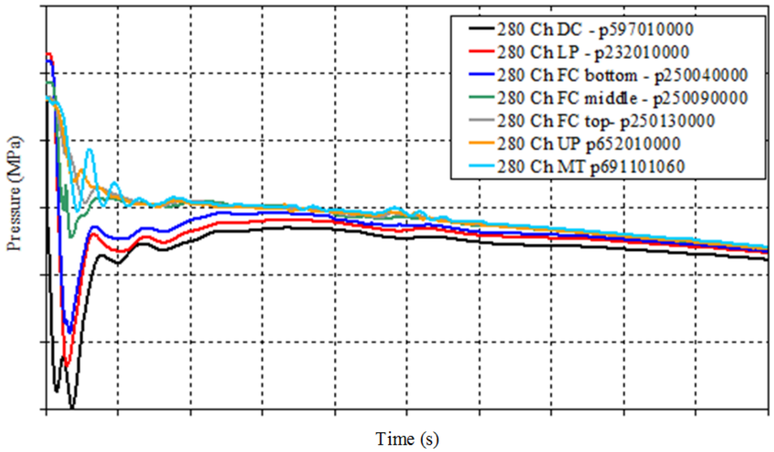


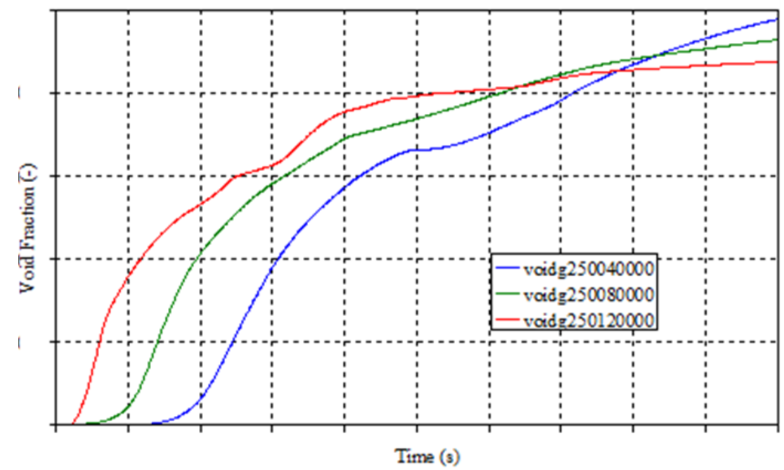
# SBDBA: 2A-LOCA in Cold Leg Scenario

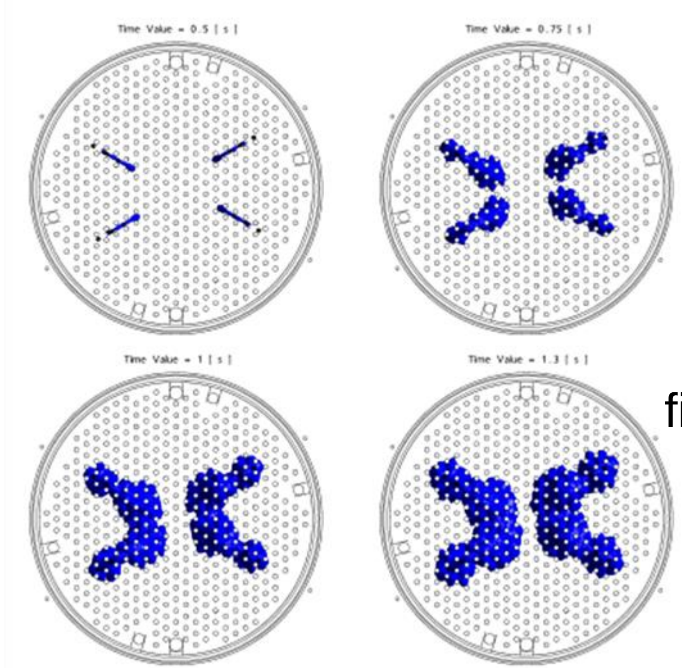
- The Double Ended Guillotine Break LOCA (2A-LOCA) in Cold Leg (SBDBA, CSA/RCA/CBA, FSAR Ch. 15.6.5.2.3.1)
  - Different break sizes (0.1A-2A), location and opening time investigated
  - Main objective: TPP, PCT, PCP, JND and JDJ performance

- Main computational tools (EM/CSA)
  - 280-ch (and 451-10nk): first few seconds of the transient with the highest detail allowed by the computational tools. Reactor power → 60-ch nodalization
  - 60-ch\ I&C-AT2 Dynetz: transient evolution and system performances
  - Moderator tank and Boron Lances: boron diffusion (Ansys-CFX)
  - Containment: RELAP (and Melcor) nodalization

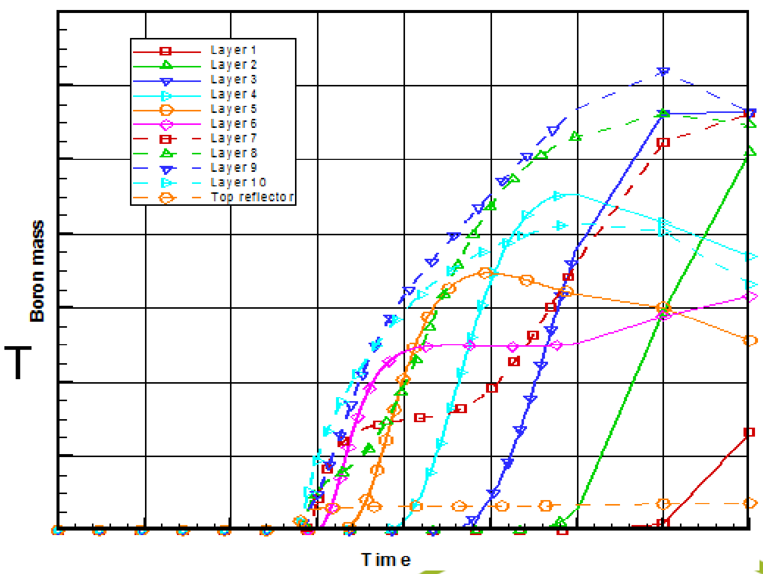
# 2A-LOCA in Cold Leg



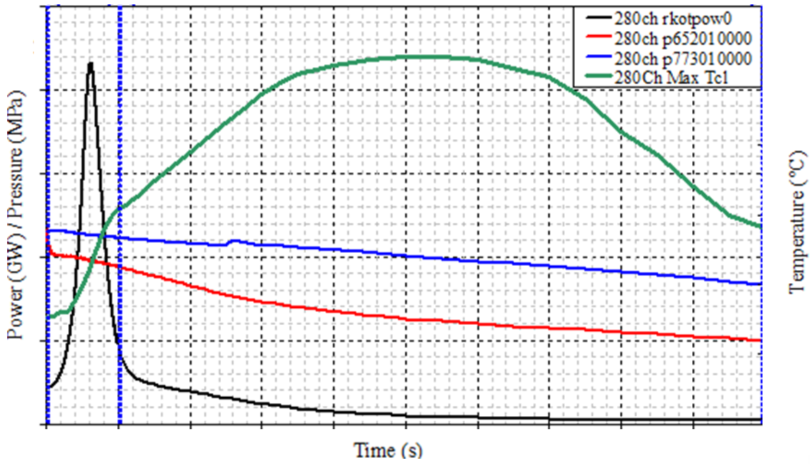



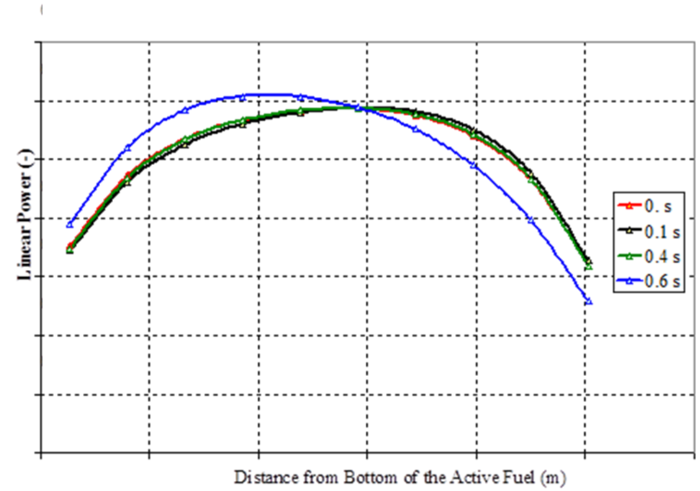



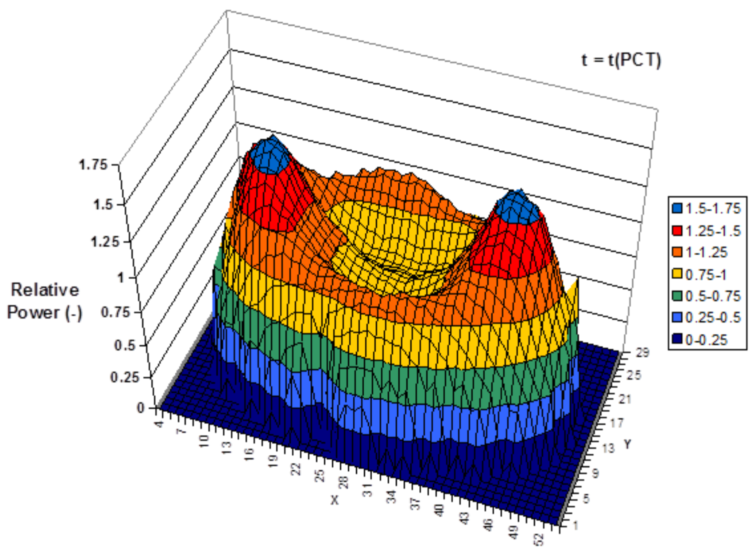

CFD to fictitious MT

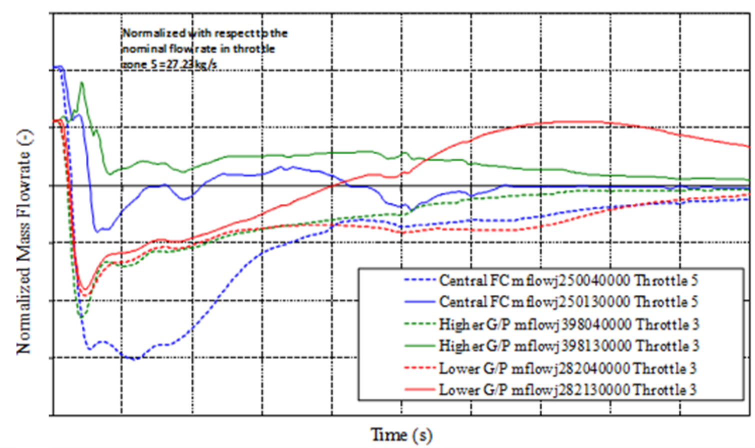


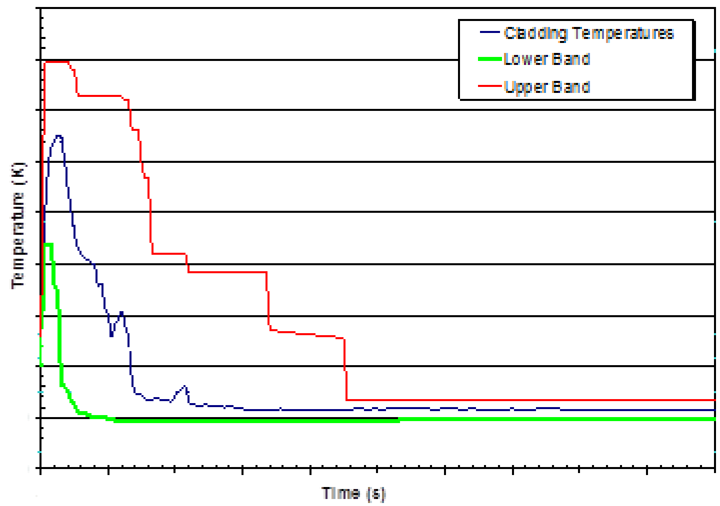
# 2A-LOCA in Cold Leg



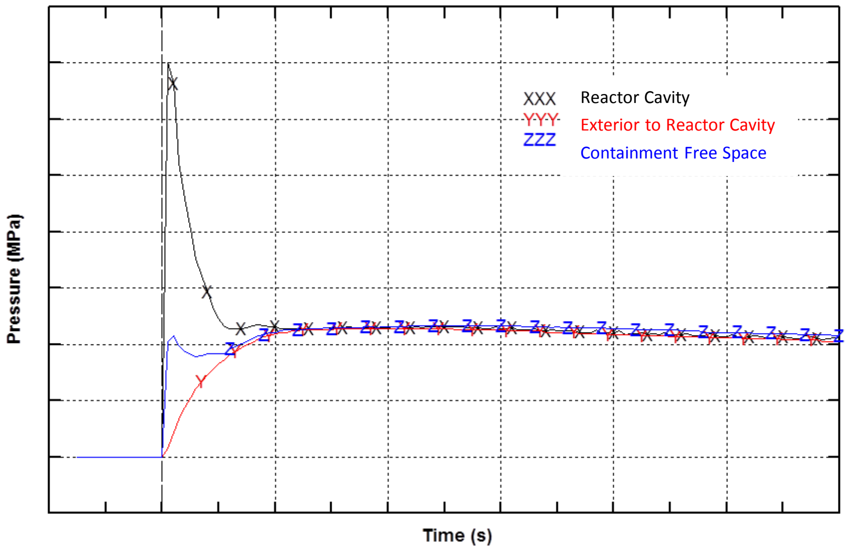



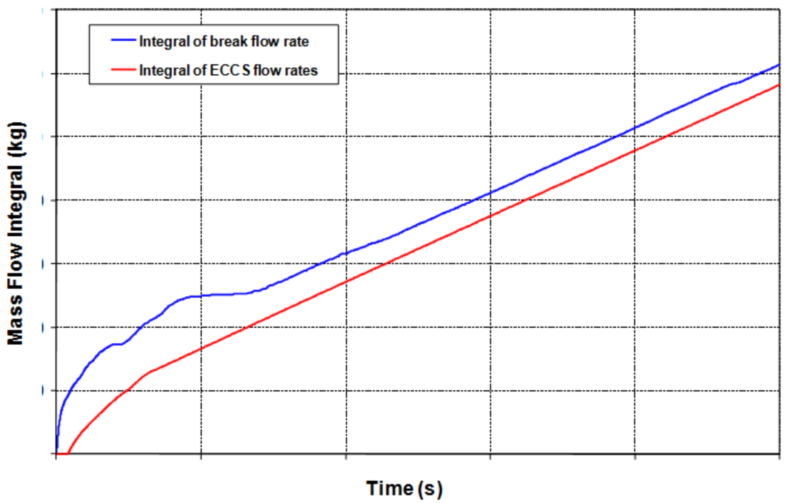





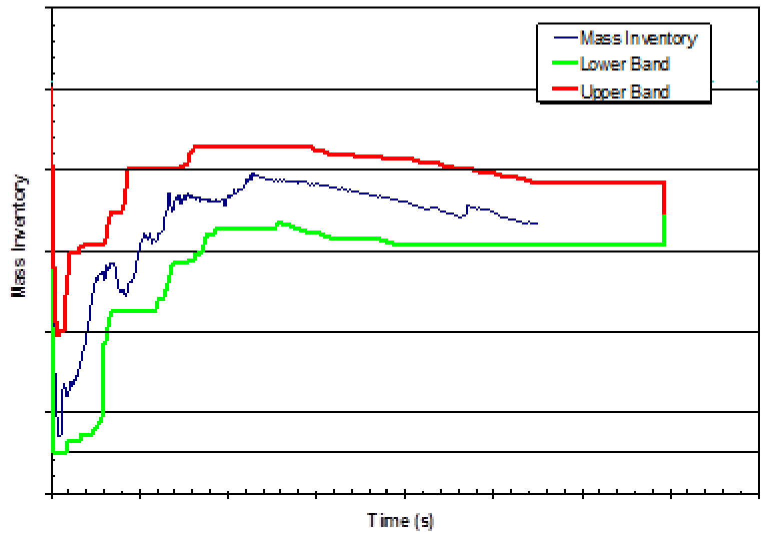
Cladding Temperatures
Lower Band
Upper Band
Temperature (K)
Time (s)

XXX Reactor Cavity
YYY Exterior to Reactor Cavity
ZZZ Containment Free Space
Pressure (MPa)
Time (s)

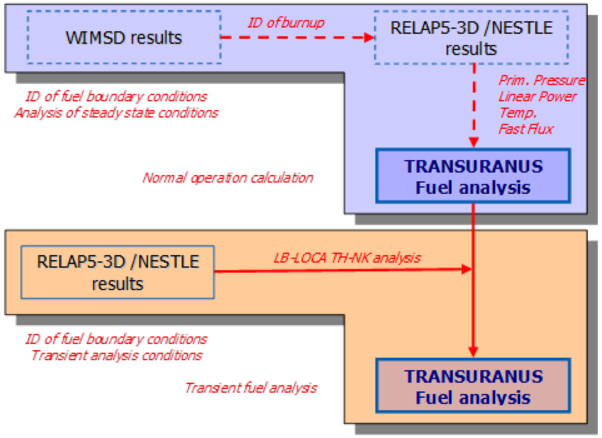
Integral of break flow rate
Integral of ECCS flow rates
Mass Flow Integral (kg)
Time (s)

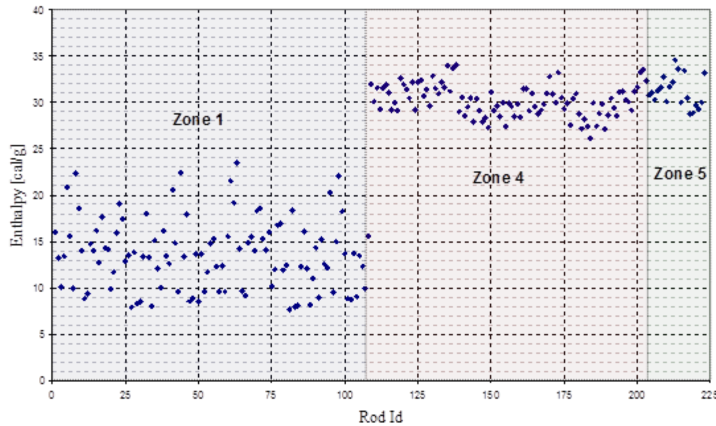



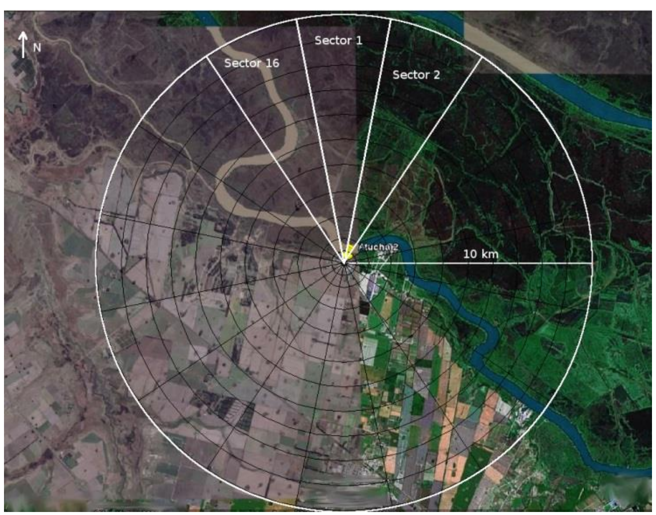
Mass Inventory
Lower Band
Upper Band
Mass Inventory
Time (s)

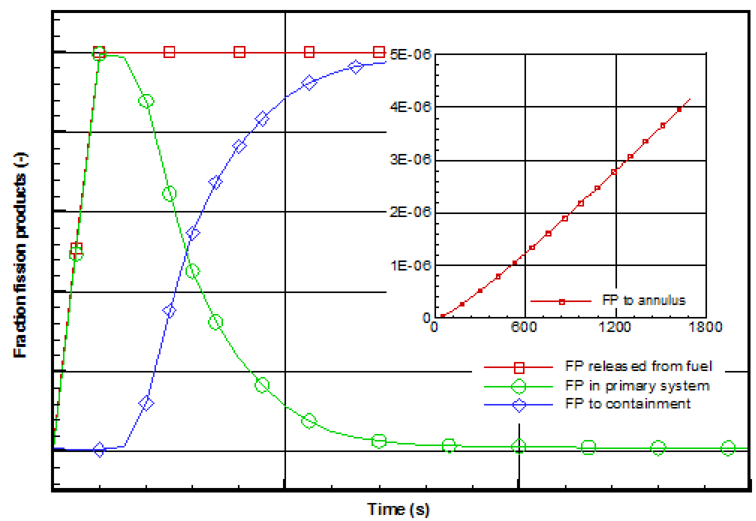
# 2A-LOCA in Cold Leg

- EM/CBA → TRANSURANUS (451 calculations), BIC from 280\451 channels calculations
- EM/RCA → MCNP-Origen, 60chan(transport of FP), CONT-R, MACCS2



- BEPU approach for the Chapter 15 of FSAR presented – Atucha-II PHWR
- To adopt and to prove (to the regulatory authority) an adequate quality for the computational tools
  - Selection of PIE
  - Several computer codes and nodalization (including I&C, 3DNK, CFD)
  - Coupling and interconnection among the codes
  - Specific issues coming from the specific design of Atucha-II
  - Qualification process (SCCRED)
- To account for the uncertainty
  - CIAU and CIAU-TN
- Seven years of activity involving more than 30 scientists and recognized international experts
  - Atucha-II licensed by ARN on May 29, 2014
  - **First criticality on June 3, 2014**