



NUCLEAR RESEARCH GROUP SAN PIERO A GRADO (GRNSPG)
NUCLEAR AND INDUSTRIAL ENGINEERING (NINE)



Activities and Perspectives for cooperation with CTMSP

A. Petruzzi, F. D'Auria

Innovations in Nuclear Technology 2012 Brazil: Challenges and Opportunities

**Auditorio Mario Covas, Escola Politécnica da Universidade de São Paulo (EPUSP)
São Paulo, Brazil, December 10-11, 2012**

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GRNSPG-NINE COMPETENCES, TECHNOLOGIES AND ACTIVITIES

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BEPU APPROACHES AND CHALLENGE IN THE CURRENT LICENSING OF NPP



PART-1

GRNSPG-NINE COMPETENCES, TECHNOLOGIES AND ACTIVITIES



GRNSPG-NINE Mission

The *San Piero a Grado Nuclear Research Group (GRNSPG)*

was created in **December 2003**

to maintain and improve the Italian competences

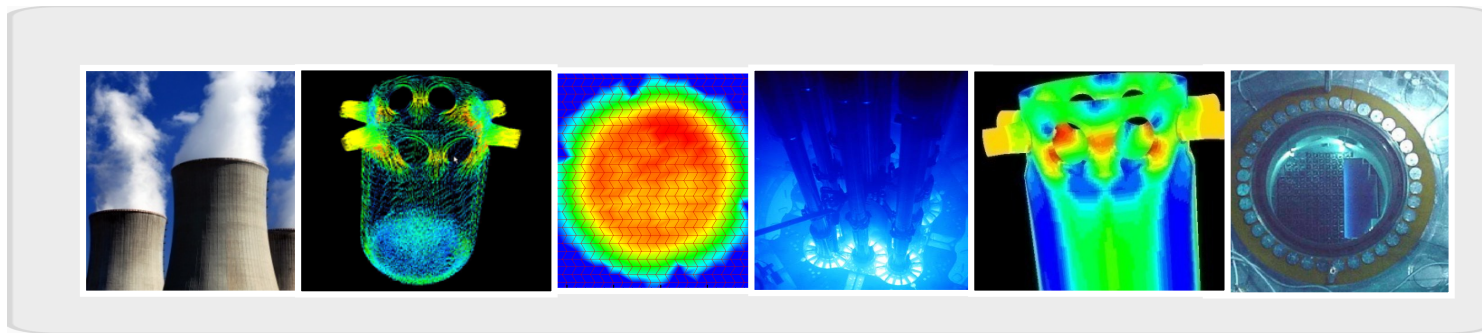
in the field of the nuclear technology,

performing **R&D, Engineering Services and Training activities,**

according to the tradition of the

Department of Mechanics, Nuclear and Production Engineering (DIMNP)

and of the *University of Pisa (UNIFI)*





GRNSPG-NINE Mission

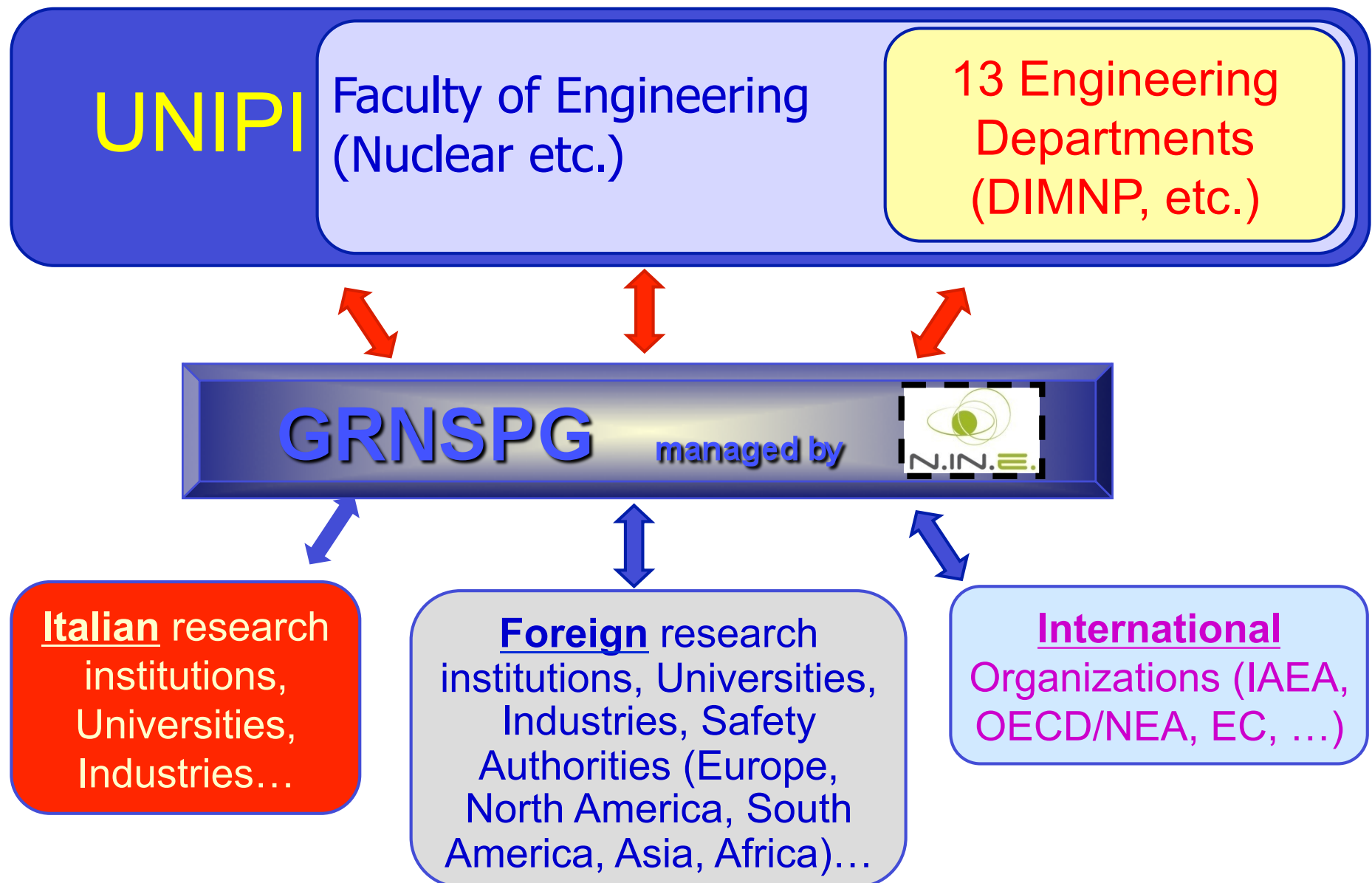


- ❑ A **brand new company**, born in **2011** *within* the GRNSPG and with the auspices of Prof. D'Auria
- ❑ Founded by a **group of long-term members of GRNSPG**
 - Dino Araneo, Marco Cherubini, Walter Giannotti, Daniele Melideo, Fabio Moretti, Nikolaus Muellner, Alessandro Petruzzi, Fulvio Terzuoli
- ❑ ... wishing to **enforce the “GRNSPG Project”** by providing a flexible means *to overcome some inherent limitations of UNIP* *administrative support*, and to *broaden opportunities of access to industry-oriented collaborations*
- ❑ ... while taking advantage of the **Academic background**, and keeping a key role in **project management**, in the course of **technical activities** and in the continuous technical and scientific growing process of GRNSPG





FRAMEWORK





HUMAN RESOURCES

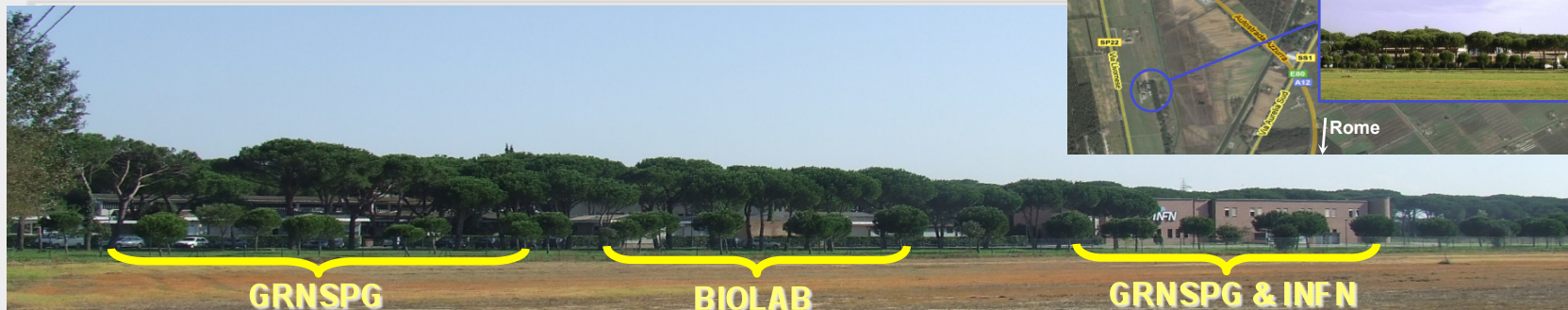
- ❑ **~60 Members** working in both technical and managerial areas
 - Full professors at UNIPi
 - Philosophy Doctors in Safety of the NPP
 - Professional Engineers (Nuclear, Mechanics, Aerospace)
 - Others (Physicists, Information Technology experts, ...)
- ❑ **Full-time collaborators**
Young and Senior Experts (engineers and other specialists)
- ❑ **Partial-time collaborators**
foreign researchers (from Regulatory Bodies, Civil and Military Research Institutions, Electric Utilities of Brazil, India, Russia, Argentina, Bulgaria, France, Slovakia, USA...) hosted for long periods (6-12 months)





HEADQUARTERS

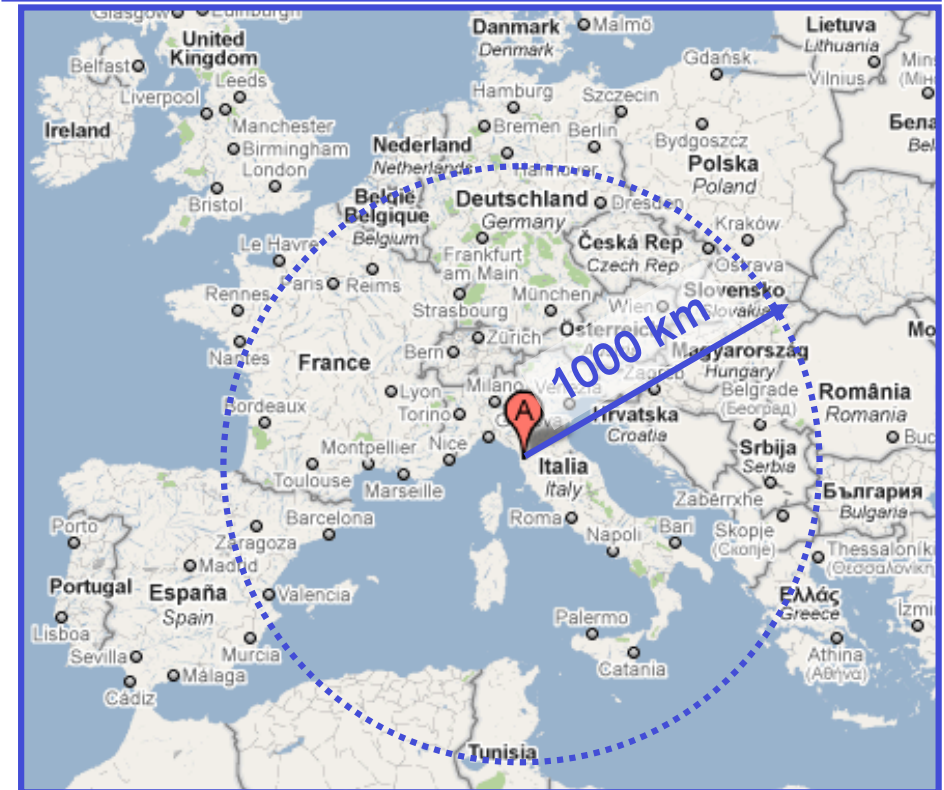
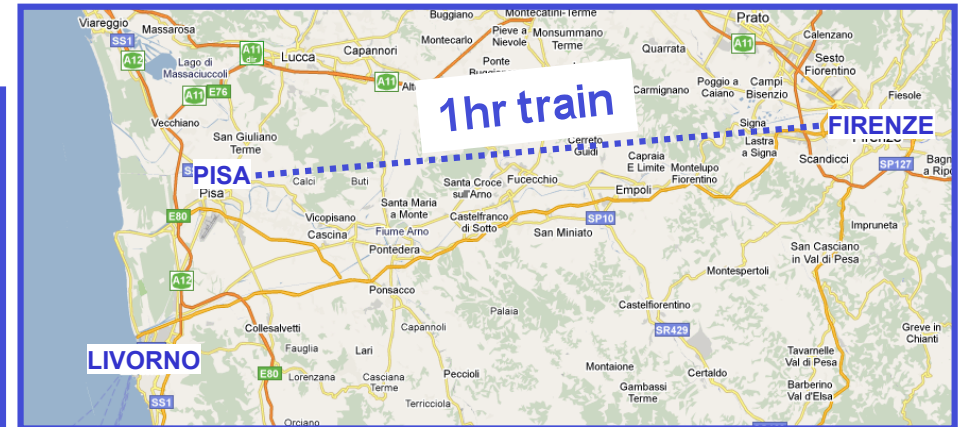
- ❑ Location: San Piero a Grado, in the land near Pisa
- ❑ ~ **2500 m²** internal space available
- ❑ High tech site, also hosting :
 - Istituto Nazionale Fisica Nucleare Laboratories (INFN)
 - Laboratories of Chemistry for Bio-active Polymer Synthesis
- ❑ Easily connected with
 - International Airport
 - Highway
 - Railway





EASY CONNECTIONS

Gruppo Ricerca Nucleare San Piero a Grado
Nuclear and Industrial Engineering





THE GRNSPG-NINE WORLD OF COMPETENCE



Gruppo Ricerca Nucleare San Piero a Grado
Nuclear and Industrial Engineering



CONCLUSIONS



□ **GNOTI Nuclear**
Gruppo di Consapevolezza e
CoNOscenza nei settori della
Tecnologia Nucleare e delle
Radiazioni Ionizzanti

□ **FONESYS**
Forum & Network of System
Thermal-hydraulic Codes in
Nuclear Reactor Safety

BACK

• Objectives:

- To promote the use of SYS-TH Codes and the application of the BEPU approaches
- To establish acceptable and recognized procedures and thresholds for V&V
- To create a common ground for discussion on possible improvements and advancements in code use and development

• Members:

- VVT Technical Research Centre of Finland
- Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), France
- AREVA NP SAS, France
- Gesellschaft für Anlagen und Reaktorsicherheit (GRS), Germany
- Gruppo di Ricerca Nucleare San Piero a Grado / University of Pisa, Italy
- Korea Atomic Energy Research Institute (KAERI), Republic of Korea
- Korea Institute of Nuclear Safety (KINS), Republic of Korea
- Idaho National Laboratory (INL), USA

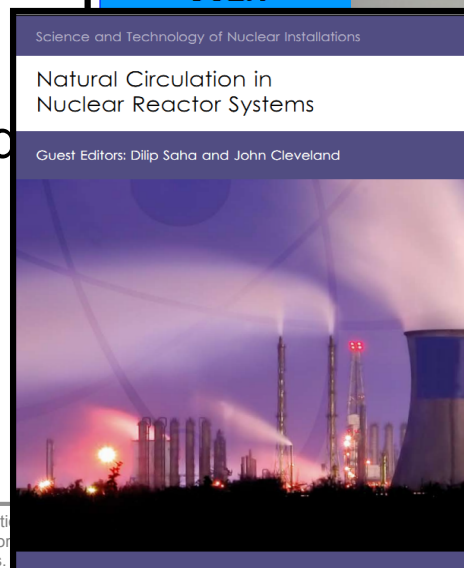
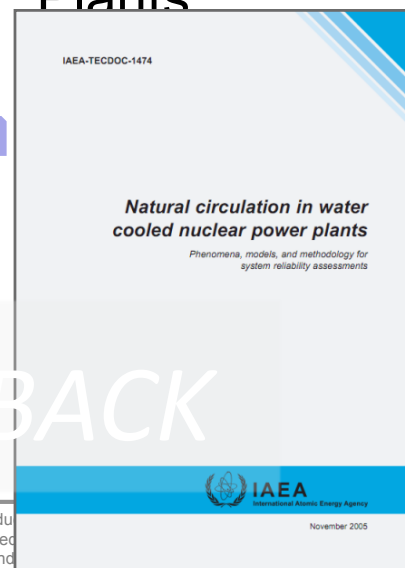


GRNSPG-NINE EDUCATION AND TRAINING



- **3D S.UN.COP** – Seminar and training on Scaling, UNcertainty and 3D COuPled code calculations in nuclear technology (www.GRNSPG-NINE.ing.unipi.it/3dsuncop)

- **IAEA-UNIPi Training on Natural Circulation Phenomena and Modelling in Water Cooled Nuclear Plants**



- Trieste, ICTP/IAEA framework
June 27- July 2, 2004
- Trieste, ICTP/IAEA framework
June 25-29, 2007
- Idaho Falls (ID, USA), INL/IAEA framework
May 19-23, 2008
- Trieste, ICTP/IAEA framework
June 23-27, 2008
- **Pisa, IAEA framework**
June 22-26, 2009
- Trieste, ICTP/IAEA framework
May 17-21, 2010
- Harbin (China)
July 11-16, 2011
- Corvallis, Oregon State University
July 2012

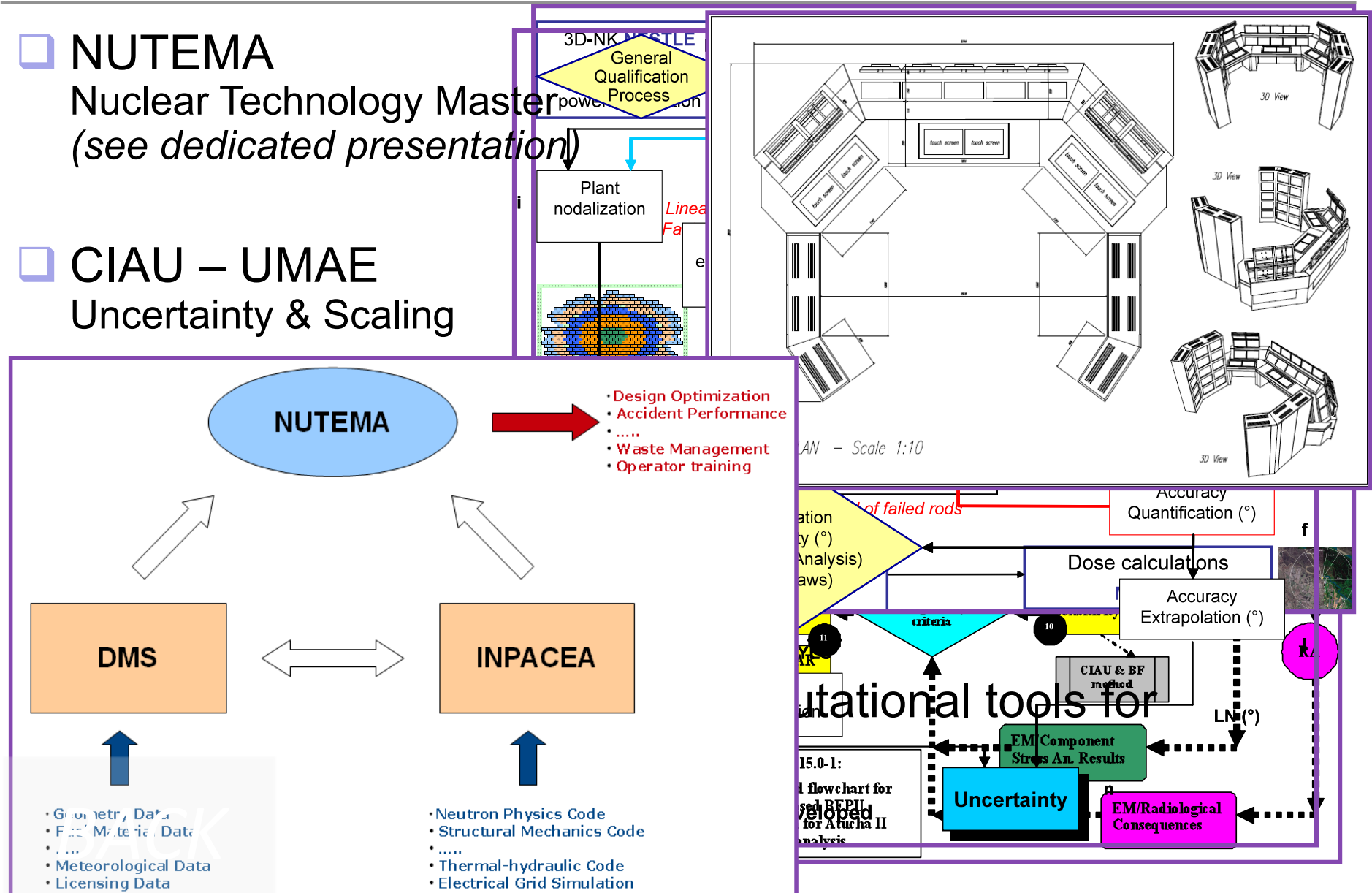


GRNSPG-NINE INNOVATION



- NUTEMA
Nuclear Technology Master
(see dedicated presentation)

- CIAU – UMAE
Uncertainty & Scaling





Cooperation with International Organizations

OECD/NEA

Organization for the Economic
Cooperation and Development
Nuclear Energy Agency

IAEA

International Atomic Energy

ENS

European Nuclear Society



Am



IAEA

OECD

Nuclear Energy

• Contributions to IAEA publications on Safety Standards:

- *Safety Reports Series SRS-23: Accident Analysis for Nuclear Power Plants (2002)*
- *Safety Reports Series SRS-52: Best Estimate Safety Analysis for Nuclear Power Plants: Uncertainty Evaluation (2008)*
- *Safety Guide SSG-2: Deterministic Safety Analysis for Nuclear Power Plants (2009)*
- *TECDOC 1474: Natural Circulation in Water Cooled Nuclear Power Plants*

• Coordinated Research Projects:

- *Heat Transfer Behaviour and Thermo-hydraulics Code Testing for SCWRs (2008-)*
- *Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors (2008-2011)*
- *IAEA CRP FUMEX-III : CRP on Fuel Modeling at Extended Burnup (2008-2012)*
- *"Innovative Methods in Research Reactor Analysis: Benchmark against Experimental Data on Neutronics and Thermalhydraulic Computational Methods and Tools for Operation and Safety Analysis of Research Reactors" (2009-2011)*

• Training:

- *Courses on Natural Circulation*

International Topical Meeting in the Safety of Nuclear Installations:
TOPSAFE 2012, 22 - 25 April 2012, in Helsinki, Finland



GRNSPG-NINE EXPERIMENTAL ACTIVITIES

Gruppo Ricerca Nucleare San Piero a Grado
Nuclear and Industrial Engineering

BACK

*Collaboration with
Nucleoeléctrica Argentina S.A.*

*Contribution to the design,
construction and operation of the
Boron Injection Test Facility (BITF) at Atucha-2 NPP*



GRNSPG EDITORIAL ACTIVITIES



- ❑ “Science and Technology of Nuclear Installations” (STNI) – Hindawi Publishing Corporation
Prof. D’Auria editor-in-chief
- ❑ “Nuclear Engineering and Design”
Prof. D’Auria long-term member of Editorial Advisory Board
- ❑ ASME
Dr Petruzzi, European Representatives from 2011



Hindawi

Hindawi Publishing Corporation

Science and Technology of Nuclear Installations


About this Journal

Submit a Manuscript

Table of Contents

Science and Technology of Nuclear Installations

VOLUME 240 (9) SEPTEMBER 2010 ISSN 0029-5493

 ELSEVIER

Nuclear Engineering and Design

An International Journal devoted to all aspects of Nuclear Fission Energy

Editor-in-Chief: Yassin Hassan
Editors: Jason Chao
Borut Mavko
Dominique Bestion


NUCLEAR ENGINEERING AND DESIGN

TOPICAL ISSUE

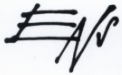
Experiments and CFD Code Applications to Nuclear Reactor Safety (XCFD4NRS)

Guest Editors
Brian L. Smith
Dominique Bestion
Yassin Hassan

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Available online at
 ScienceDirect
www.sciencedirect.com

Affiliated with the European Nuclear Society (ENS) and with the International Association for Structural Mechanics in Reactor Technology, e.V. (IASMIRT)





GRNSPG QUALITY ASSURANCE



Gruppo Ricerca Nucleare San Piero a Grado
Nuclear and Industrial Engineering

ZERTIFIKAT ♦ CERTIFICATE ♦ 認証証書 ♦ CERTIFICADO ♦ CERTIFICAT



CERTIFICATO

Nr 50 100 9924

Si attesta che / This is to certify that
IL SISTEMA QUALITÀ DI
THE QUALITY SYSTEM OF

UNIVERSITA' DEGLI STUDI DI PISA
DIREZIONE AMMINISTRATIVA

GRUPPO DI RICERCA NUCLEARE SAN PIERO A GRADO (GRNSPG)

SEDE LEGALE:

SEDE OPERATIVA:

LUNGARNO A. PACINOTTI 43-44
I-56126 PISA (PI)

VIA PROVINCIALE LIVORNESE 1291
I-56122 SAN PIERO A GRADO (PI)

È CONFORME AI REQUISITI DELLA NORMA
HAS BEEN FOUND TO COMPLY WITH THE REQUIREMENTS OF

UNI EN ISO 9001:2008

Riferirsi al manuale della qualità per eventuali dettagli delle esclusioni
ai requisiti della norma ISO 9001:2008
Refer to quality manual for possible details of exclusions of requirements
of the norm ISO 9001:2008

Questo certificato è valido per il seguente campo di applicazione
This certificate is valid for the following product or service range

Ricerca, sviluppo, progettazione di attività sperimentali ed analisi di
sicurezza e coordinamento progetti nel settore della tecnologia nucleare
per la produzione di energia, per conto di enti ed aziende pubblici o
privati, nazionali ed internazionali. Progettazione ed erogazione di
interventi formativi nel settore della tecnologia nucleare per la
produzione di energia (EA 34, 35, 37)

Research and development, experiment design, safety evaluation and
project coordination in the field of process and nuclear reactor safety
power generation, for national and international private and public
institutions and companies. Design and provision of training in the field
of process and nuclear reactor safety power generation (EA 34, 35, 37)



Per l'Organismo di Certificazione
For the Certification Body
TUV Italia S.r.l.

Data di emissione / Issue date
2010-10-29

SGQ N° 546A SR N° 9950 PRO N° 5818
SGA N° 0182 ITA N° 0816 ISO N° 001E
SGR N° 005F

Membro degli Accordi di Mutuo Riconoscimento
RA, IR e IAF
Signatory of EA, IR and IAF Mutual Recognition
Agreements

Andrea Viti
Amministratore Delegato - CEO

Data di scadenza / Expiry date
2013-10-28

"La validità del presente certificato è subordinata a sorveglianza periodica a 12 mesi e al riesame completo del
sistema di gestione aziendale con periodicità triennale"

"The validity of the present certificate depends on the annual surveillance every 12 months and on the complete
review of company's management system after three-years"

TUV Italia • Gruppo TÜV SÜD • Via Carducci 125, Pal. 23 • 20099 Sesto San Giovanni (MI) • Italia • www.tuv.it TÜV®

In October 2010, the Quality System of
GRNSPG has been certified to comply
with the requirements of UNI EN ISO
9001:2008



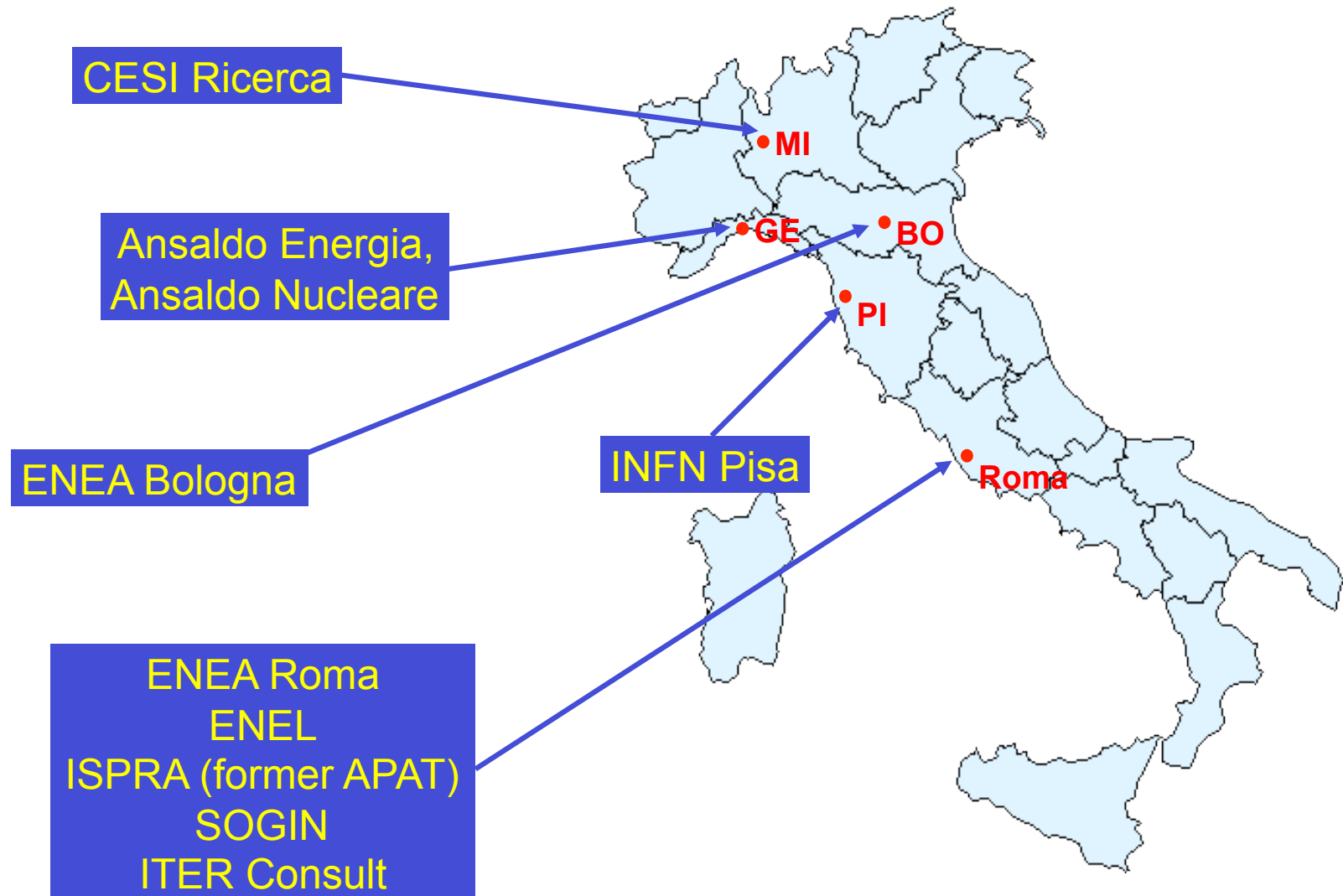
ASME NQA-1 certification in progress

BACK



GRNSPG-NINE CONNECTIONS (1/6)

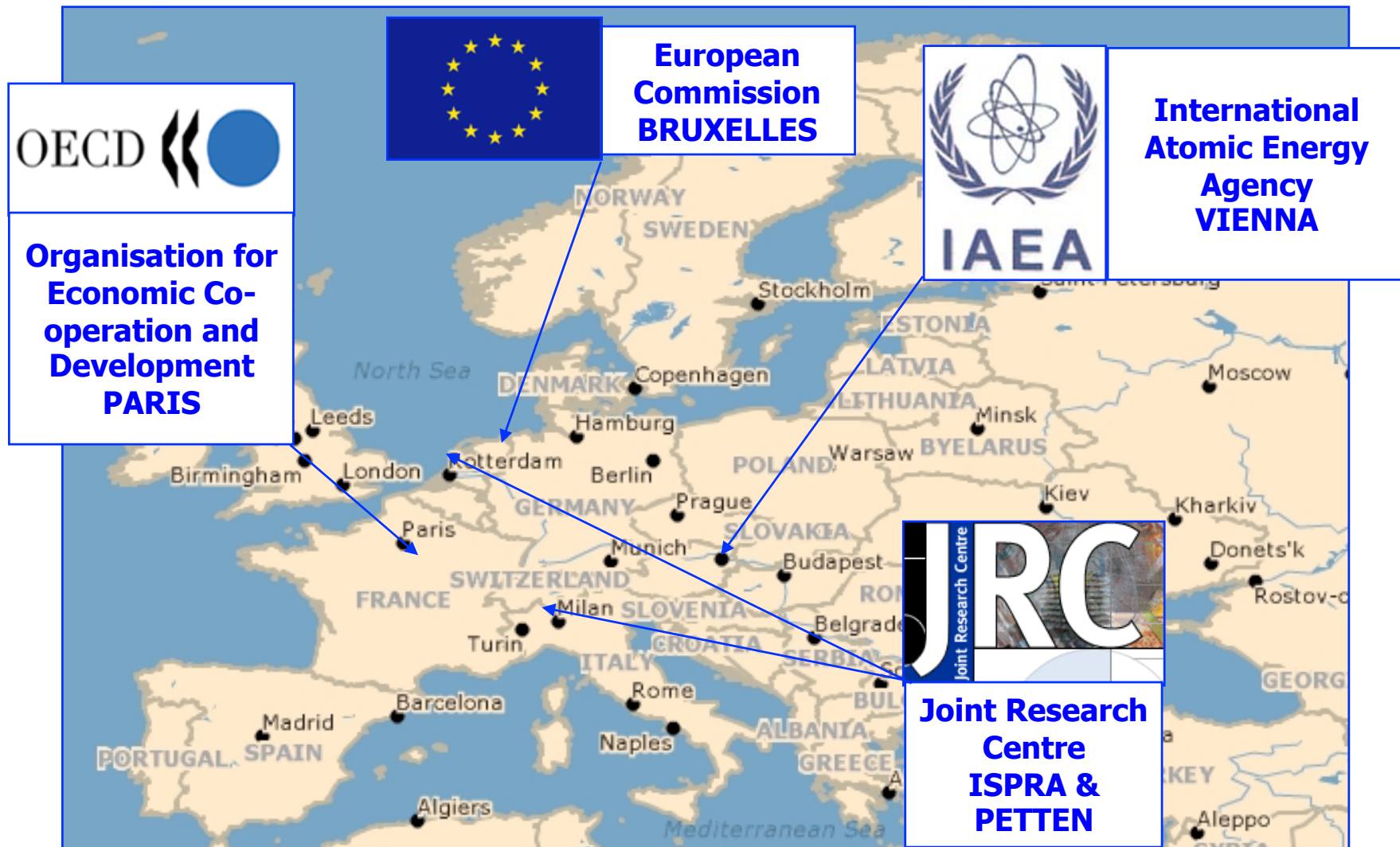
Italian Institutions and Companies





GRNSPG-NINE CONNECTIONS (2/6)

International Organizations

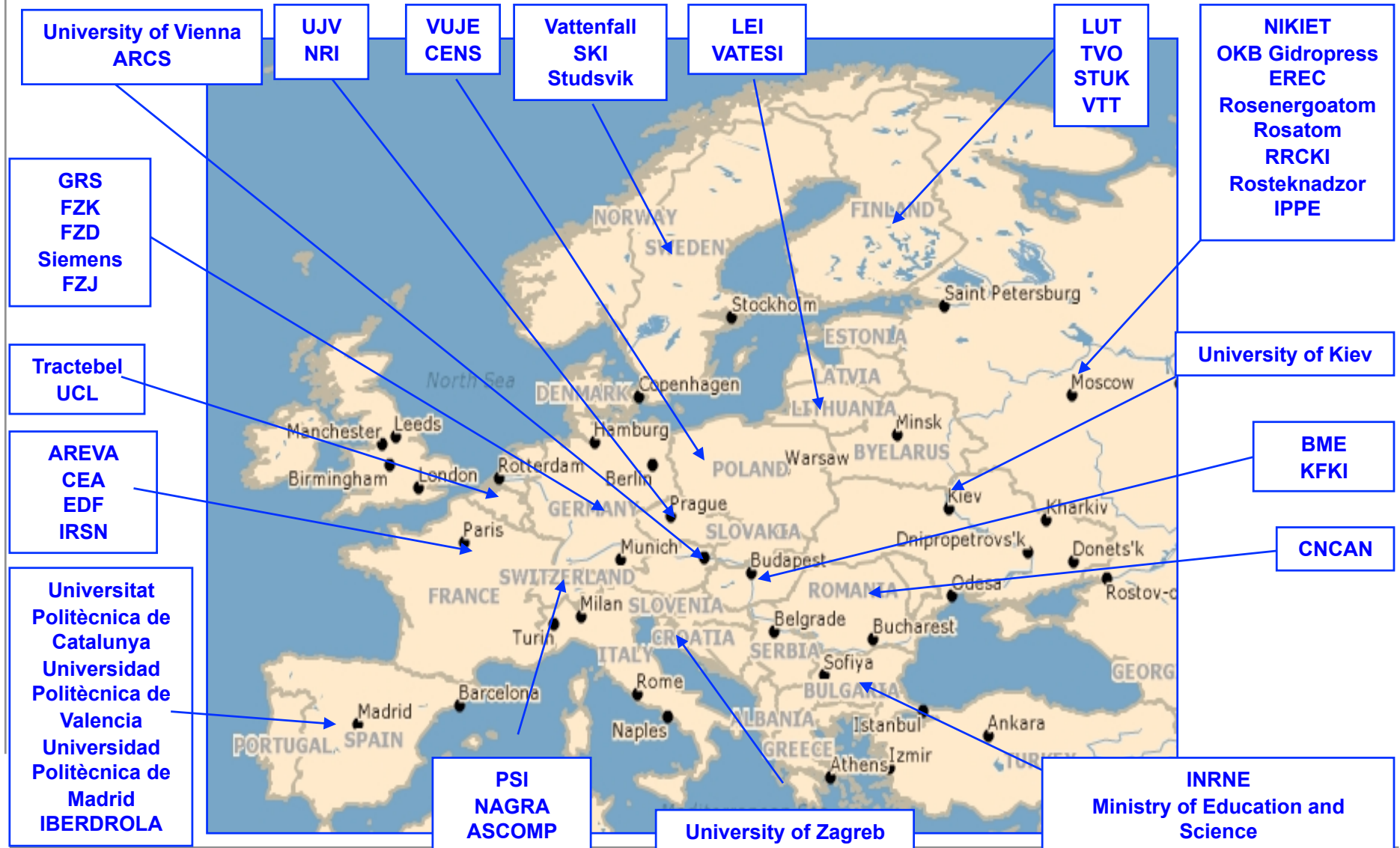




GRNSPG-NINE CONNECTIONS (3/6)

European National Companies and Organizations

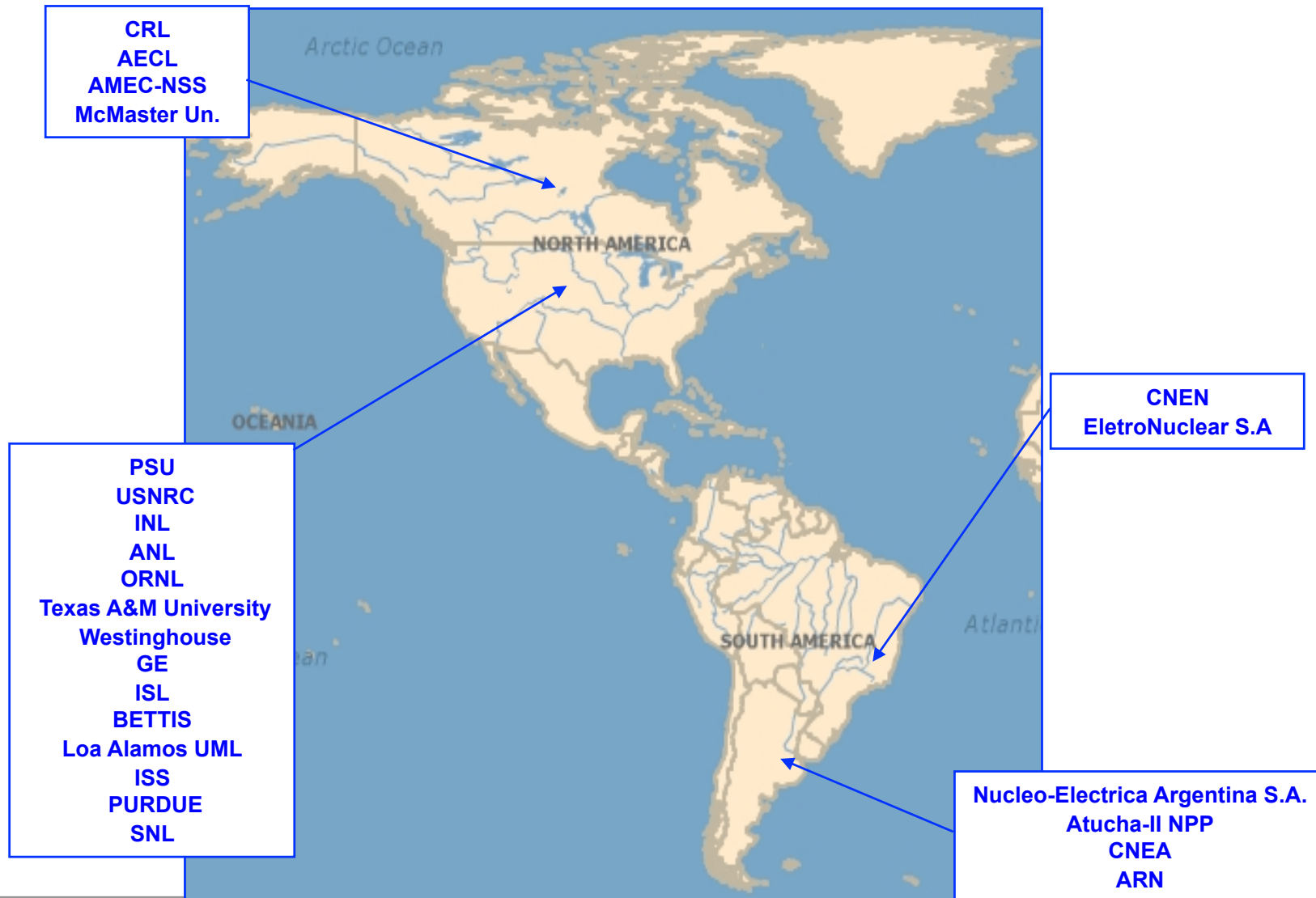
Gruppo Ricerche Nucleari San Piero a Grado
Nuclear and Industrial Engineering





GRNSPG-NINE CONNECTIONS (4/6)

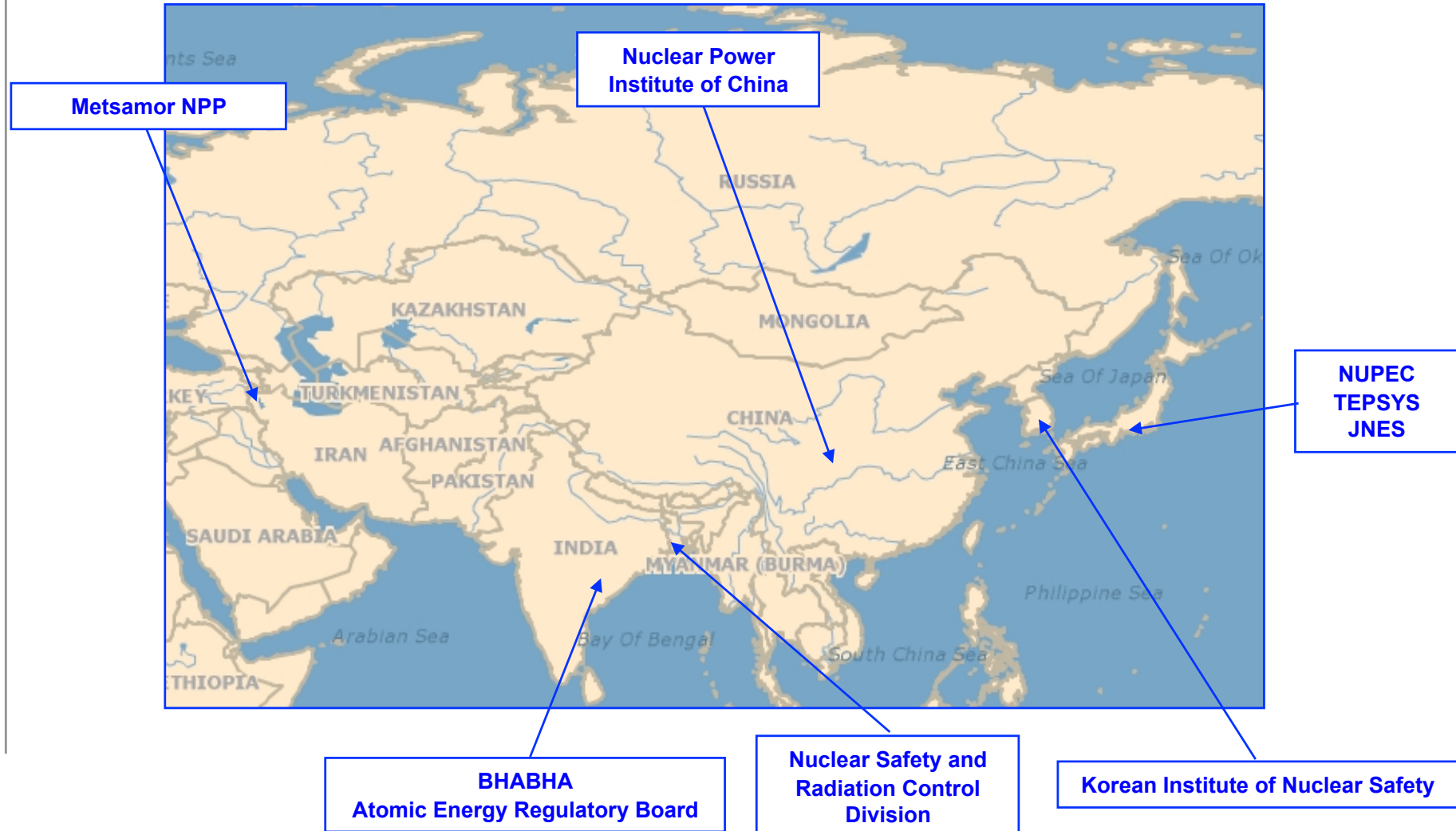
North and South America





GRNSPG-NINE CONNECTIONS (5/6)

Asia





GRNSPG-NINE CONNECTIONS (6/6)

Africa

University of Algeri
University of Tizi Ouzou

Tajoura Nuclear
Research Center

Atomic Energy
Authority





GRNSPG-NINE COMPUTATIONAL RESOURCES (1/4)

Access to the following **computational tools** (for NPP design and safety assessment)

- ☐ Thermal hydraulics codes
CATHARE2, RELAP5, RELAP5-3D®, TRACE, MARS, PIPENET
- ☐ Lattice physics codes
DRAGON, MONTEBURNS, SCALE 5.1 Package
- ☐ 3D neutron kinetics codes
PARCS, NESTLE, QUABBOX
- ☐ Particle transport codes
MCNP 5, SCALE5.1
- ☐ Fuel pin mechanics codes
TRANSURANUS, FUEL-SIM, FRAP
- ☐ Coupled system codes
PARCS-RELAP5, PARCS-TRACE, QUABBOX-RELAP5, RELAP5-FRAP, RELAP5-ANSYS, RELAP5-3D®
- ☐ Structural mechanics codes
ANSYS, PIPESTRESS, GTSTRUDL, SAP2000, SQUIRT,
- ☐ CFD codes
ANSYS CFX-11, FLUENT, TRIO_U, NEPTUNE-CFD
- ☐ Severe accident codes
MELCOR, SCDAP/RELAP5, COCOSYS
- ☐ Tools for uncertainty evaluation
UMAE, CIAU, FFTBM, TSUNAMI
- ☐ CAD and meshing tools
PRO Engineer, Autocad, ANSYS ICEM, GAMBIT
- ☐ Risk analysis and environment impact evaluation
HARIA2, IDDA, ASTRA



GRNSPG-NINE COMPUTATIONAL RESOURCES (2/4)

List of **NPP** input decks available (analyses performed)

➤ PWR

ANGRA 1&2 (LB-LOCA, ATWS)
AP-1000 (SGTR, Severe Accident)
EPR (NC Study)
Krsko (LOFW)
PWR-900 (Framatome) (SB-LOCA, CT)
Zion (LB-LOCA)
Trino (PTS)
PUN
TMI1&2
AP600
EPP

➤ BWR

Peach Bottom (Turbine Trip)
Ringhals (BWR Stability)
Caorso
Montalto di Castro
Leibstadt
Dodewaard

➤ VVER

Kozloduy 3&4 (LB-LOCA, IB-LOCA)
Kozloduy 5&6 (MSLB, MCP Trip)
Busher (LB-LOCA, SB-LOCA)
Temelin 2 (MSLB, PTS, Severe Accident)
Metsamor 2 (LOCAs, Containment, Various Transients)
Balakovo 3 (AM Procedures)
Zaporozhye 5 (PORV Stuck Open)
Mochovce 1 &2 (SB-LOCA)

➤ Others

Atucha 2 (FSAR Chapter 15)
Atucha 1 (Power Excursion)
Smolensk 3 (Multiple Tube Rupture)
Ignalina 2
CANDU-Darlington (LOF)
GCFR prototype - (Gen. IV)



GRNSPG-NINE COMPUTATIONAL RESOURCES (3/4)

List of **input decks** suitable for **code validation**
(minimum reference list – many more available)

➤ ITF-PWR & VVER

Loft, Bethsy, Lobi, Rosa-IV, Spes, Pactel, PMK, PKL, PSB-VVER, UPTF, Semiscale, ROCOM (CFD)

➤ ITF-BWR

Fist, Piperone, Rosa-III, Fix-II

➤ RESEARCH REACTORS

FRJ-2 (23 MW MTR), IAEA 10 MW (MTR), UMLRR (1 MW MTR), TRIGA Pavia (250 kW), NUR (1 MW MTR)

➤ Others

Various SETF suitable for (within the framework a general Quality Assurance Program) demonstrating threshold quality for computational tools (Boiling Channel, CCFL, Blowdown, condensation, numerics, stability, etc.)



GRNSPG-NINE COMPUTATIONAL RESOURCES (4/4)

❑ Hardware set-up:

- >200CPU Linux-cluster for parallel computing
- ~ 100 personal computers
- Fire-walled network
- 1 server for central management of network, users and data
- Data storage & back-up units

❑ Access to **CINECA** consortium resources (through UNIPI participation)

- IBM SP5 (512 processors, 3.89TFlop/s)
- IBM BCX (5120 cores, 26.6 TFlop/s)

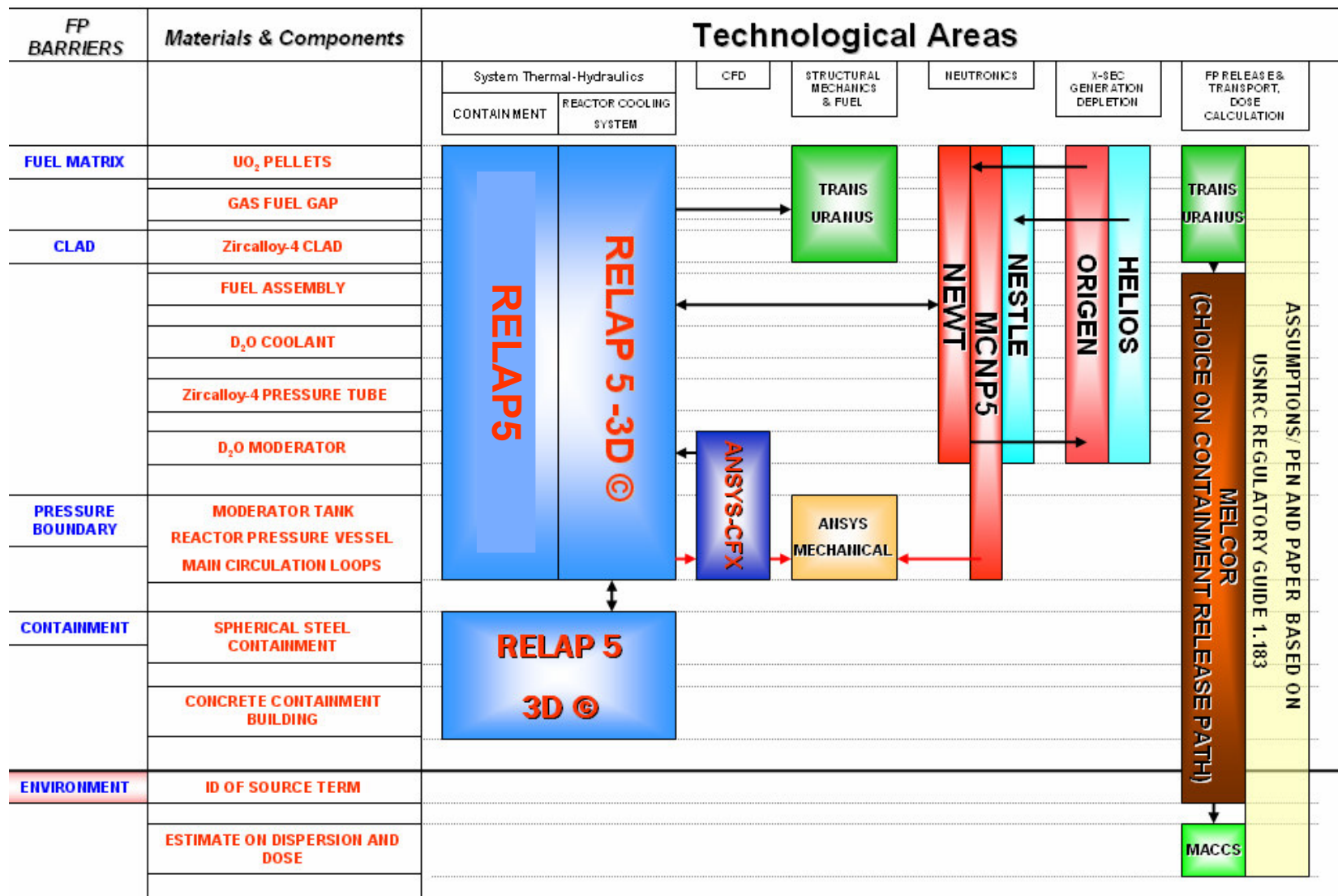
Linux-cluster for parallel computing





GRNSPG-NINE COMPUTATIONAL CODES (1/2)

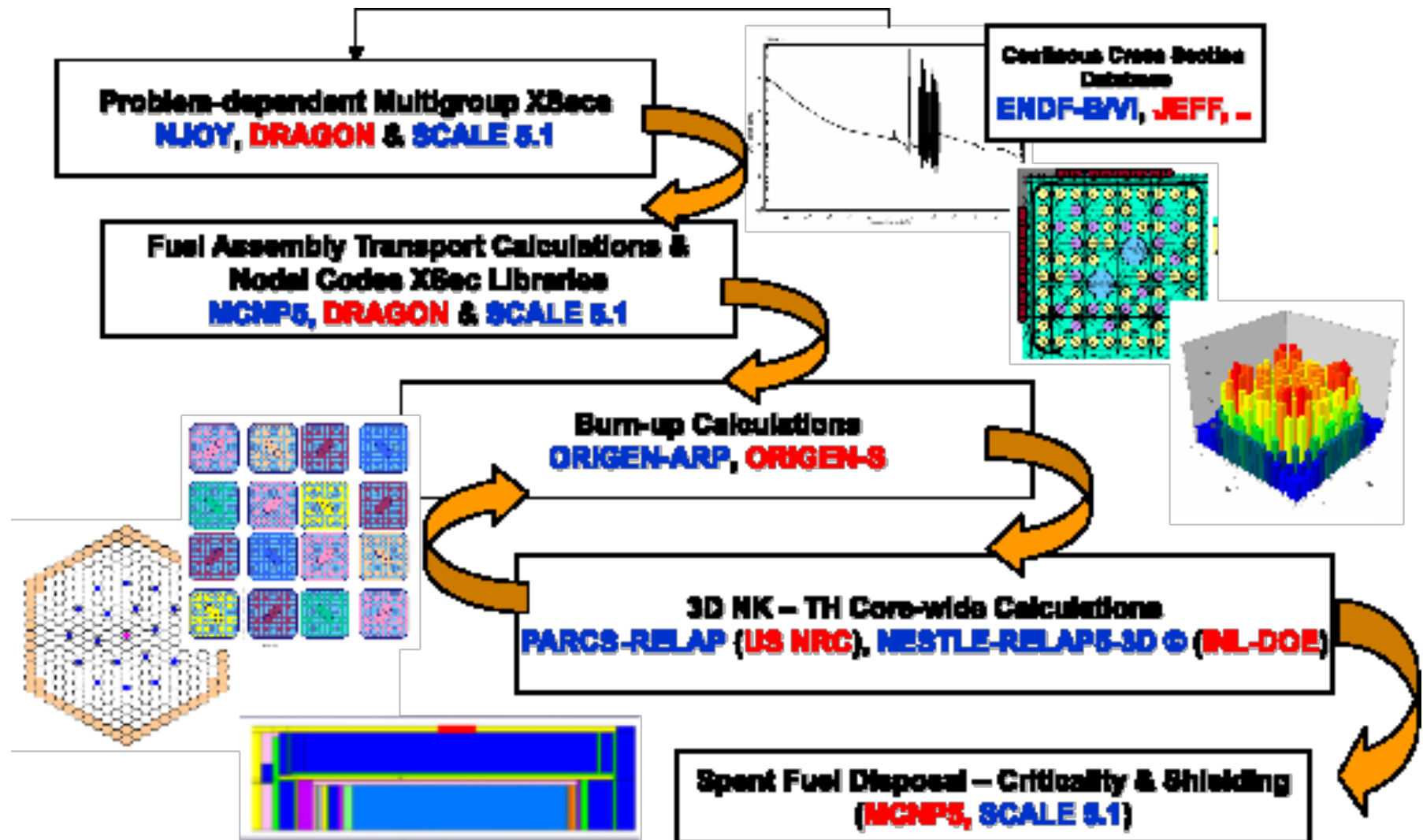
General Chain of Codes





GRNSPG-NINE COMPUTATIONAL CODES (2/2)

NK Chain of Codes





RECENT MAIN CONTRACTUAL AGREEMENTS (1/3)

Nuclear safety related activities

- ❑ **NA-SA, Argentina (2007-2014)** – “Atucha-2 platform for thermal-hydraulic design issues and deterministic safety technology” (4 agreements)
GRNSPG being in charge of the preparation of the FSAR-Chapter 15 and review of all FSAR Chapters
- ❑ **CNNC-CNPE, China (2012-2016)** – Support to develop Safety Technical Competences
- ❑ **Brazil (2012-2013)** - CHF Investigation Project
- ❑ **Brazil (2013-2014)** - Engineering services supply to perform technical studies to review the Reactor core design of the LABGENE
- ❑ **KEPCO, Korea (2012)** – Two-Phase Natural Circulation Instability Analysis for Passive Auxiliary Feed Water System (PAFS) in APR+
- ❑ **ROLLS-ROYCE, UK (2012)** – Support to develop Competences on WWER Design and Safety Analysis
- ❑ **CEA, France (2010-2011)** – Development of CATHARE model of AP1000



RECENT MAIN CONTRACTUAL AGREEMENTS (2/3)

Nuclear safety related activities

- ❑ **AMEC-NSS, Canada (2009)** – Analysis of LOF Transient in DNGS by RELAP5.
- ❑ **KINS, Korea (2008)** – Cooperative Research (Service) agreement on Advanced Thermal-Hydraulic System Code Verification
- ❑ **LEI, Lithuania (subcontract for LEI of EC contract) (2008)** – "Enhancements of VATESI and its Technical Support Organizations specialists knowledge through seminars and internships"
- ❑ **NPIC, China (2008)** – Visiting Programme (VIPRO)
- ❑ **EDF, France (2007-08)** – Collaboration follow-up, for supporting SB-LOCA analysis procedure adopted by EDF
- ❑ **AREVA, France (TACIS Project EC, 2007)** – TACIS Project for mixing investigation lower plenum
- ❑ **EDF, France (2005)** – Project addressing the boron issue in PWR
- ❑ **CEA – Cadarache, France (2005)** – Reliability of passive systems (natural circulation)



RECENT MAIN CONTRACTUAL AGREEMENTS (3/3)

Nuclear safety related activities

- ❑ **CEA – Grenoble , France (2004)** – Project for assessment and development of CATHARE
- ❑ **GIDROPRESS, Russia (TACIS Project EC, 2003-2005)** - TACIS project for Accident Management for the VVER1000 (PSB facility) and RBMK Deterministic Safety Technology
- ❑ **EC Projects (2004-2015)** – NURESIM (2004-2007), NURISP (2008-2011) Integrated Project (EU 6th FP) and NURESAFE (2013....)
- ❑ **IRSN, France (2003)** – Project related to CATHARE application in uncertainty study

Structural mechanics

- ❑ **Pressurized Thermal Shock** analysis in VVER-1000 RPV and Atucha-II
- ❑ Structural integrity analyses for Atucha-II reactor (Cooperation with NA-SA)
- ❑ **NPP piping stress analysis** [Cooperation with Ansaldo Nucleare; UNIPI-GRNSPG qualified as official supplier after QA audit]
- ❑ **Leak-Before-Break** analysis
- ❑ Analysis of **fuel and moderator mechanical behaviour** end reciprocal interaction in **RBMK reactors**



RECENT MAIN PROJECTS [NOT FUNDED]

Nuclear safety related activities

☐ OECD-NEA PROJECTS:

- ☐ BEMUSE Project (Uncertainty)
- ☐ BFBT Benchmark (Subchannel)
- ☐ PSBT Benchmark (subchannel)
- ☐ UAM (Uncertainty)
- ☐ PREMIUM (Uncertainty)
- ☐ Peach Bottom Benchmark (3D NK-TH)
- ☐ VVER1000 Coolant Transient Benchmark (3D NK-TH)
- ☐ TMI Benchmark (3D NK-TH)
- ☐ BWR Stability Benchmark (3D NK-TH)
- ☐ PKL-2 Project (CFD/TH)
- ☐ MASSLWR (SYS-TH)
- ☐ SANDIA (Fuel)
- ☐ Best Practice Guideline (CFD)

☐ IAEA Projects

- ☐ Safety Guide and TECDOC
- ☐ Reliability of Passive Systems
- ☐ Support to development of Safety Capability in New Nuclear Countries (Poland, Malaysia, Vietnam, Jordan)
- ☐ Analysis of EBR

☐ Internal Projects:

- ☐ Development of CIAU and CIAU-TN
- ☐ Assessment of RELAP5, RELAP5-3D, CATHARE codes
- ☐ Development of SCRED (Standard Consolidated Reference Experimental and Calculated Database)
- ☐ NUTEMA



OTHER ACTIVITIES

Education & Training

- ☐ Training courses on application of uncertainty methodology (CIAU)
- ☐ **3D SUNCOP seminars** (<http://www.grnspg.ing.unipi.it/3dsuncop/>)
- ☐ Training courses on reactor physics codes
- ☐ Training courses on stress analysis
- ☐ “Laurea” (MSc degree) and PhD theses in Pisa
- ☐ Tutorship of Doctorates in foreign Universities, including Barcelona, Rio de Janeiro, Tehran, Zagreb, Vienna, etc.

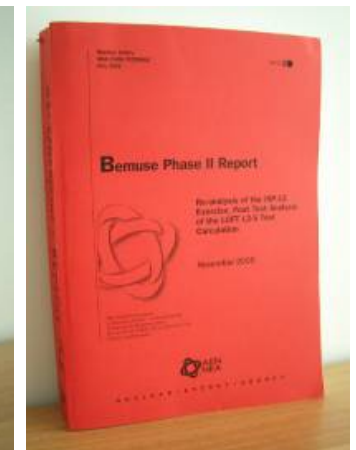
Editorial activities

International Journal: “Science and Technology of Nuclear Installations”
(*HINDAWI Publishing Corporation*) – Editor-in-Chief: Prof. D’Auria (2009-2011)



RECENT TECHNICAL-SCIENTIFIC PRODUCTION

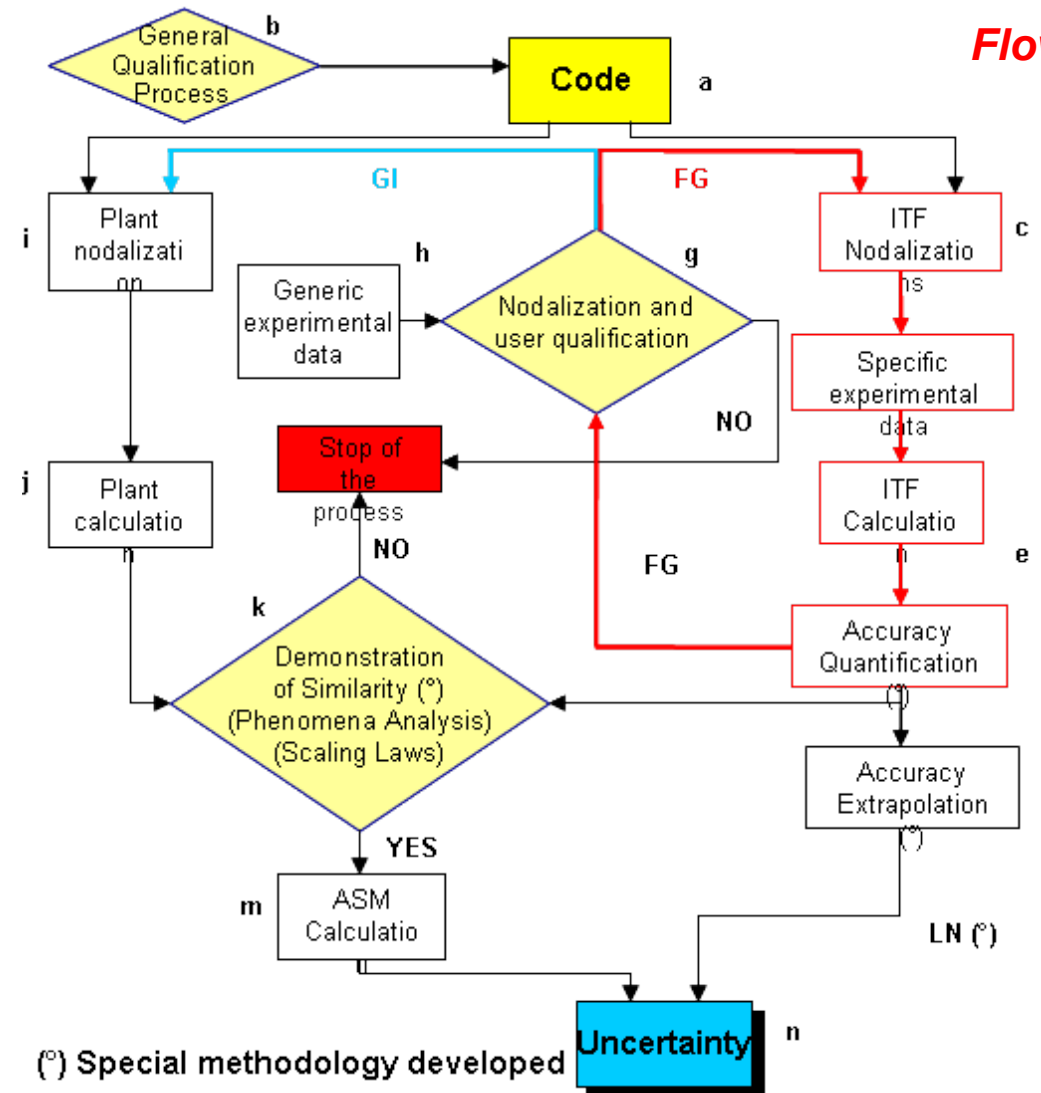
- ❑ Dozens of Papers on International Journals
- ❑ > 100 Papers in Proceedings of International Conferences
- ❑ 10 Textbooks
- ❑ > 30 Research Final Reports
- ❑ > 200 Project Reports





Scaling Analysis

Flow diagram of UMAE



(°) Special methodology developed

Qualification Procedures

STEADY STATE: TH & GEOMETRICAL PARAMETERS

QUANTITY	ACCEPTABLE ERROR (%)
1 Primary circuit volume	1 %
2 Secondary circuit volume	2 %
3 Non-active structures heat transfer area (overall)	10 %
4 Active structures heat transfer area (overall)	0.1 %
5 Non-active structures heat transfer volume (overall)	14 %
6 Active structures heat transfer volume (overall)	0.2 %
7 Volume vs. height curve (i.e. "local" primary and secondary circuit volume)	10 %
8 Component relative elevation	0.01 m
9 Axial and radial power distribution (°°)	1 %
10 Flow area of components like valves, pumps orifices	1 %
11 Generic flow area	10 %
(*)	
12 Primary circuit power balance	2 %
13 Secondary circuit power balance	2 %
14 Absolute pressure (PRZ, SG, ACC)	0.1 %
15 Fluid temperature	0.5 % (°°)
16 Rod surface temperature	10 K
17 Pump velocity	1 %
18 Heat losses	10 %
19 Local pressure drops	10 % (°°)
20 Mass inventory in primary circuit	2 % (°°)
21 Mass inventory in secondary circuit	5 % (°°)
22 Flow rates (primary and secondary circuit)	2 %
23 Bypass mass flow rates	10 %
24 Pressurizer level (collapsed)	0.05 m
25 Secondary side or downcomer level	0.1 m (°°)

(*) The % error is defined as the ratio:

$$\frac{|\text{reference or measured value} - \text{calculated value}|}{\text{reference or measured value}}$$

The "dimensional error" is the numerator of the above expression

(*) With reference to each of the quantities below, following a one hundred s "transient-steady-state" calculation, the solution must be stable with an inherent drift < 1% / 100 s

(°°) Additional consideration needed

(**) And consistent with power error

(°) Of the difference between maximum and minimum pressure in the loop

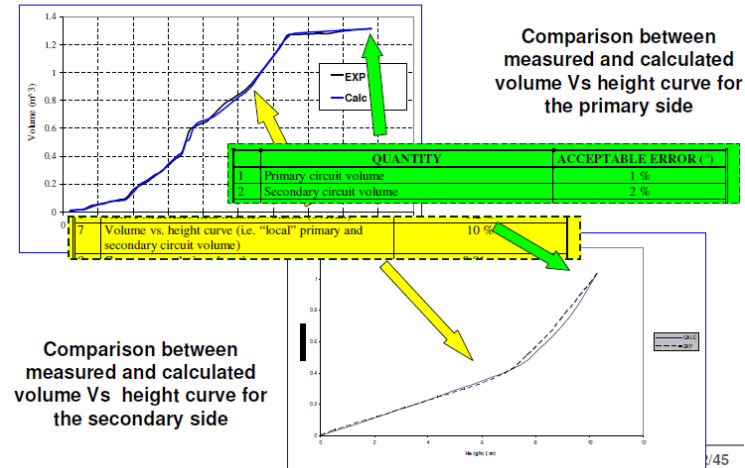
(°°) And consistent with other errors

21/45

FULFILLING CODE-NODALIZATION ACCEPTANCE CRITERIA (SS AND 'ON-TRANSIENT', INCLUDING APPLICATION OF FFTBM) DOES NOT IMPLY 'NO ERROR'.

RATHER THIS IMPLIES 'CONTROLLED ERROR' SUCH THAT EXPECTED ERRORS ARE BOUNDED BY THE UNCERTAINTY.

Volume Vs Height Curve



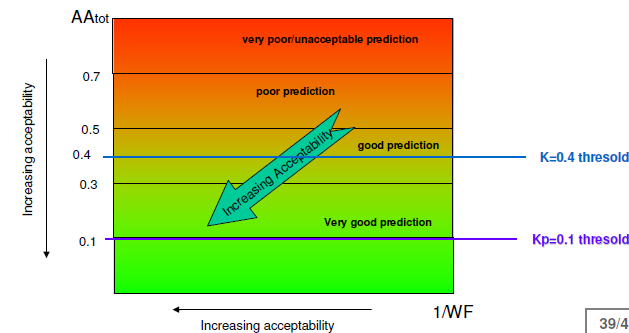
QUANTITATIVE ACCURACY EVALUATION by FFTBM

Factors for the definition of an acceptability criterion

- (AA)_{tot} for the whole transient
- average amplitude AA

$$AA_{tot} < K$$

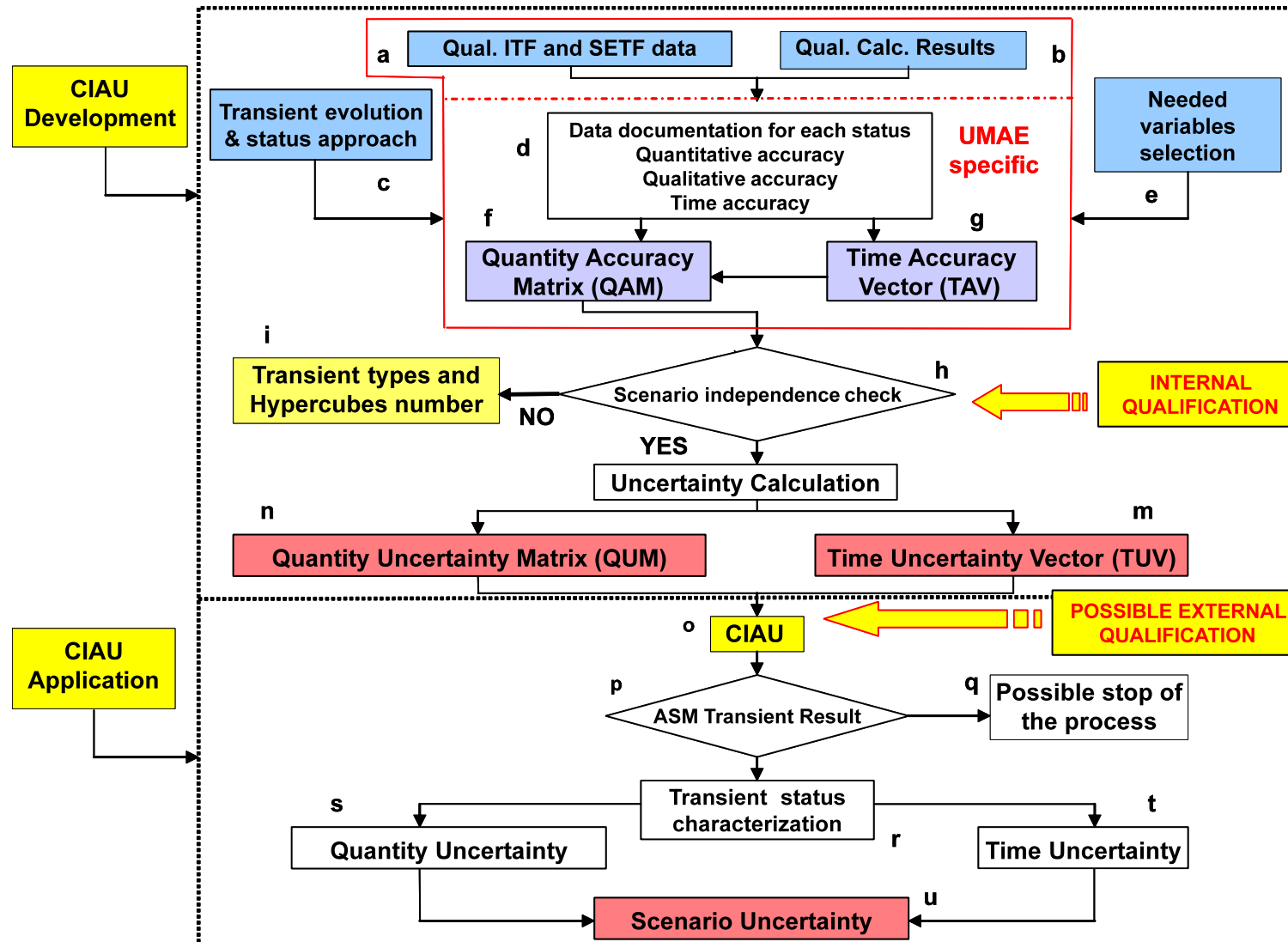
$$AA < K_p$$



39/45

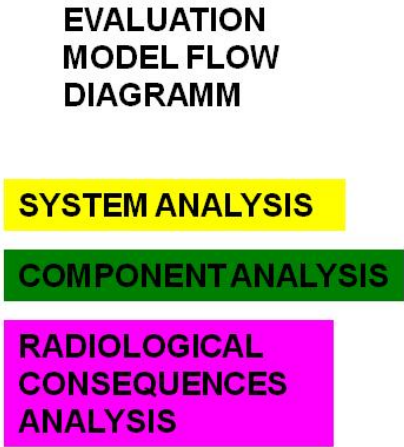


The CIAU Uncertainty Evaluation tool





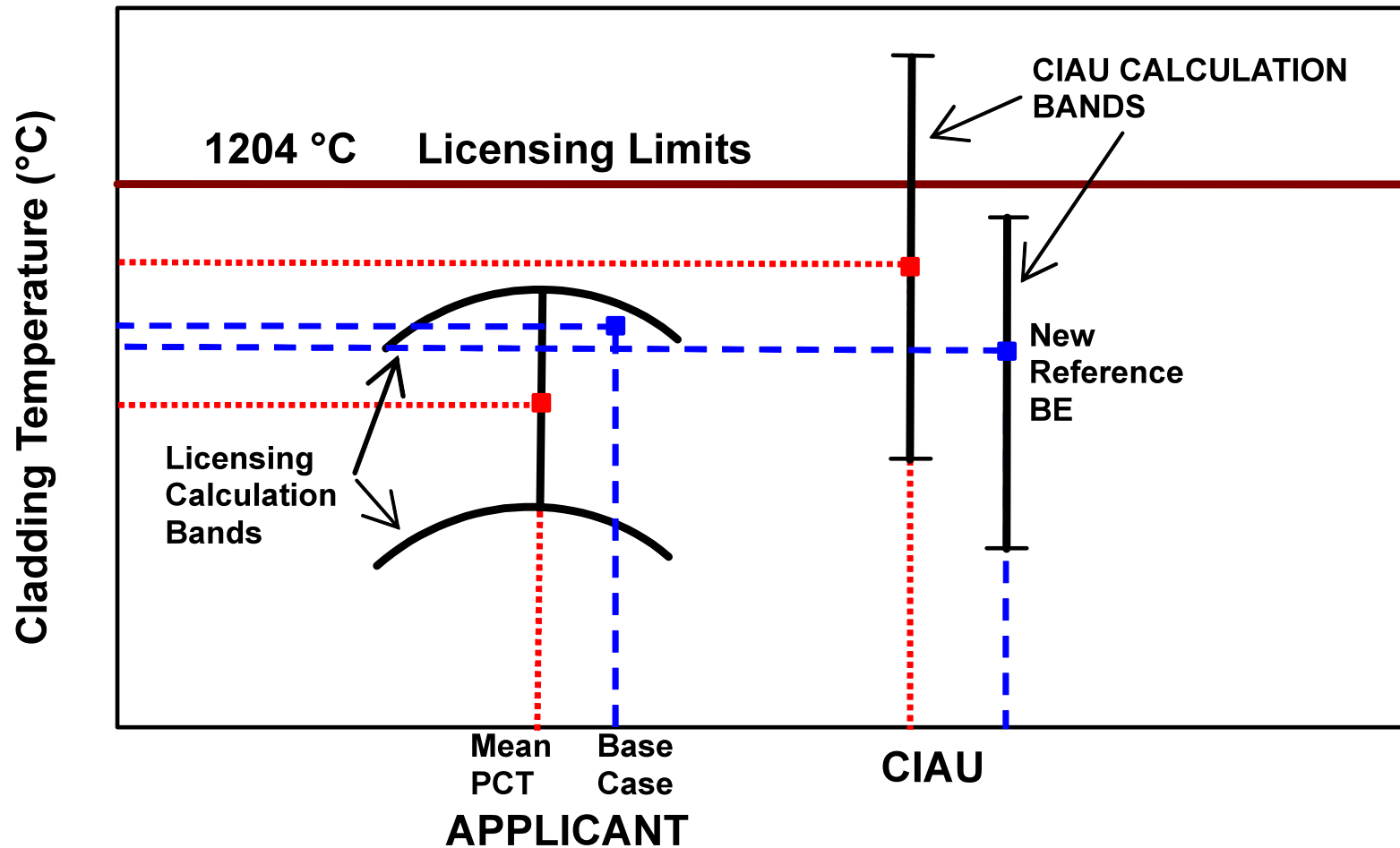
Use of “Best Estimate Plus Uncertainty” approach in Atucha-2 licensing





GRNSPG-NINE Technological Knowledge (5/26)

Angra-2 LBLOCA Uncertainty Evaluation

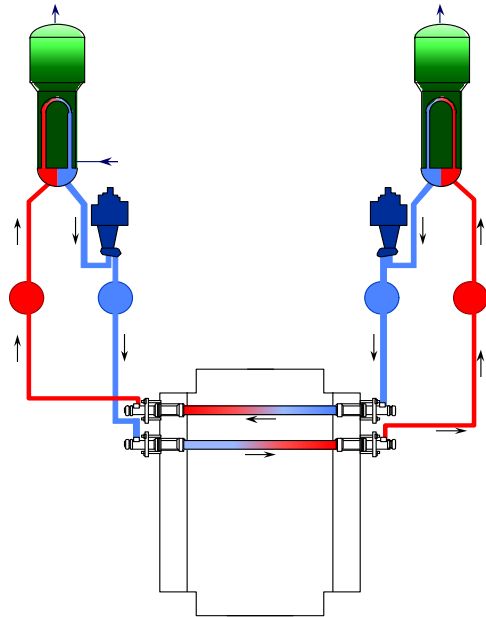




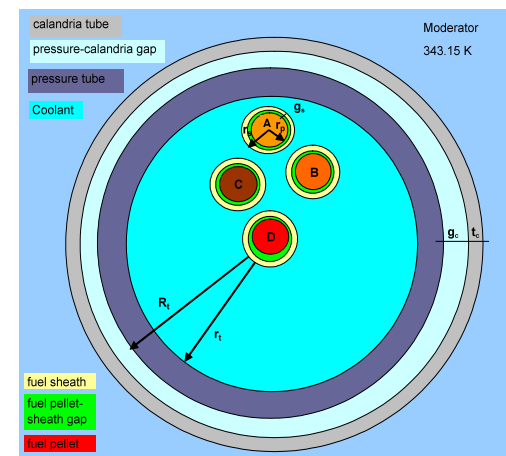
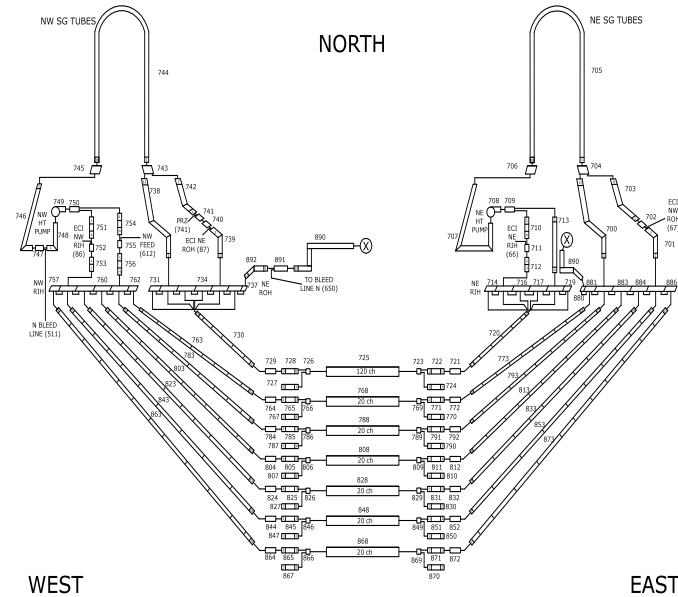
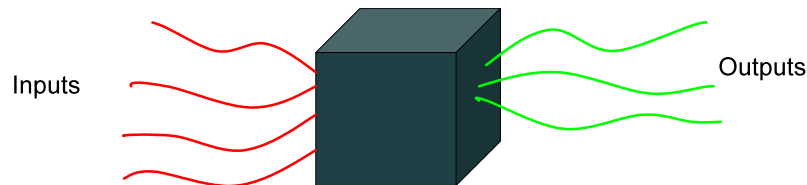
GRNSPG-NINE Technological Knowledge (6/26)



CANDU: Darlington LOF Transient by R5



Each control system is treated as a
“black box” in RELAP5-CS



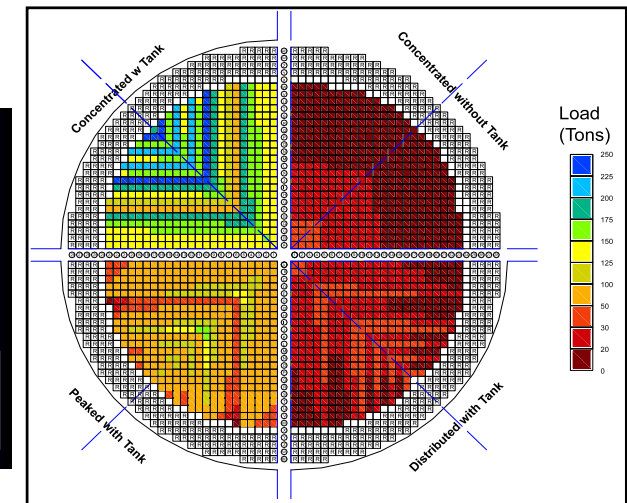
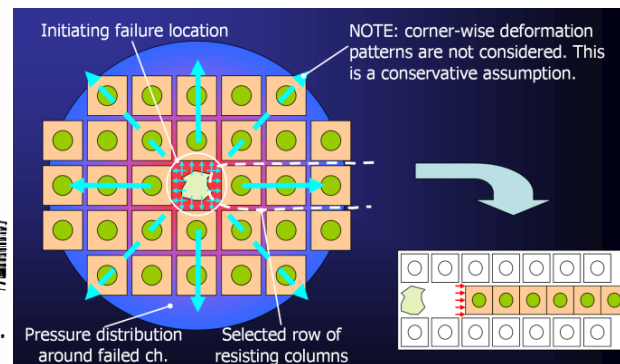
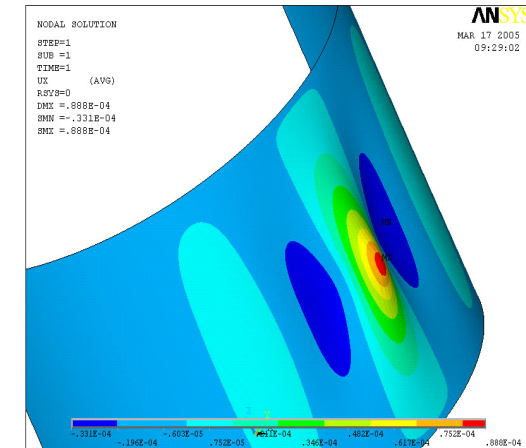
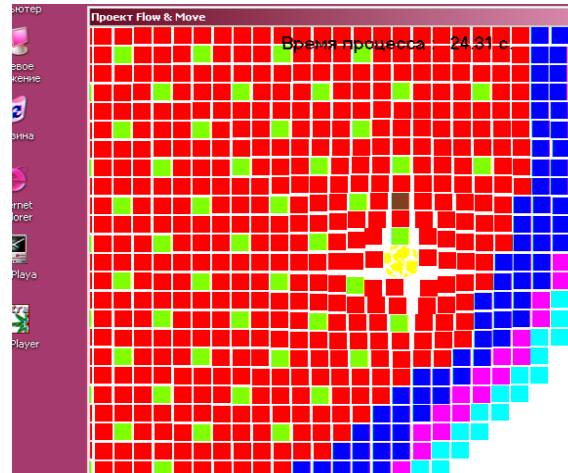
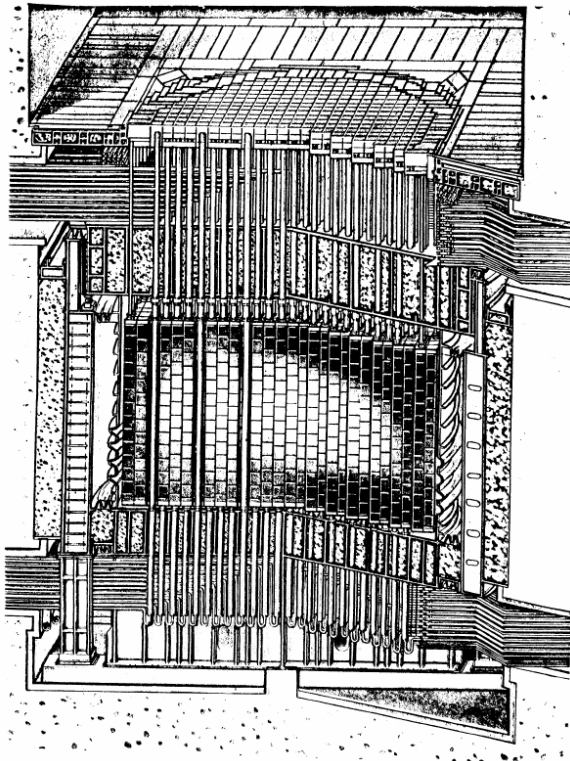
- (A) Outer ring
- (B) Intermediate ring
- (C) Inner ring
- (D) Center ring

RING	# Fuel Element	Power Rating	Power Ring
Outer	18		0
Intermediate	12		0
Inner	6		9
Center	1		0
	37		1.0000



RBMK Reactors

The “Multiple Pressure Tube Rupture” issue

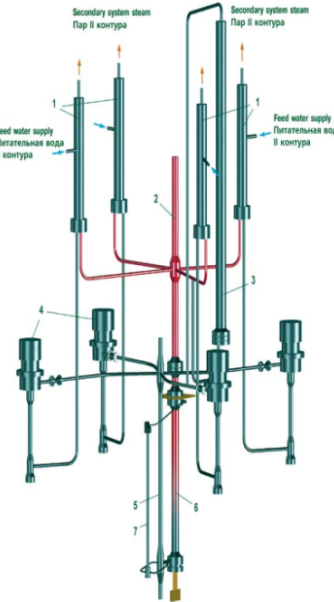
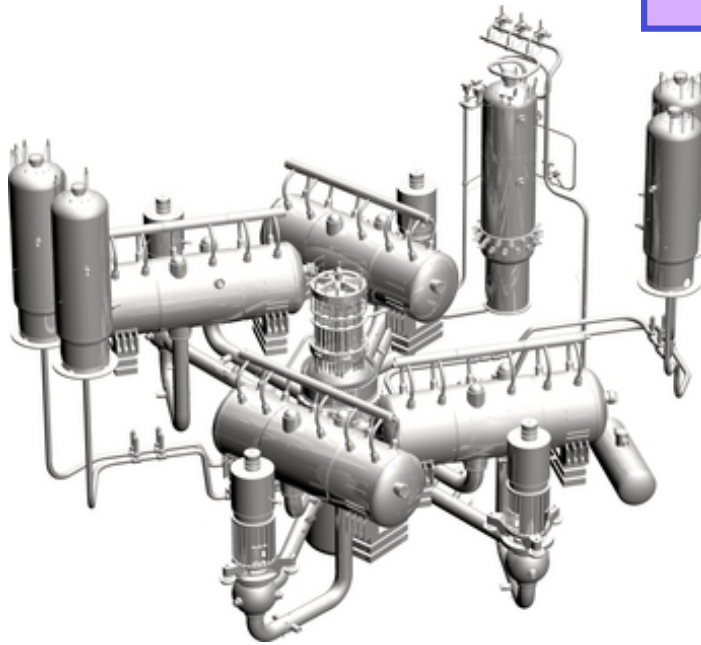




GRNSPG-NINE Technological Knowledge (8/26)



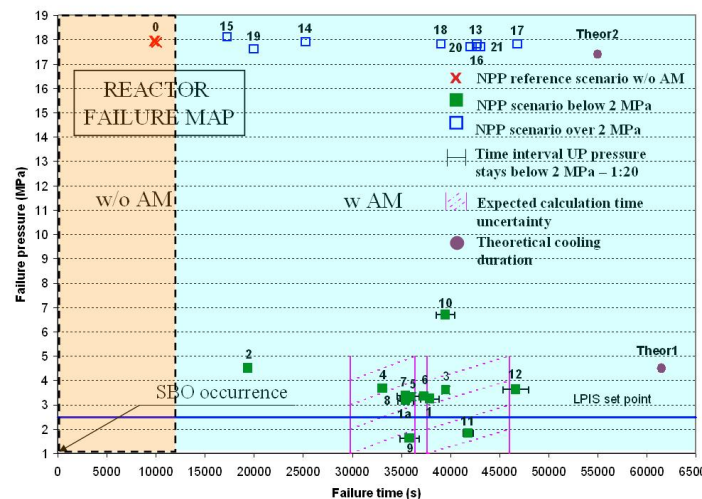
VVER-1000



Accident Management

PSB-VVER test matrix

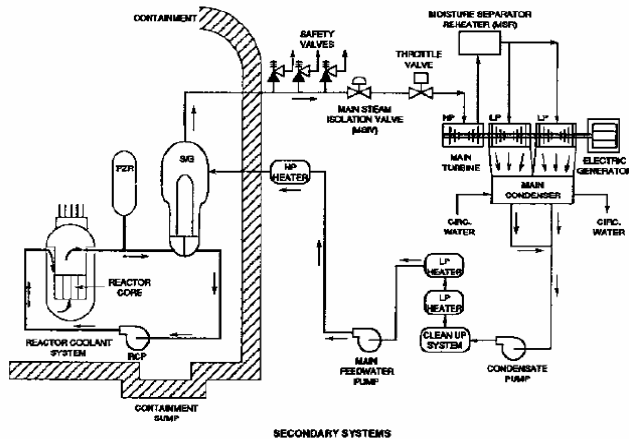
Nº	Test	Id	Test type
1	Test 1	LFW-25	LOFW. AM: SS depress. by SG1 & 4 BRU-A opening.
2	Test 2	LFW-28	LOFW. AM: SS depress. by SG1 & 4 BRU-A opening and PS depress.
3	Test 3	PrzVS-01	PORV stuck open. Similar to Zaporozhye Accident
4	Test 4	CL-0.7-08	0.7% SBLOCA AM: SS depress. by SG2 & 3 BRU-A opening (on T core exit).
5	Test 5	SL-100-01	SL break and PRISE. HPIS failure. AM: PS depress. by PORV opening & SS cooldown 60 K/h
6	Test 6	LFW-27	LOFW. AM: PS Feed&Bleed by PORV opening (after 30 min).
7	Test 7	BO-05	SBO. AM: SS depress. by SG1 & 4 BRU-A opening, water from external source
8	Test 8	CL-0.5-03	0.5% SBLOCA. HPIS & LPIS failure. AM: PS F&B by PORV opening and make-up system.
9	Test 9	PSh-1.4-05	PRISE BRU-A stuck open. AM: SS cooldown 60 K/h
10	Test 10	NC-6	NC. Drainage and refilling phases
11	Test 11	CL-0.7-12	0.7% SBLOCA. HPIS failure. AM: SS cooldown 30 K/h & 1 HPIS recovery.
12	Test 12-1	CL-0.7-11	0.7% SBLOCA. HPIS & LPIS failure. AM: SS cooldown 30 K/h, & make-up system.
13	Test 12-2*	CL-0.7-10	Repeatability test
14	Test 13*	BO-06	SBO. AM: SS depress. by SG1 & 4 BRU-A opening, water from external source
15	Test 14*	PSh-1.4-07	PRISE. AM: SS cooldown 60 K/h
16	Test 15*	CL-0.7-13	0.7% SBLOCA. AM: SS depress. by SG2 & 3 BRU-A opening & PORV opening





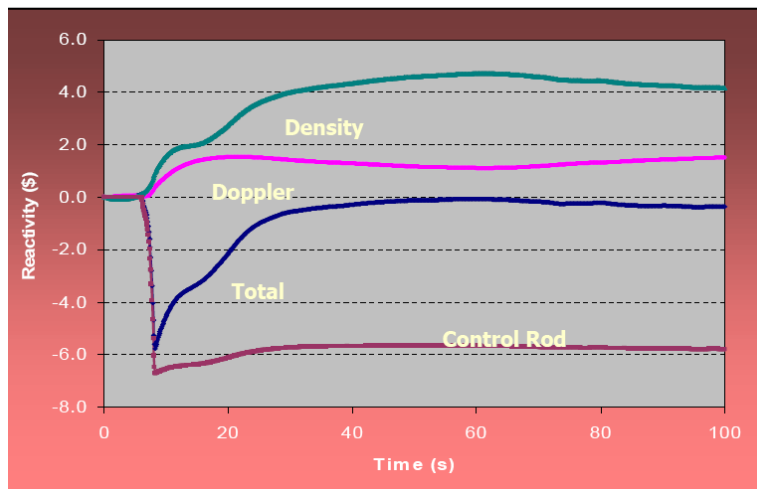
GRNSPG-NINE Technological Knowledge (9/26)

PWR MSLB Transient

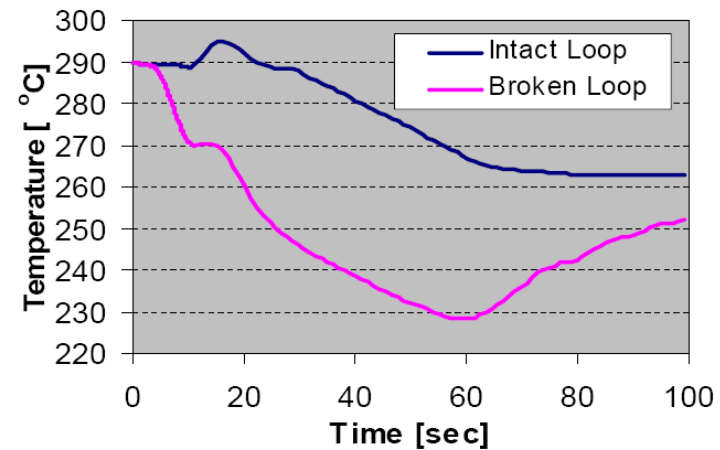


PWR Primary & Secondary circuit

Core Power – Different Codes



Reactivity Transient

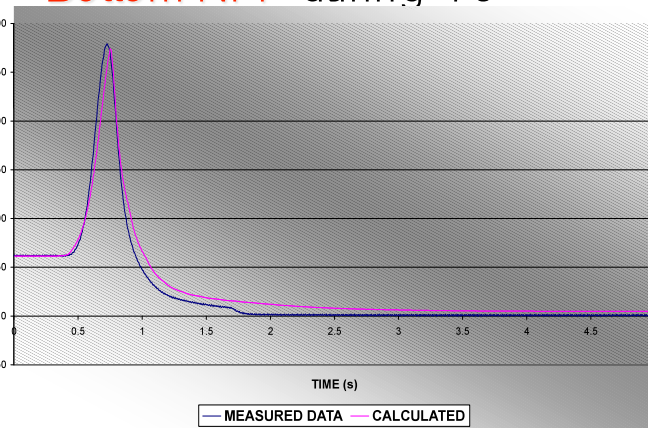


Temperature Transient in Cold Legs

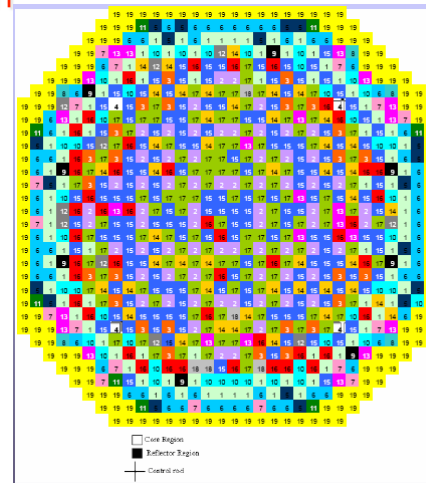


Peach Bottom BWR TT

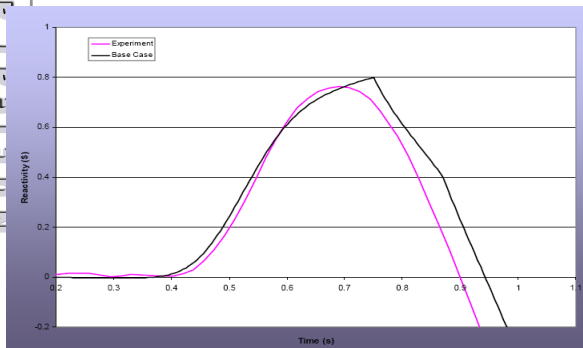
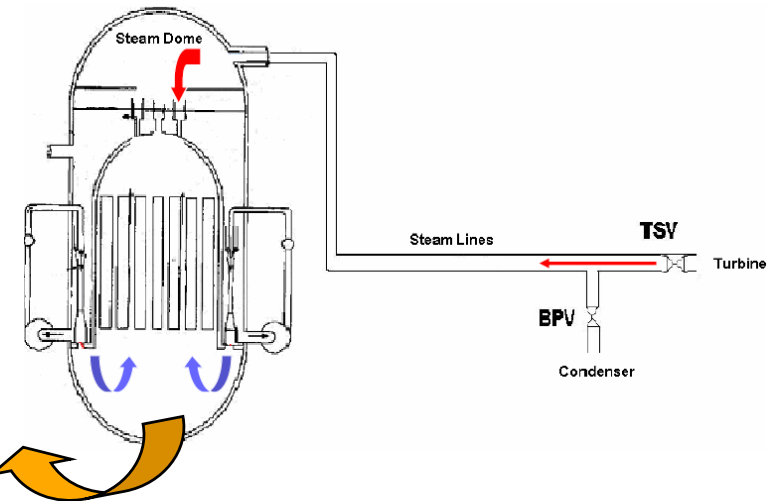
OECD NEA sponsored Benchmark
Based on Plant Data available
Turbine Test executed on Peach
Bottom NPP during '70



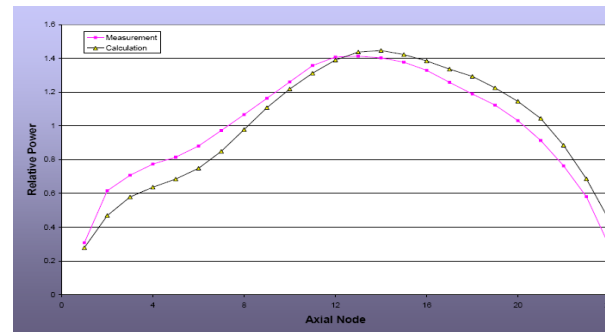
Power



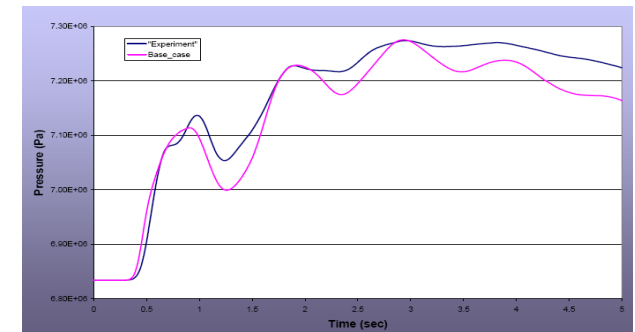
3D NK Modelling



Reactivity



Axial Power



Pressure Trend



Rod Ejection Transient

Rod Ejection Accident simulated for VVER-1000 core

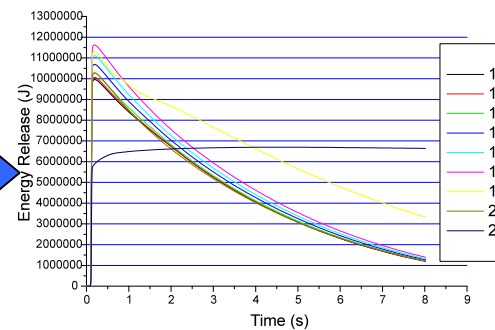
Analyses performed to show impact of **Burnup** on the **Energy Release**

- ★ Different Behavior at Beginning of Life - End of Life

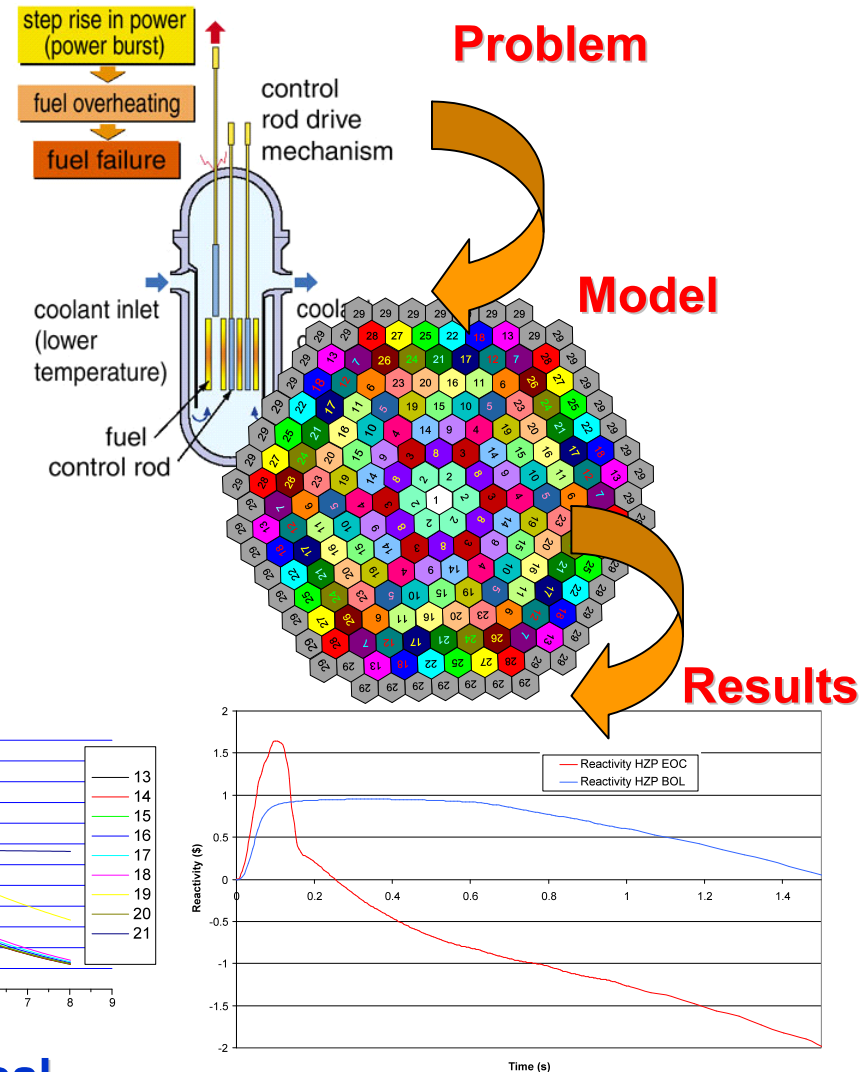
Comparison of **Analytical Methods** vs. **Numerical Methods**: \propto reducing of 100% energy peak value

$$E(\infty) = \frac{\Lambda}{|\mu|} \left(R + \frac{\rho_0 - \beta}{\Lambda} \right)$$

Analytical



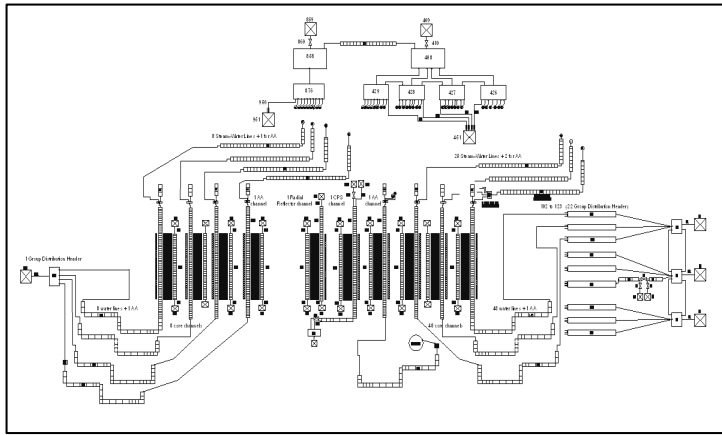
Numerical





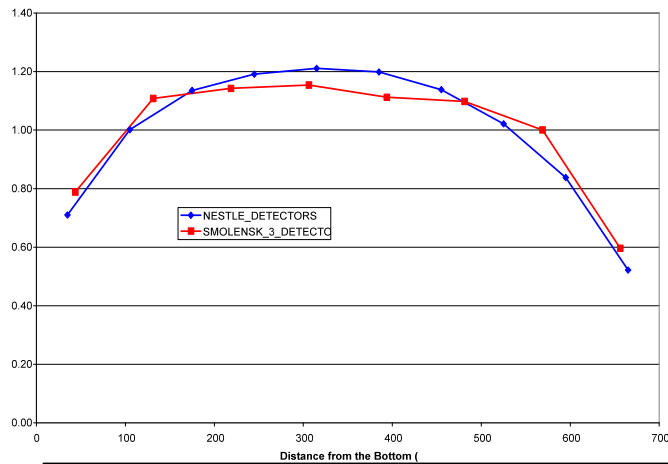
GRNSPG-NINE Technological Knowledge (12/26)

RBMK Analyses

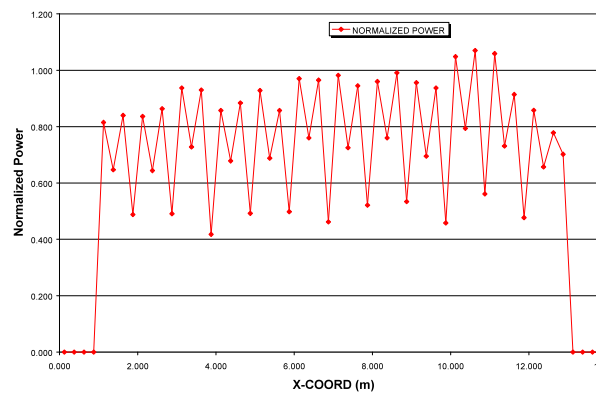


RELAP5-3D® TH model

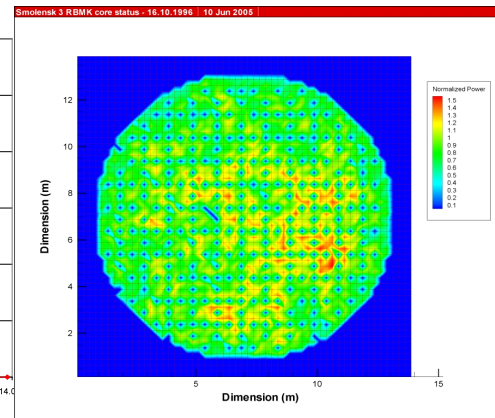
NESTLE 3D NK model



Axial Core Peaking Factor



y-averaged Core Power



2D Core Power

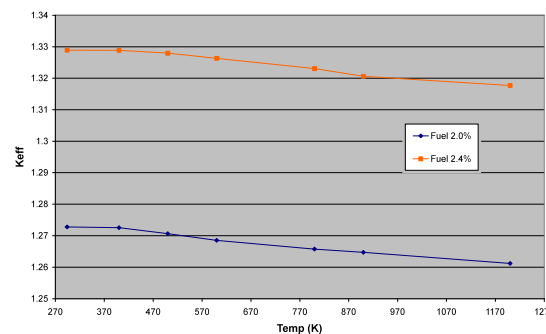


GRNSPG-NINE Technological Knowledge (13/26)

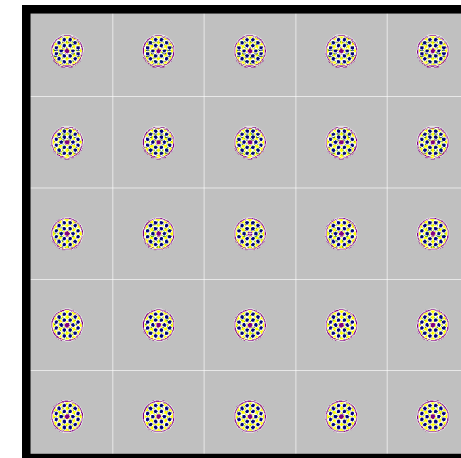
RBMK Analyses: MCNP Calculation

Precise **Monte-Carlo** calculations executed for evaluate

- ★ Systems Criticality (research reactors, fissile materials, reactor cells)
- ★ Reactivity Coefficients
- ★ Pin Power Reconstruction

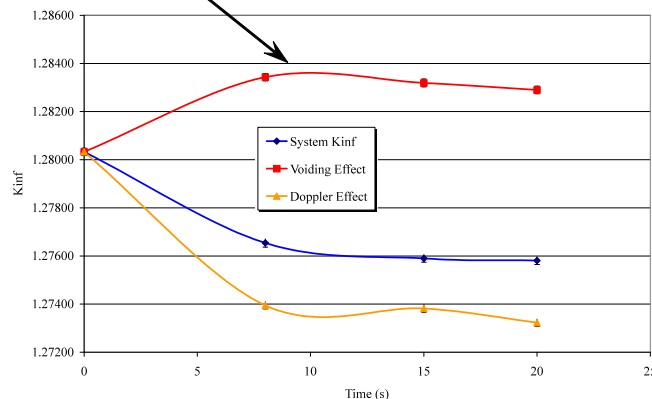


MC Reactivity Calculations



RBMK Lattice Model

Positive void effect



2.0% System Criticality

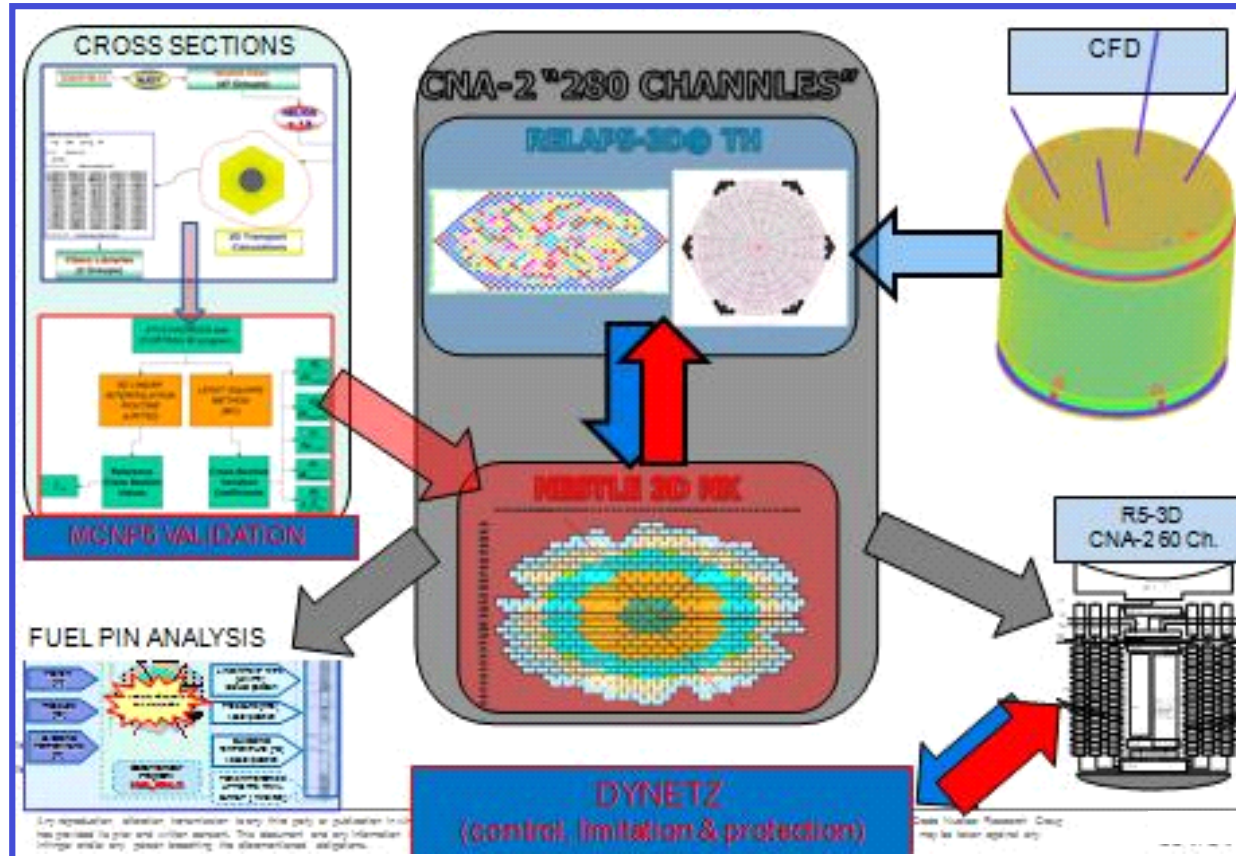
Ratios of Tallies - Fuel 2.0%	$X1/Xi$, %		$X2/Xi$, %		$X3/Xi$, %	
	Thermal	Total	Thermal	Total	Thermal	Total
Fission	-2.8	-0.3	-2.2	0.2	-0.5	-0.5
Absorption (fuel)	24.3	8.0	24.5	7.1	-0.2	0.9
(excluding fission)	-1.2		-0.8		-0.4	
Absorption (water)	21.1		18.3		2.7	
	-84.3	-83.9	-84.2	-83.8	-0.4	-0.4
	-76.7		-76.7		-0.4	
ϕ (in fuel)	10.7	22.8	10.7	23.0	-0.1	-0.2
	29.1		29.5		-0.2	
Scattering (graphite)	7.3	17.6	7.4	17.8	-0.1	-0.1
	31.9		32.1		-0.1	

Fuel Cells reaction rates tallying



GRNSPG-NINE Technological Knowledge (14/26)

Atucha-II NPP Licensing



*Atucha-II NPP
FSAR-Chapter 15*

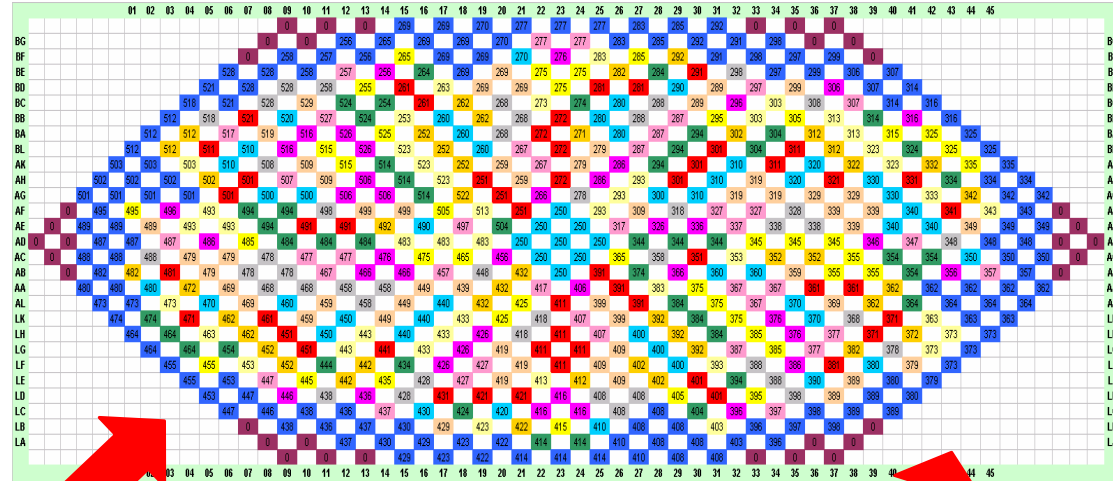




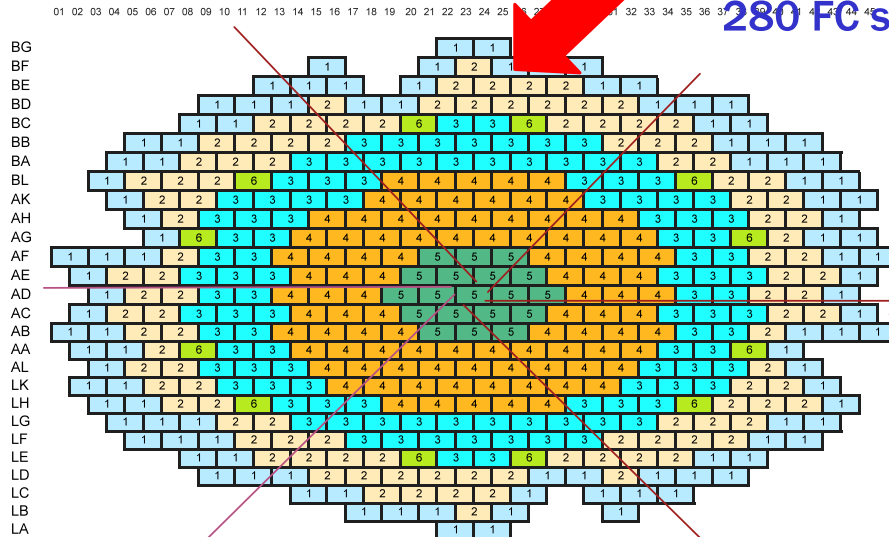
GRNSPG-NINE Technological Knowledge (15/26)

ATUCHA-II LBLOCA calculations

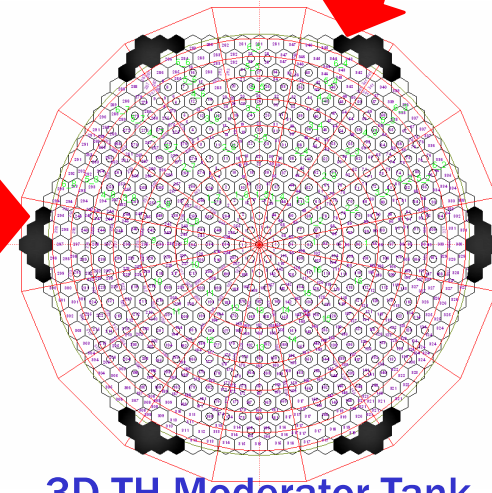
280 FC RELAP5-3D TH model used
All 451 FA simulated by 3D NK code NESTLE
Special 3D TH modeling and coupling for the Moderator Tank



280 FC simulated by RELAP5-3D®

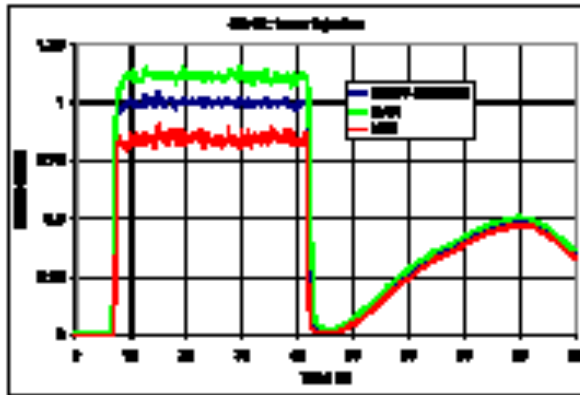


451 FA simulated by 3D NK NESTLE

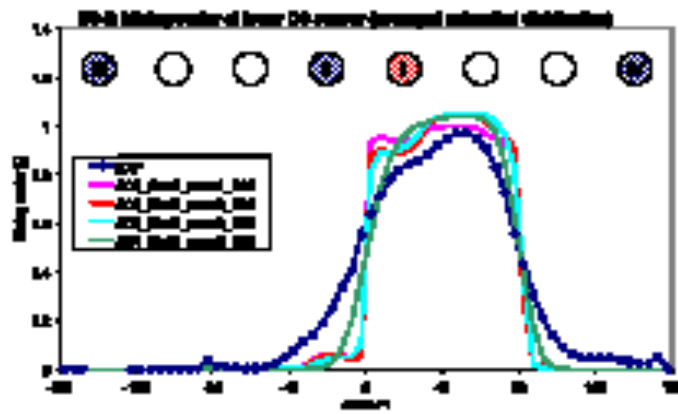


3D TH Moderator Tank

CFD Validation: ROCOM Experiment

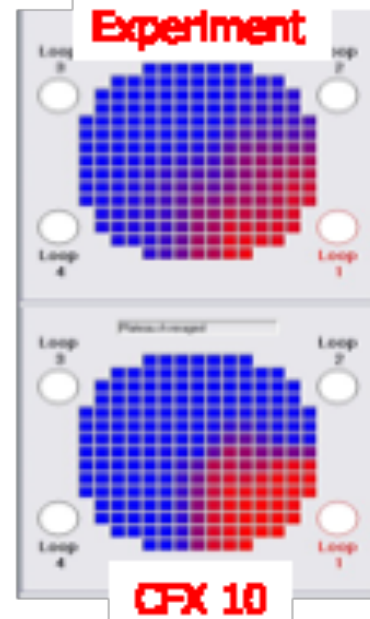


**Injection of a tracer slug in Loop #1
(simulating a deborated slug)**

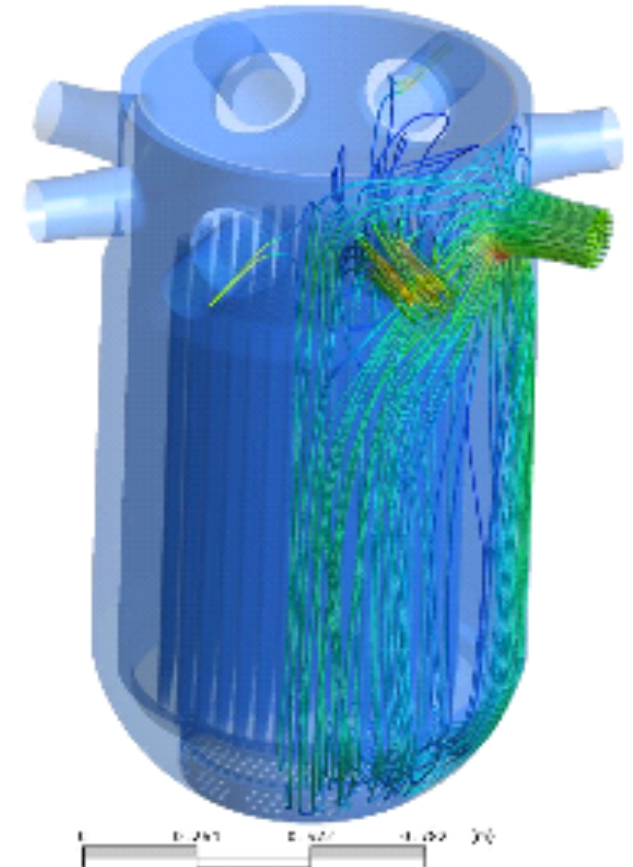


**Azimuthal profile of
tracer conc. in DC**

**Good qualitative
agreement
Tendency to
underestimate
mixing efficiency**



**Tracer concentration
at core inlet**



Tracer streamlines



ATUCHA-II LBLOCA calculations

Project TACIS R2.02/02: validation of mixing models in Russian TH codes

Support by CFD analysis

1:5 scaled model of a VVER-1000

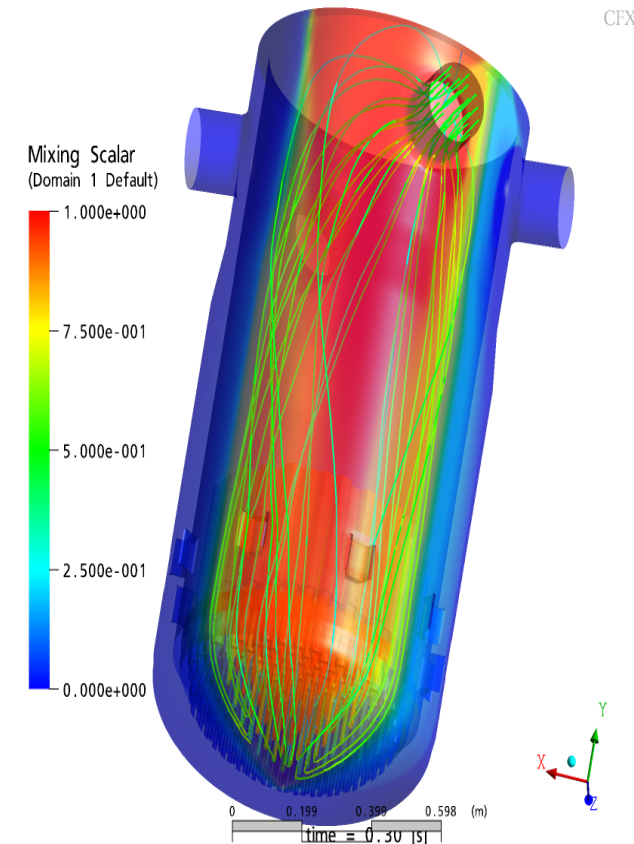
Addressing scenarios involving non-uniformities of coolant properties distribution at core inlet

deborated slug mixing

asymmetric temperature distribution

10 experiments conducted

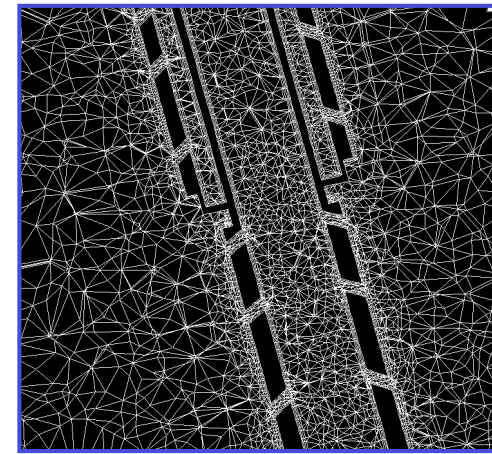
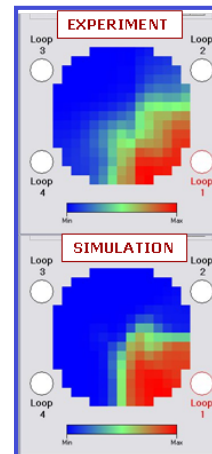
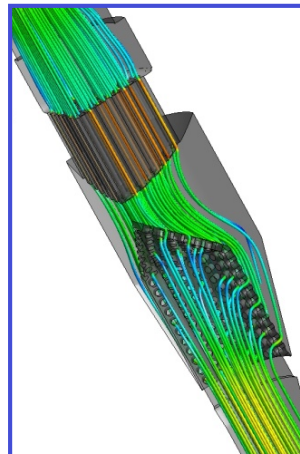
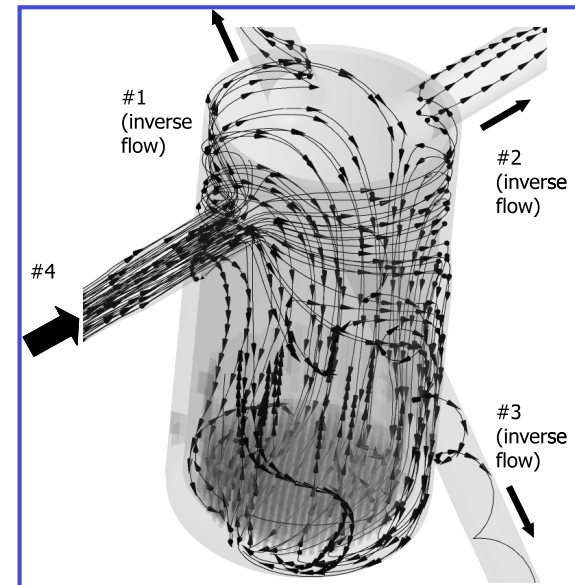
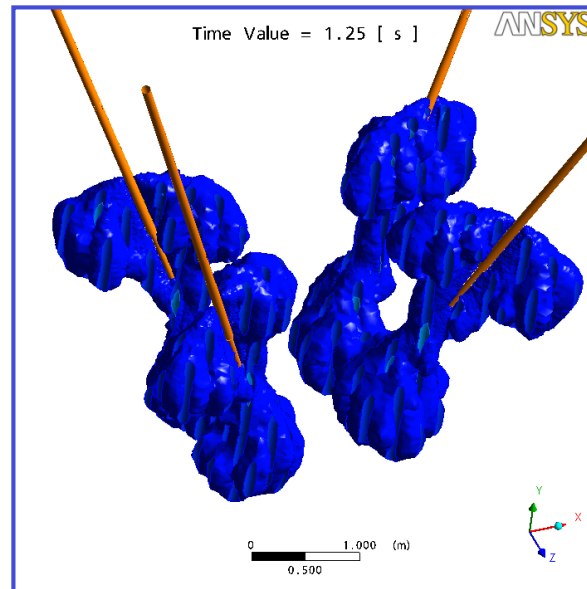
Pre- & post-test CFD analyses for each experiment



Calculated flow and tracer distribution for a 4-pump symmetric operation slug injection test



CFD: Boron Injection in Atucha-2 NPP



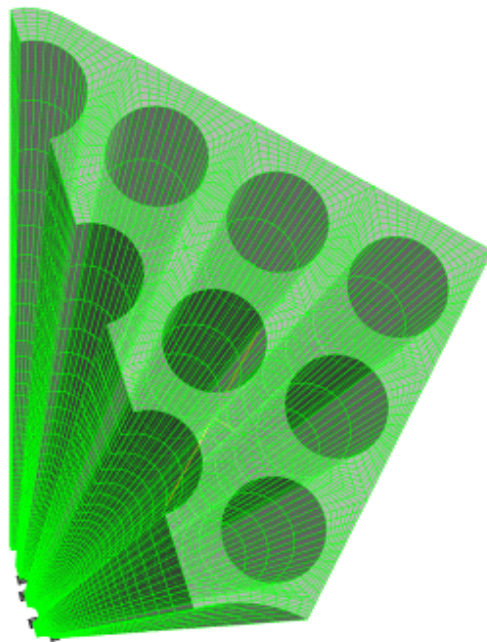


CFD 2Φ: Boiling Channels

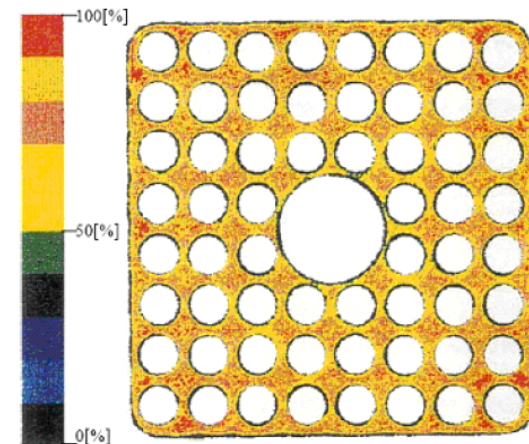
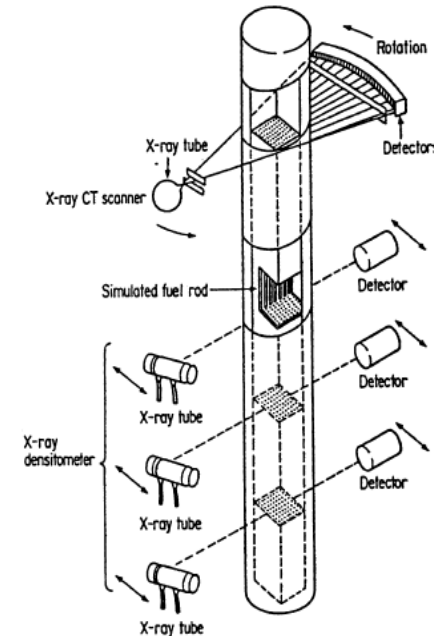
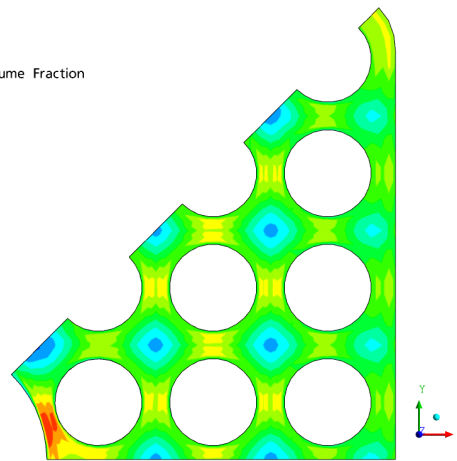
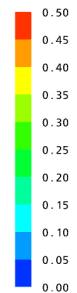
OECD BFBT Benchmark

High-resolution void distribution data
provided by NUPEC facility (BWR FA)

CFD simulations performed with
NEPTUNE-CFD and ANSYS CFX 11



Steam5v. Volume Fraction
(Contour 1)

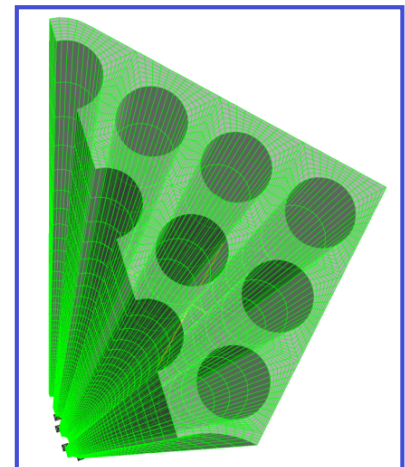
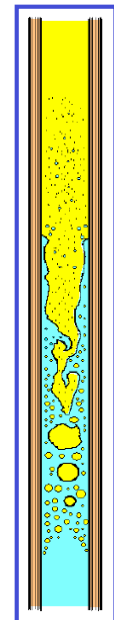
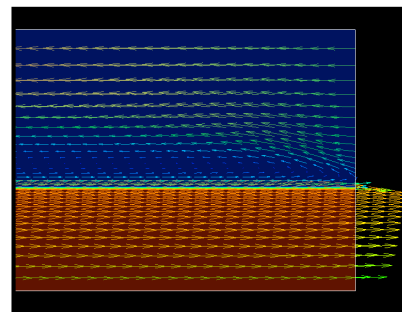
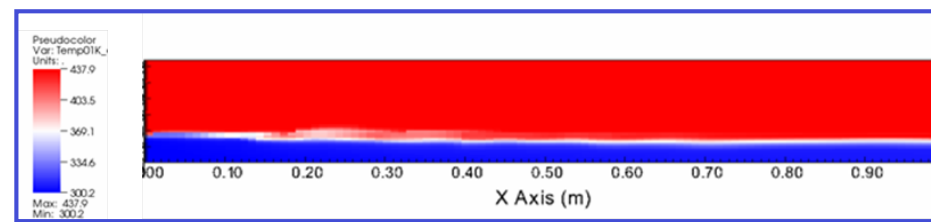
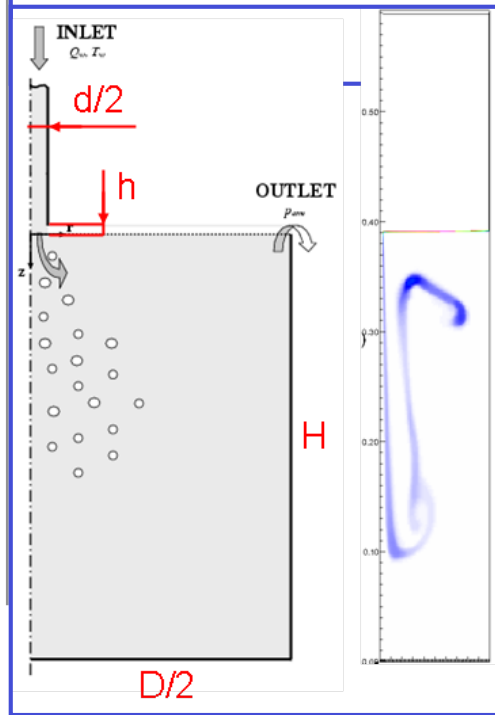
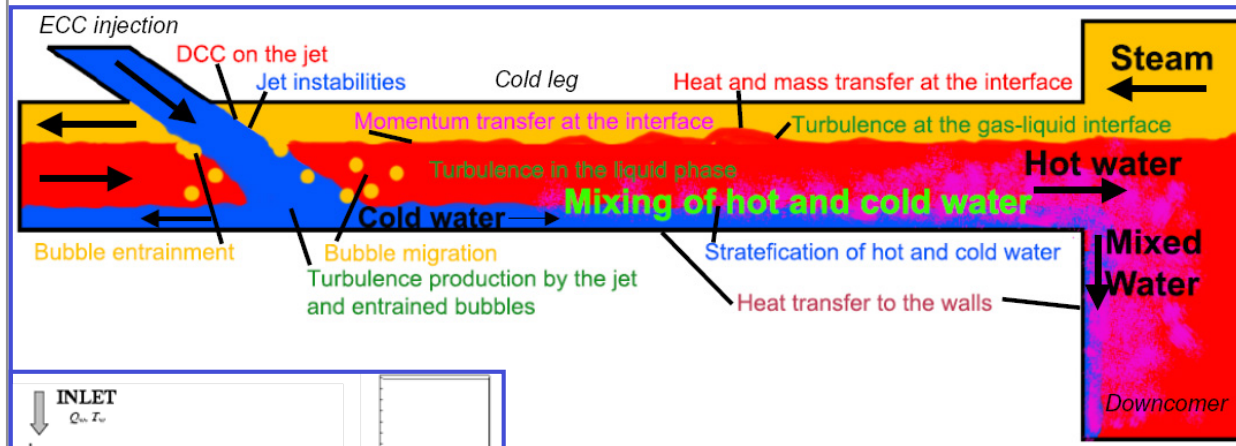




GRNSPG-NINE Technological Knowledge (20/26)



CFD 2Φ

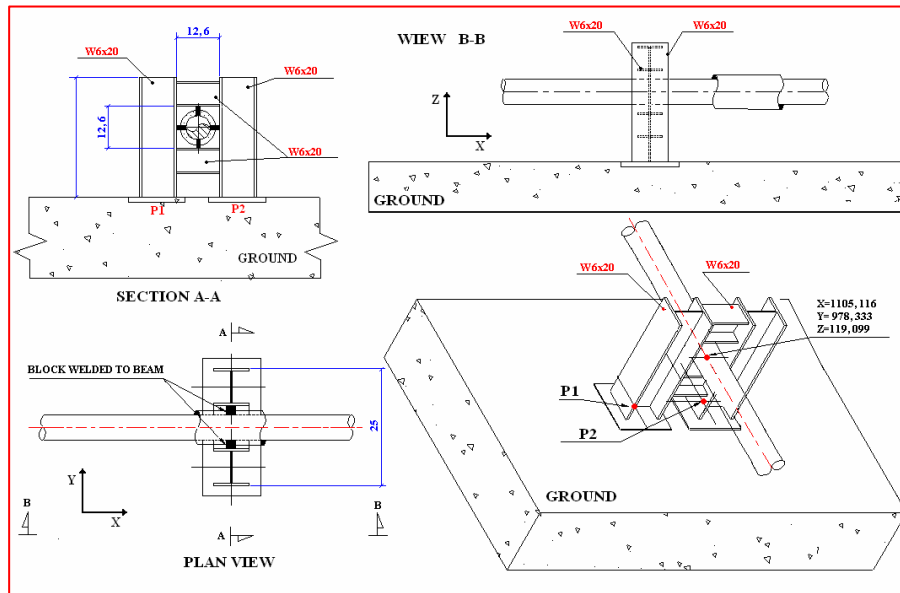




GRNSPG-NINE Technological Knowledge (21/26)

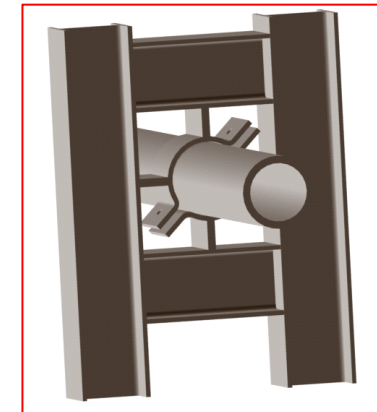
AP1000: Pipe Stress Analysis

The adopted code to verify the nuclear piping supports, according with the ASME III NF Standards, is **GTSTRUDL**.

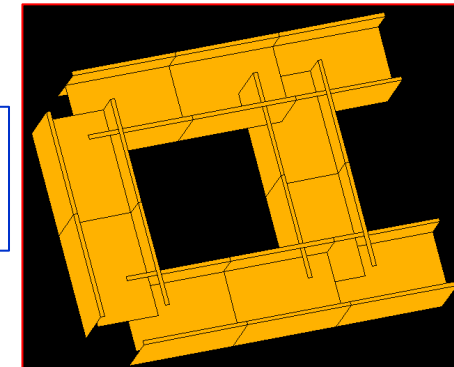


Lay-out

PRO-E
CAD 3D model



GTSTRUDL
model

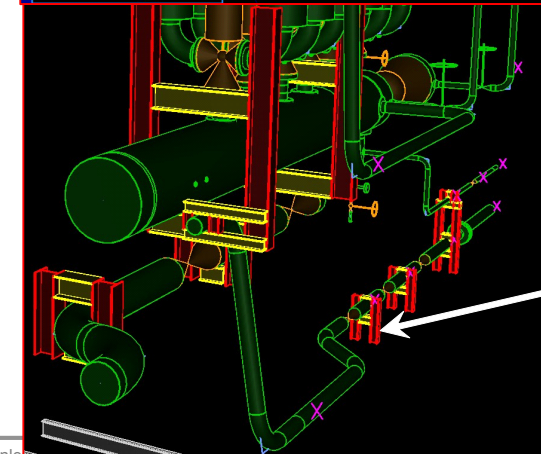
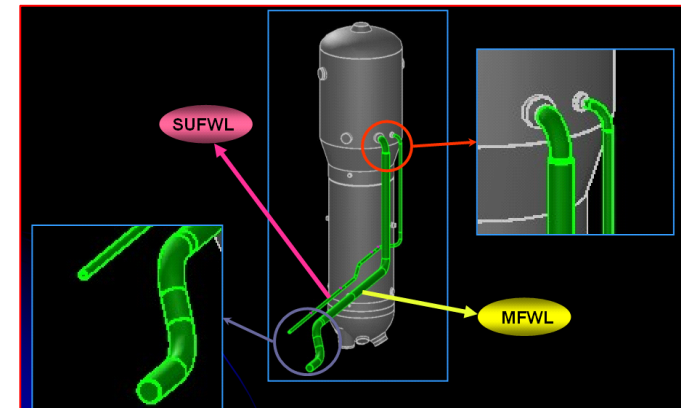
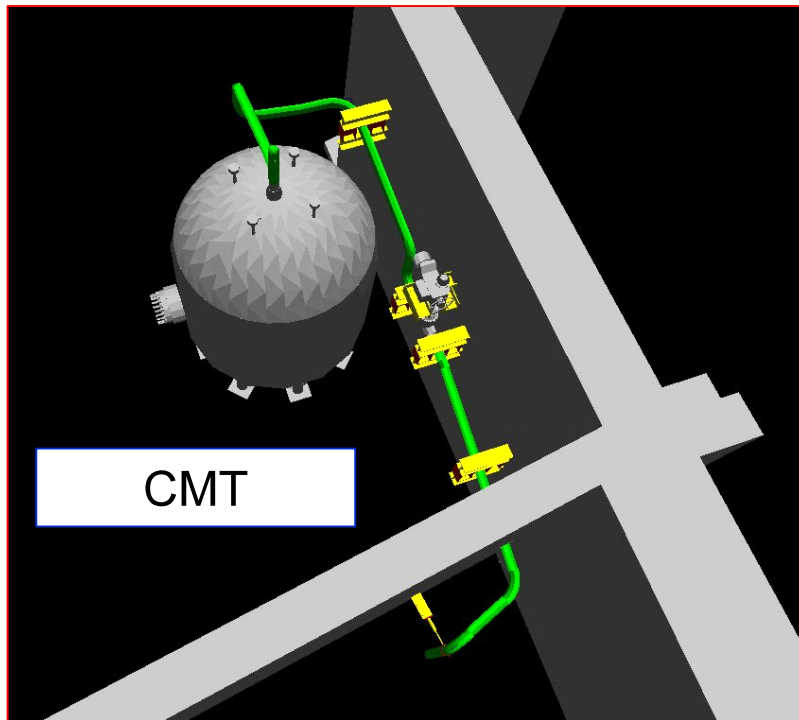




AP1000: Pipe Stress Analysis

Collaboration with “*ANSALDO Nucleare*” in the framework of the AP 1000 NPP project.

The used code is **PlantSpace Design (Bentley)**

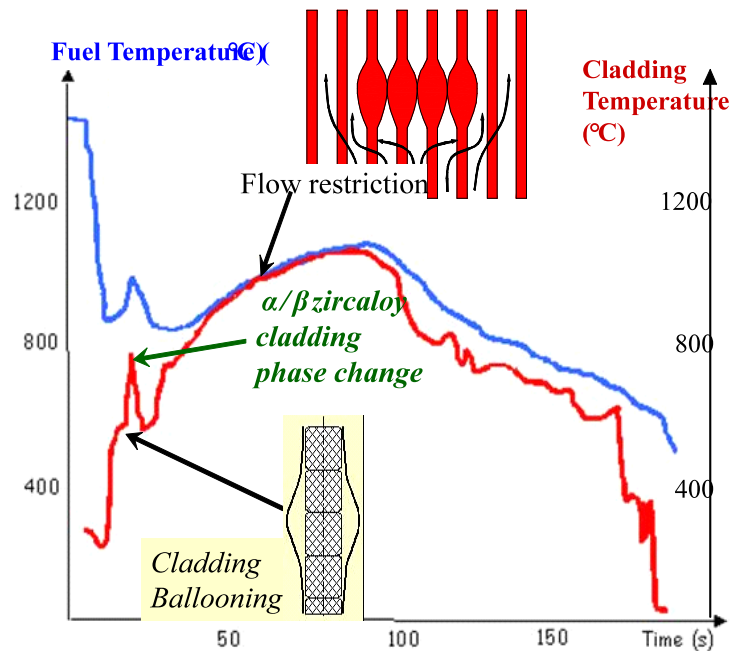


SUFWL

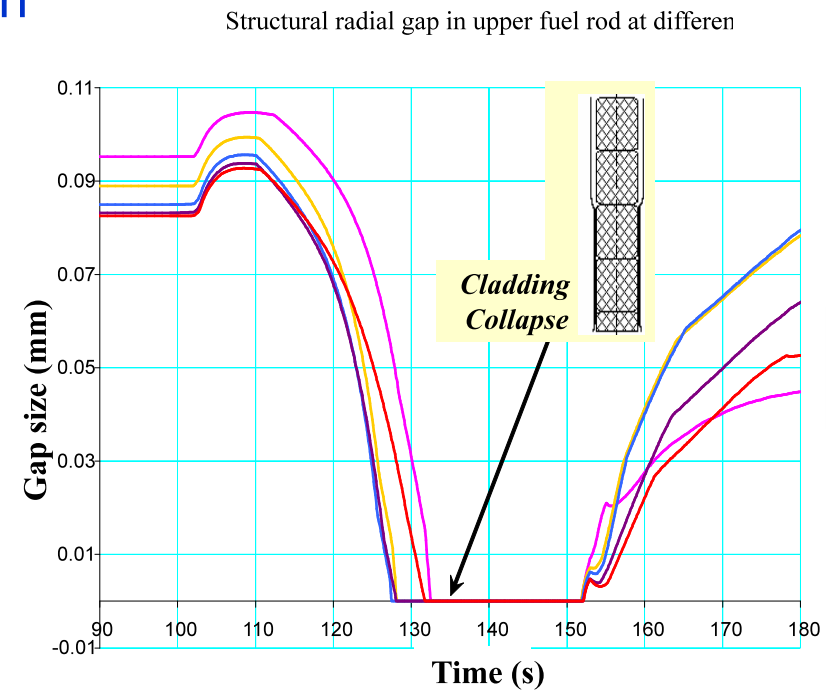


Fuel Pin Mechanics

Analyses are performed using the **FRAP code** in “stand-alone” or in **coupled** mode with **thermal-hydraulic** and **3D NK** codes. Activities are focused on the fuel behavior for determining the eventual source term **for safety analyses** purposes, **for power increase and for burn-up extension**



PWR LB LOCA Transient

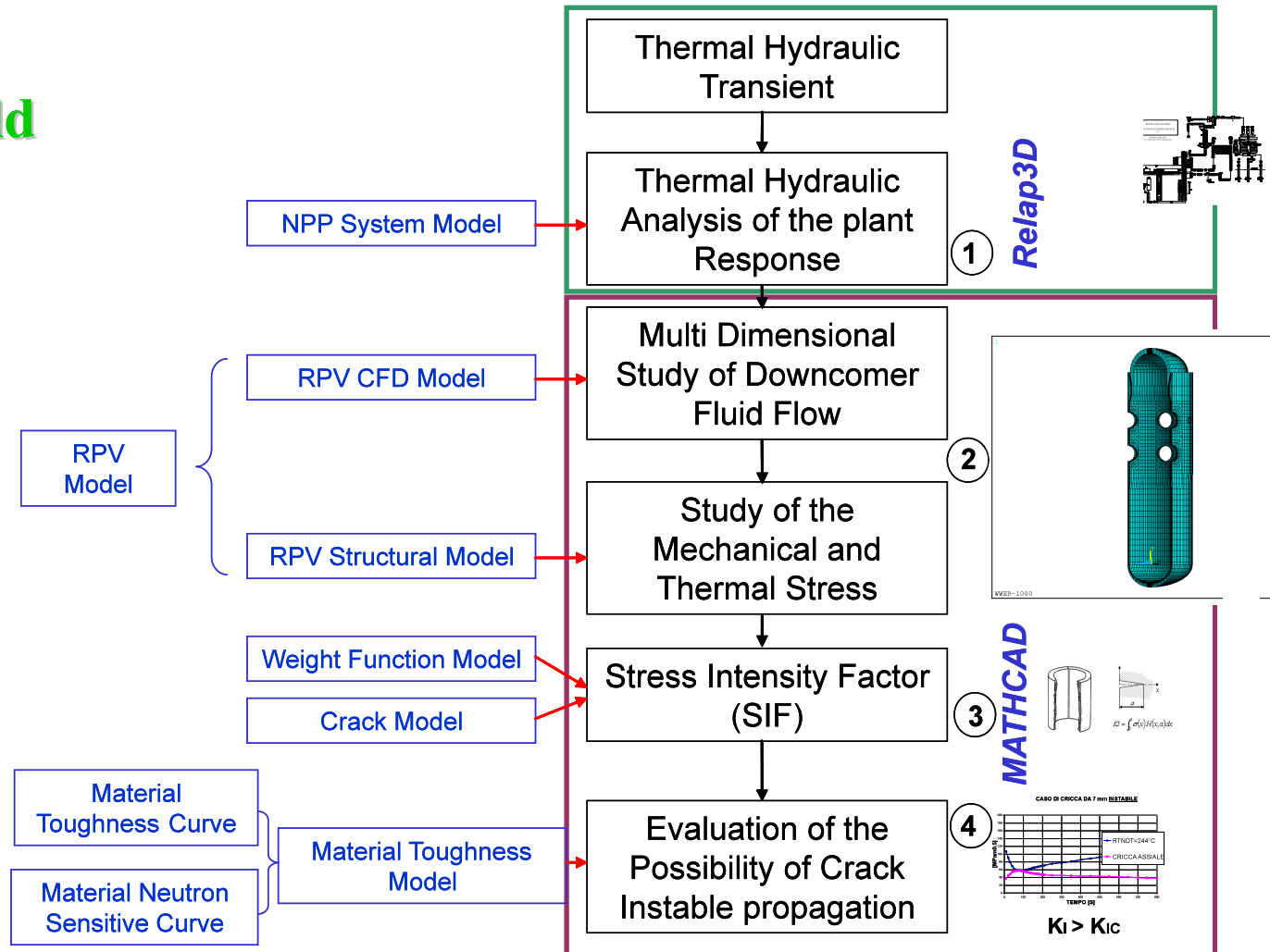
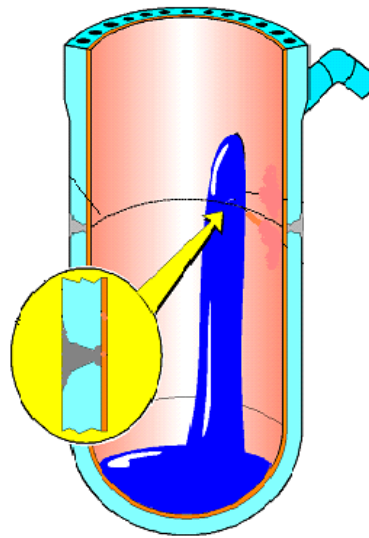


RBMK Channel Flow Blockage



PTS METHODOLOGY

PTS
200 cm² LOCA cold

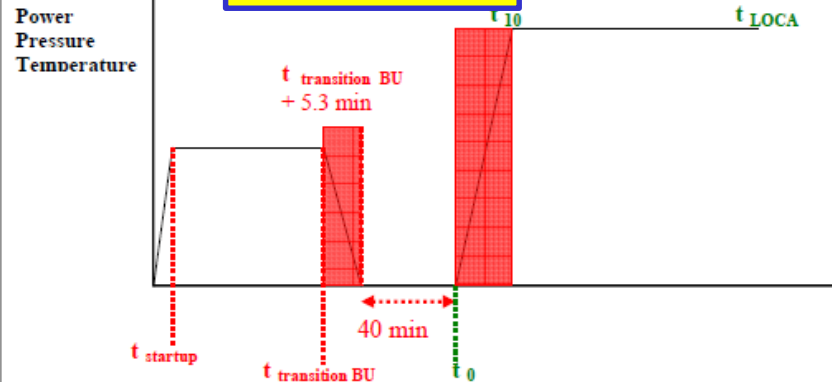




GRNSPG-NINE Technological Knowledge (25/26)

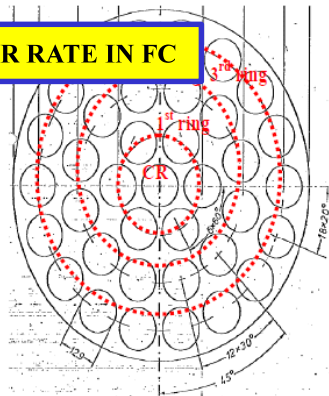
Fuel Analysis

BURN-UP HISTORY

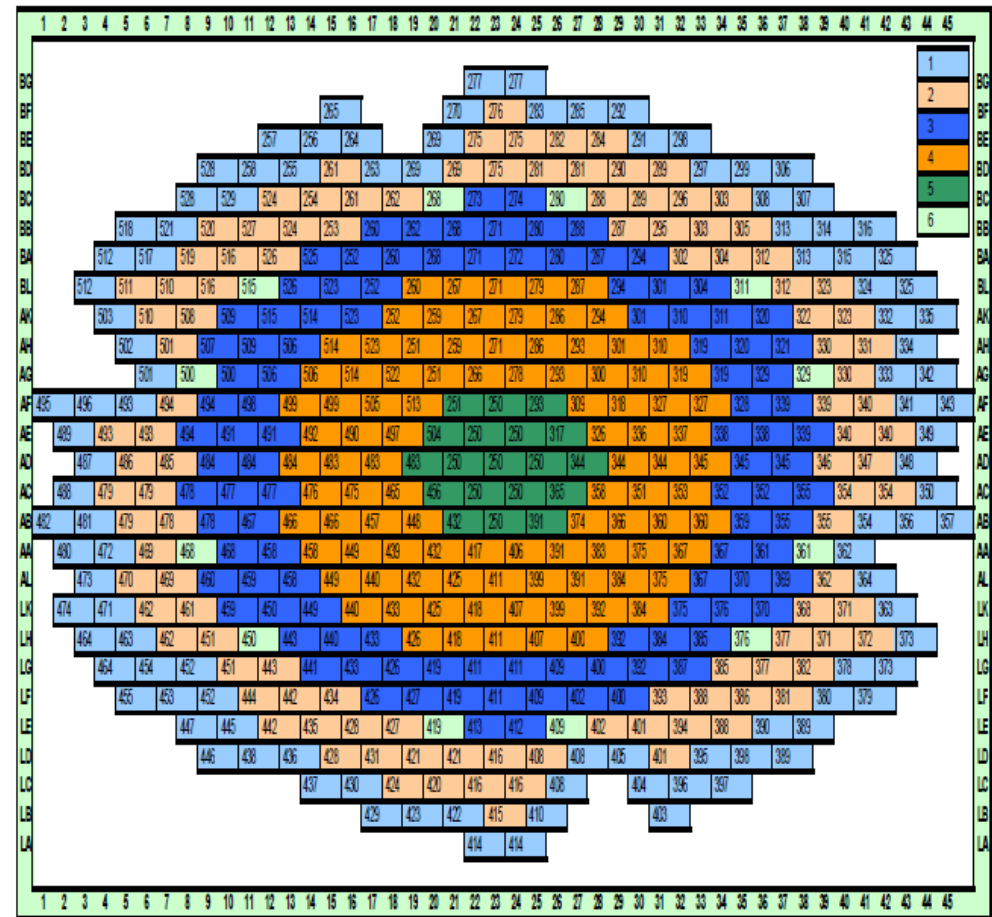


- 3rd ring containing 18 rods, linear heat rate multiplication factor: 1.1065; application
- 2nd ring containing 12 rods, linear heat rate multiplication factor: 0.9296;
- 1st ring containing 6 rods, linear heat rate multiplication factor: 0.8508;
- central rod, linear heat rate multiplication factor: 0.8222.

LINEAR POWER RATE IN FC

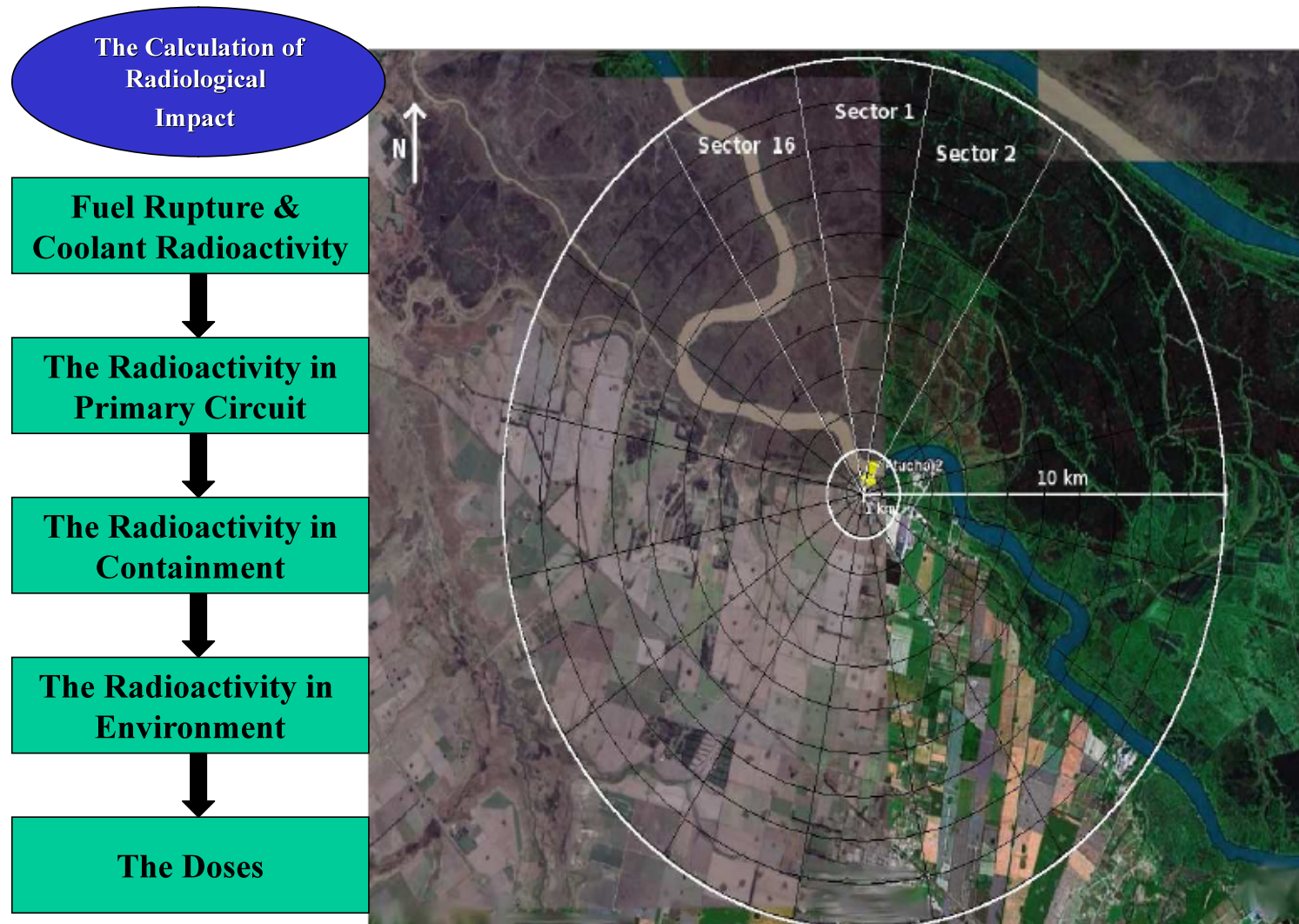


BURN-UP ZONES





Fission Product Release & Impact on Environment





PART-2

BEPU APPROACHES AND CHALLENGE IN THE CURRENT LICENSING OF NPP



BEPU AND LICENSING



1) The Approaches for Best Estimate Plus Uncertainty (BEPU)

2) The Atucha-2 NPP

3) The Licensing Framework

4) The Road-Map for BEPU

5) The BEPU Process

- The Postulated Initiating Events (PIE)
- The Computational Tools

- The

7) Selected Outcomes from FSAR Chapt. 15

8) Conclusions



CLASSIFICATION ADOPTED HEREAFTER

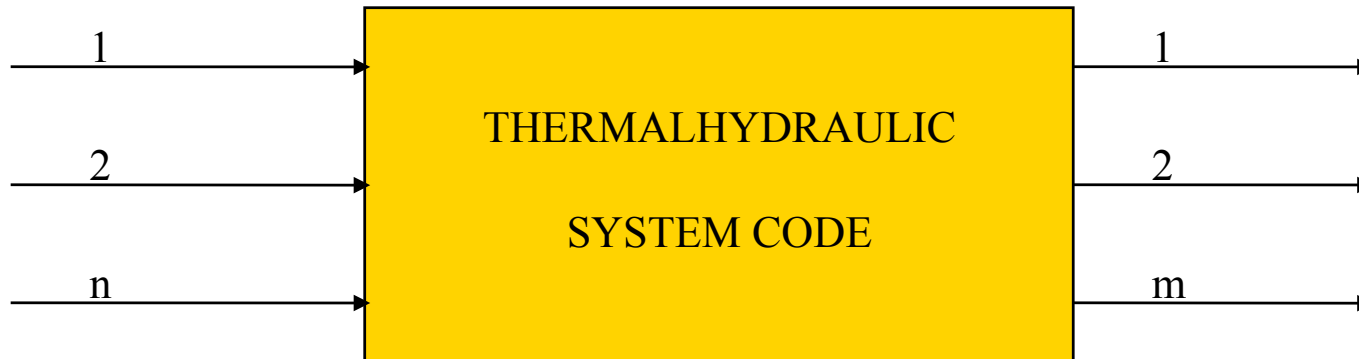
- Difference between INPUT and OUTPUT PROPAGATION
 - PROPAGATION OF CODE INPUT “UNCERTAINTIES”
 - PROPAGATION OF CALCULATION OUTPUT “ERRORS”
- Alternative Classification
 - “PURELY” DETERMINISTIC METHOD
 - “PURELY” STATISTIC METHOD
 - USE OF STATISTICS

**COMBINATIONS OF THE VARIOUS
APPROACHES CAN BE PURSUED**



1 - PROPAGATION OF CODE INPUT “UNCERTAINTIES”

Multiple input (n)



Multiple output (m)

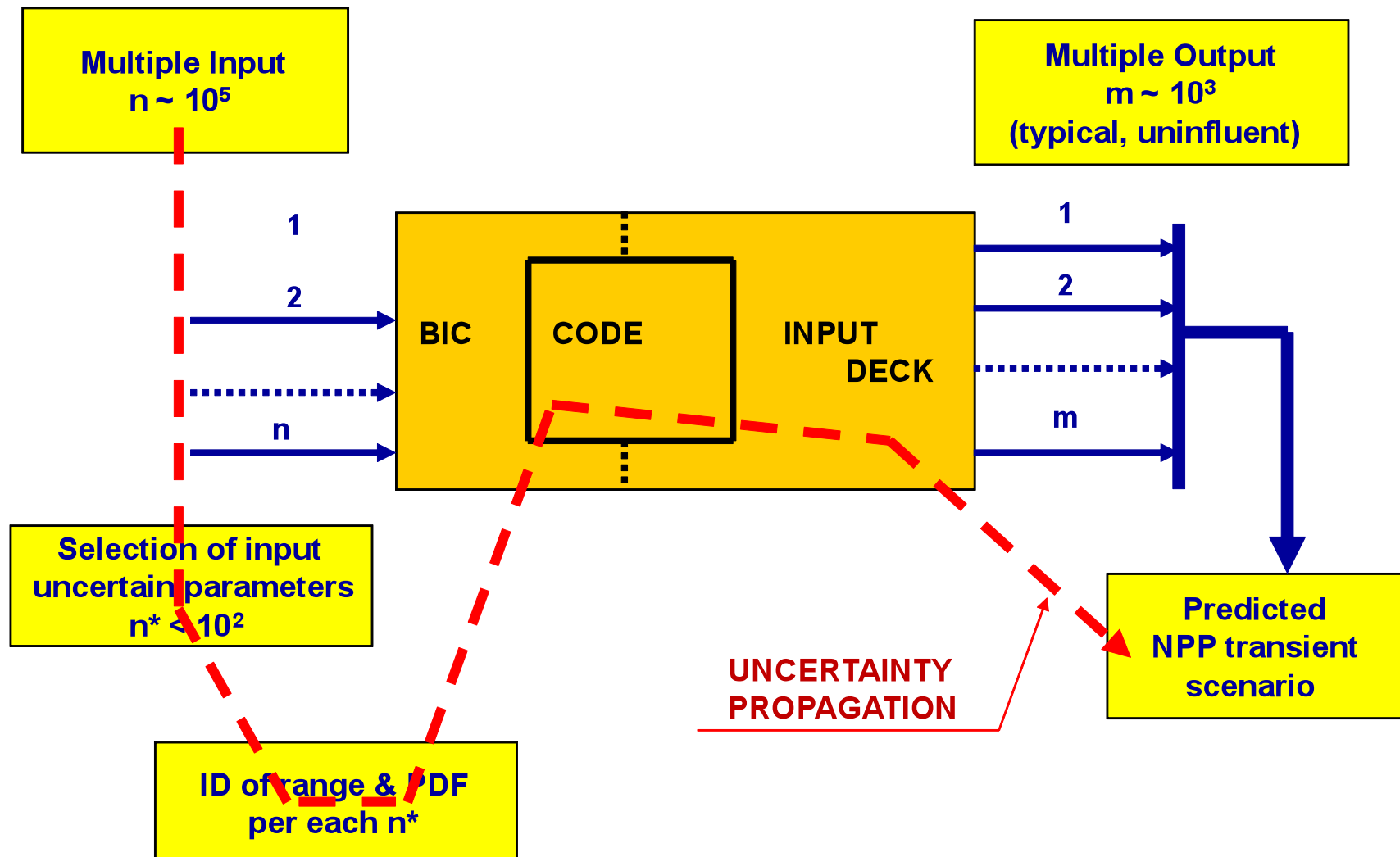
- ‘n’ can be as large as 10^5
- the dimension of ‘m’ is not a main concern

THE PROPAGATION OF CODE INPUT UNCERTAINTIES IMPLIES

- ✓ ‘n*’ must be selected with ‘n*’ of the order of 10^2 and \ll ‘n’
- ✓ range of variations and/or Probability Distribution Function (PDF) must be assigned to each of the ‘n*’ parameters

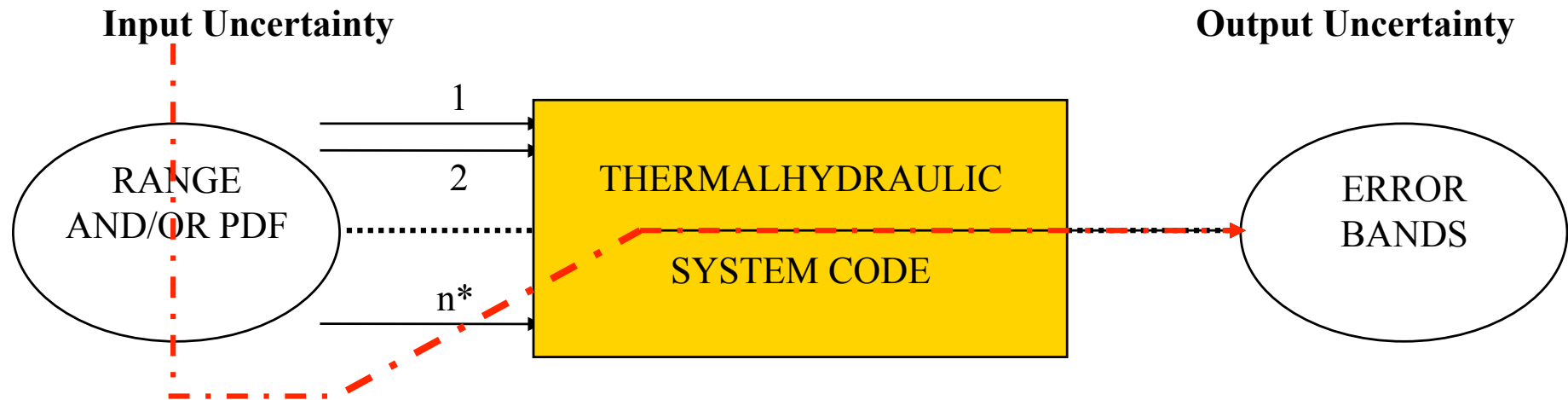


1 - PROPAGATION OF CODE INPUT “UNCERTAINTIES”



1 - PROPAGATION OF CODE INPUT “UNCERTAINTIES”

PATH FOR UNCERTAINTY EVALUATION

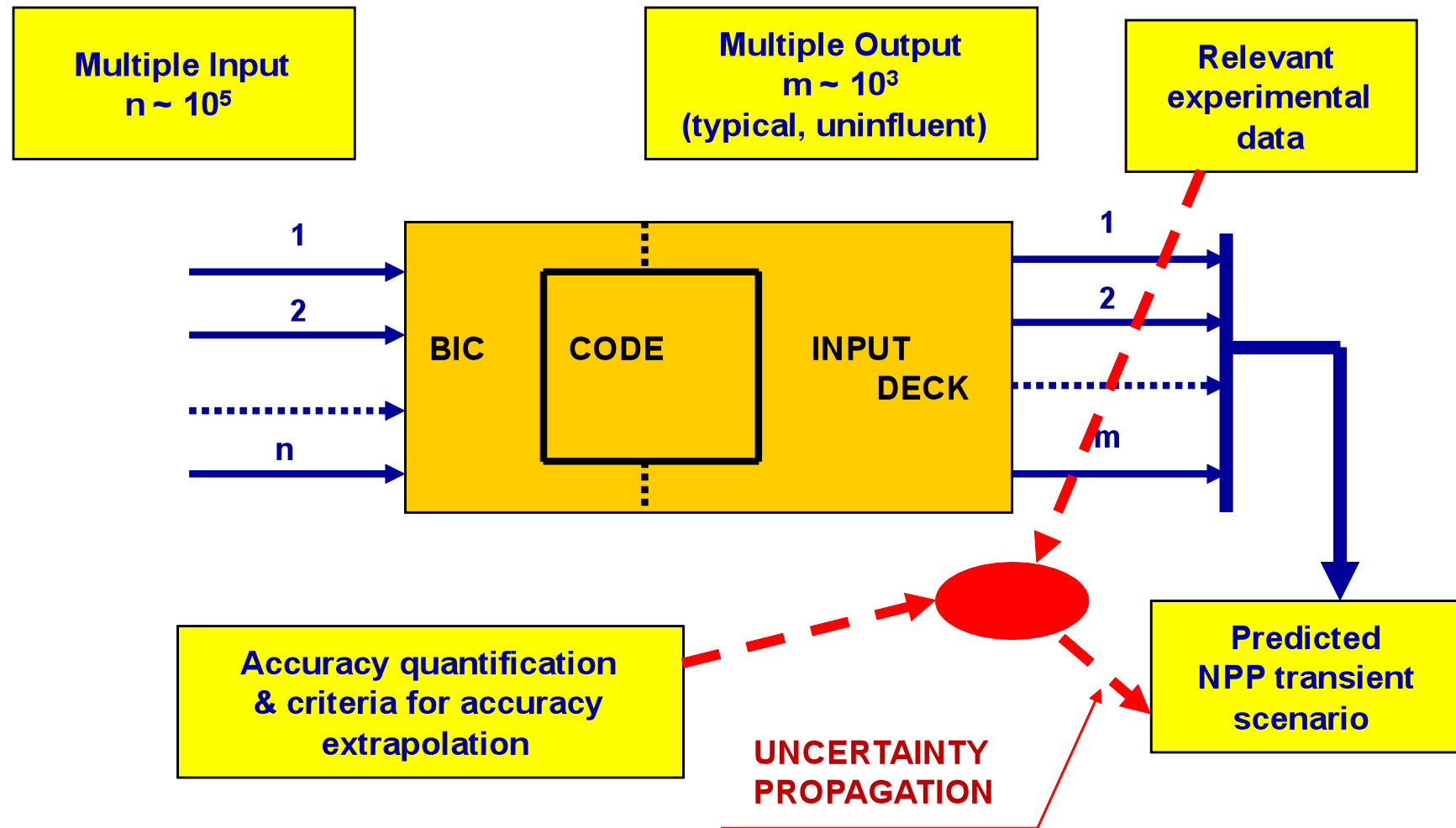


DRAWBACKS:

- Engineering judgment needed to select:
 - ‘ n^* ’ starting from ‘ n ’
 - range and/or PDF for each ‘ n^* ’
- The error propagation occurs through the code that, by definition, is an ‘imperfect’ tool



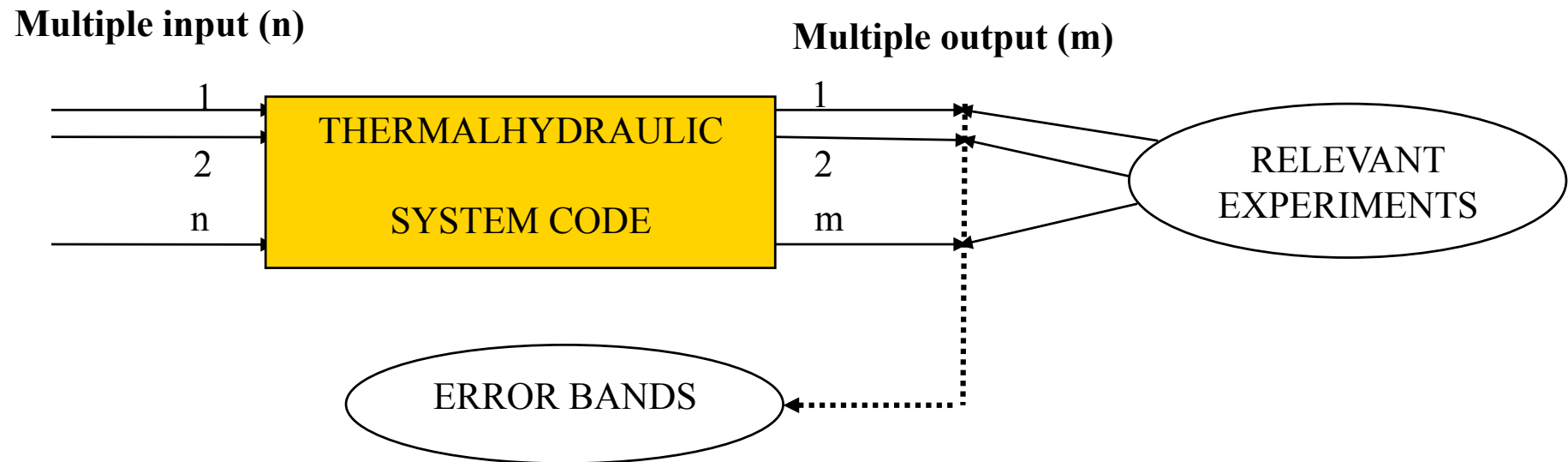
2 - PROPAGATION OF CALCULATION OUTPUT “ERRORS”





2 - PROPAGATION OF CALCULATION OUTPUT “ERRORS”

PATH FOR UNCERTAINTY EVALUATION

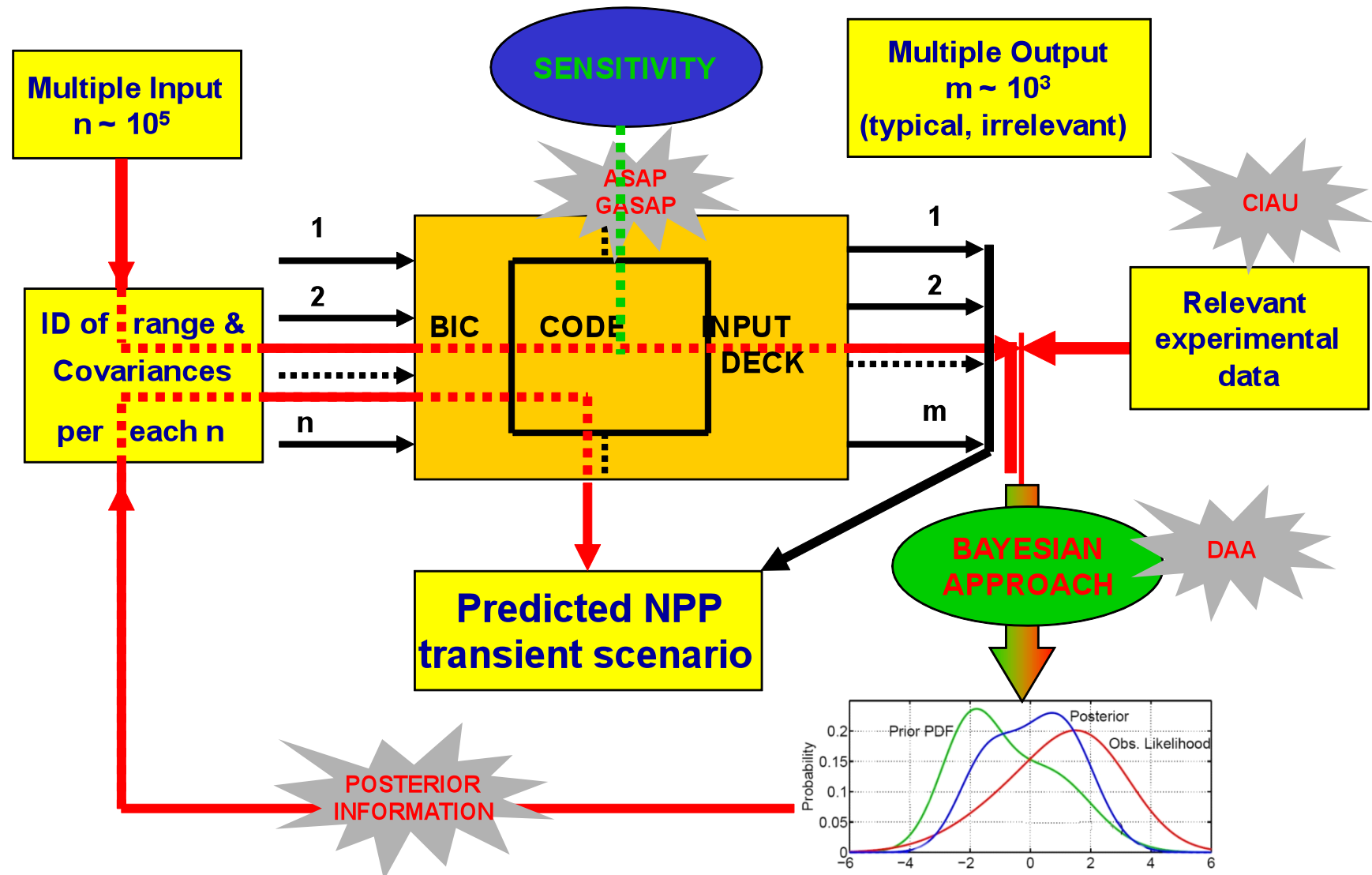


DRAWBACKS:

- The process of ‘extrapolation’ of output errors is not based upon fundamental principles
- It is impossible to distinguish contributions to the output error



3 – DATA ADJUSTMENT AND ASSIMILATION (D.G. Cacuci)



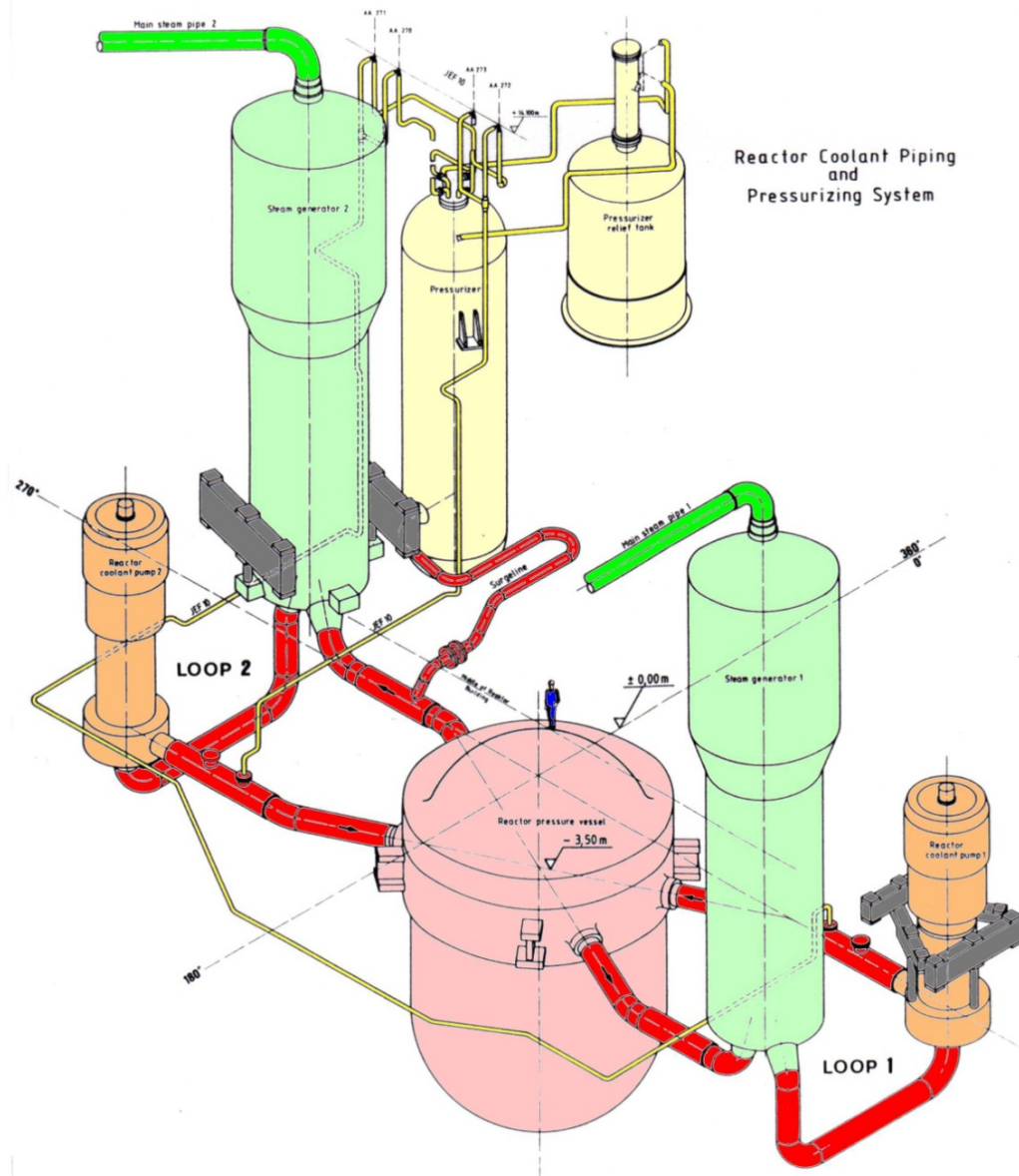


3 – DATA ADJUSTMENT AND ASSIMILATION (D.G. Cacuci)

- Pioneering approach under development in the Nuclear Safety Analysis Field
- Already applied in other fields, like Meteorology
- Based on the use/availability of:
 1. Powerful Sensitivity Tool, like **the Adjoint Sensitivity/Uncertainty Analysis Procedure (ASAP)**;
 2. Experimental Data and Database of Errors, like **the CIAU Accuracy Database**
 3. Calibration Methodology, like **the Data Adjustment and Assimilation (DAA)**



The Atucha-2 NPP



2 LOOPS
1 MCP, 1 UT SG each

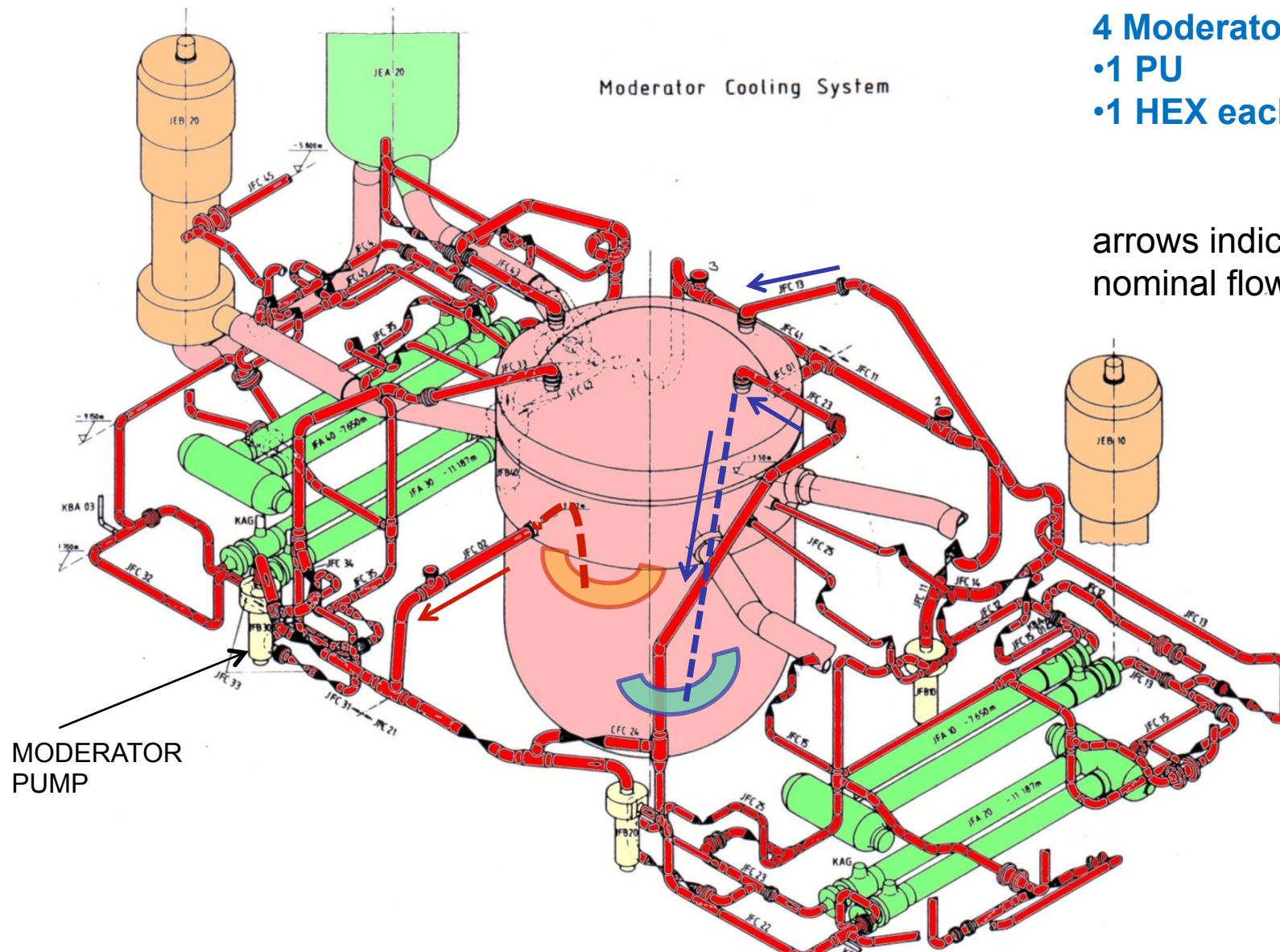
1 PRZ

2160 MWth
1958 + 203 (nom. mod. T), or
2001 + 160 (max mod T)
+
14 from MCP

451 separated FC



The Atucha-2 NPP



4 Moderator loops

- 1 PU
- 1 HEX each

arrows indicate
nominal flow direction

MODERATOR
PUMP



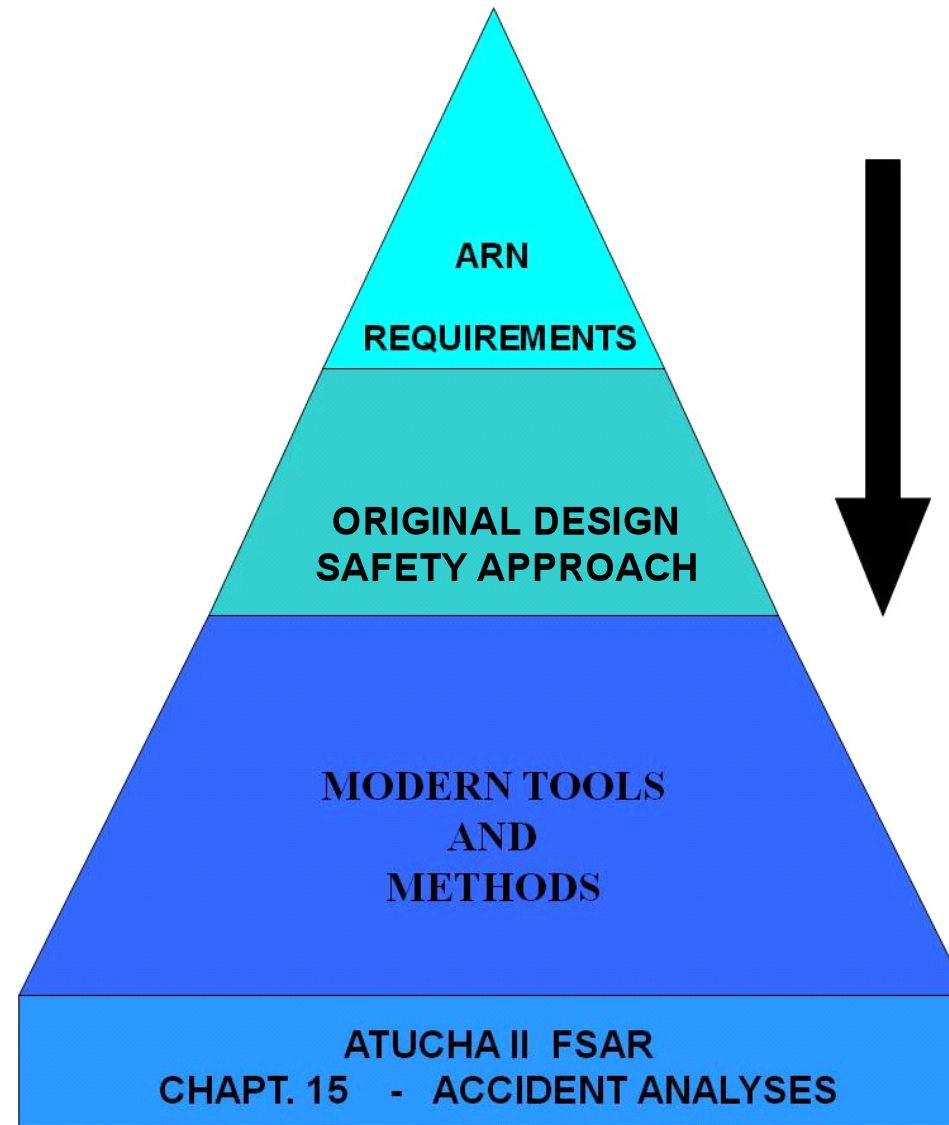
The Licensing Framework

Conservative and best estimate methods, IAEA-TECDOC-1332, 01/2003

Approach	Applied codes	Initial and boundary conditions	System availability	Regulation
Conservative	Conservative code	Conservative	Conservative assumptions	10 CFR § 50.46 (a)(1)(ii), Appendix K
Conservative	Best estimate (realistic) code	Conservative	Conservative assumptions	Current German practice; IAEA NS-G-1.2, § 4.89
Best estimate + uncertainty	Best estimate code + uncertainties	Realistic + uncertainty; partly most unfavourable conditions	Conservative assumptions	§ 50.46 (a)(1)(i), Appendix A; IAEA NS-G-1.2, § 4.90; Draft Revision of German Nuclear Regulation
Risk informed	Best estimate code + uncertainties	Realistic + uncertainty	PSA-based assumptions	Draft change of 10 CFR 50.46



The Licensing Framework





The Road-Map for BEPU

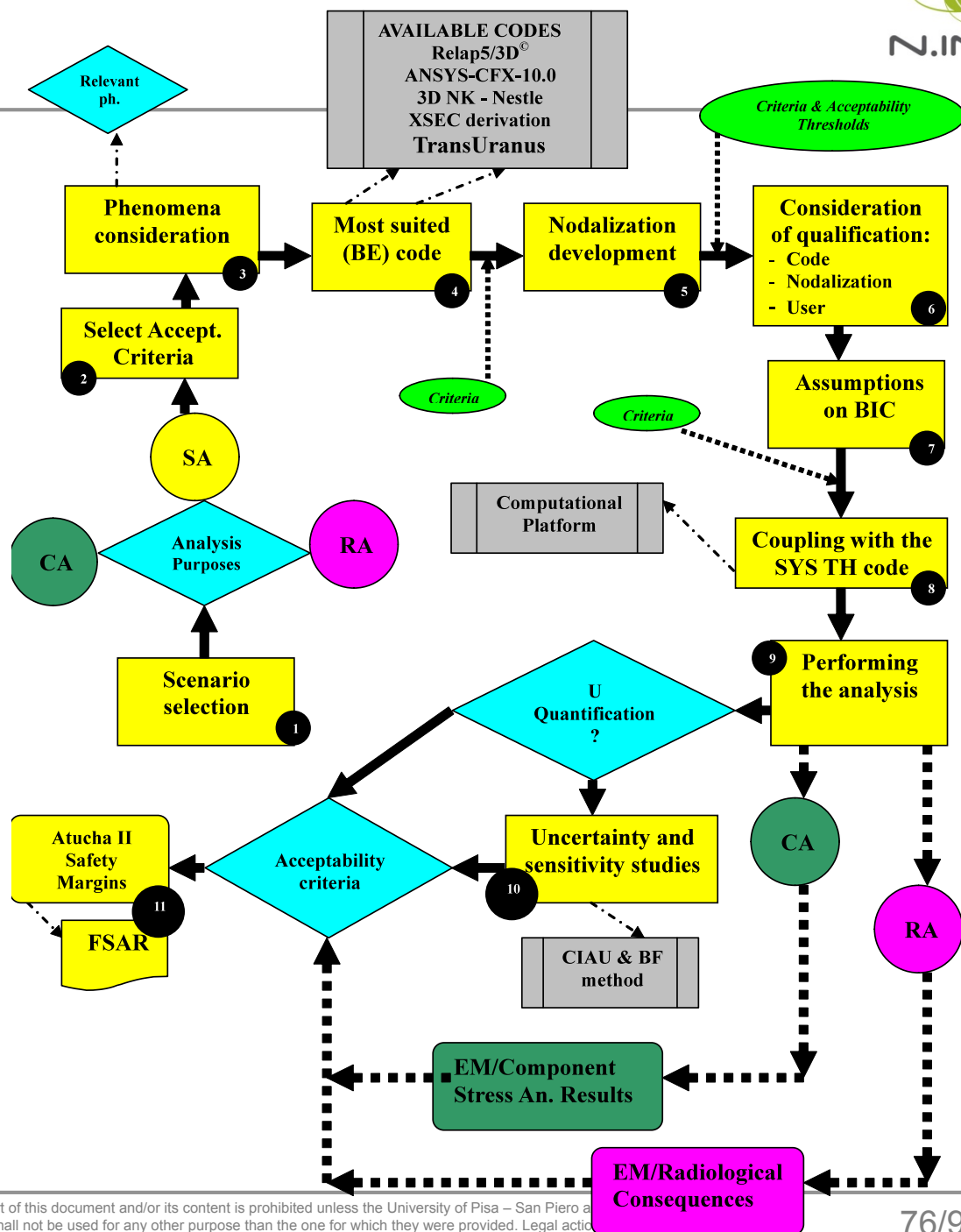


EVALUATION MODEL FLOW DIAGRAMM

SYSTEM ANALYSIS

COMPONENT ANALYSIS

RADIOLOGICAL
CONSEQUENCES
ANALYSIS





THE BEPU PROCESS

THE POSTULATED INITIATING EVENTS (PIE)



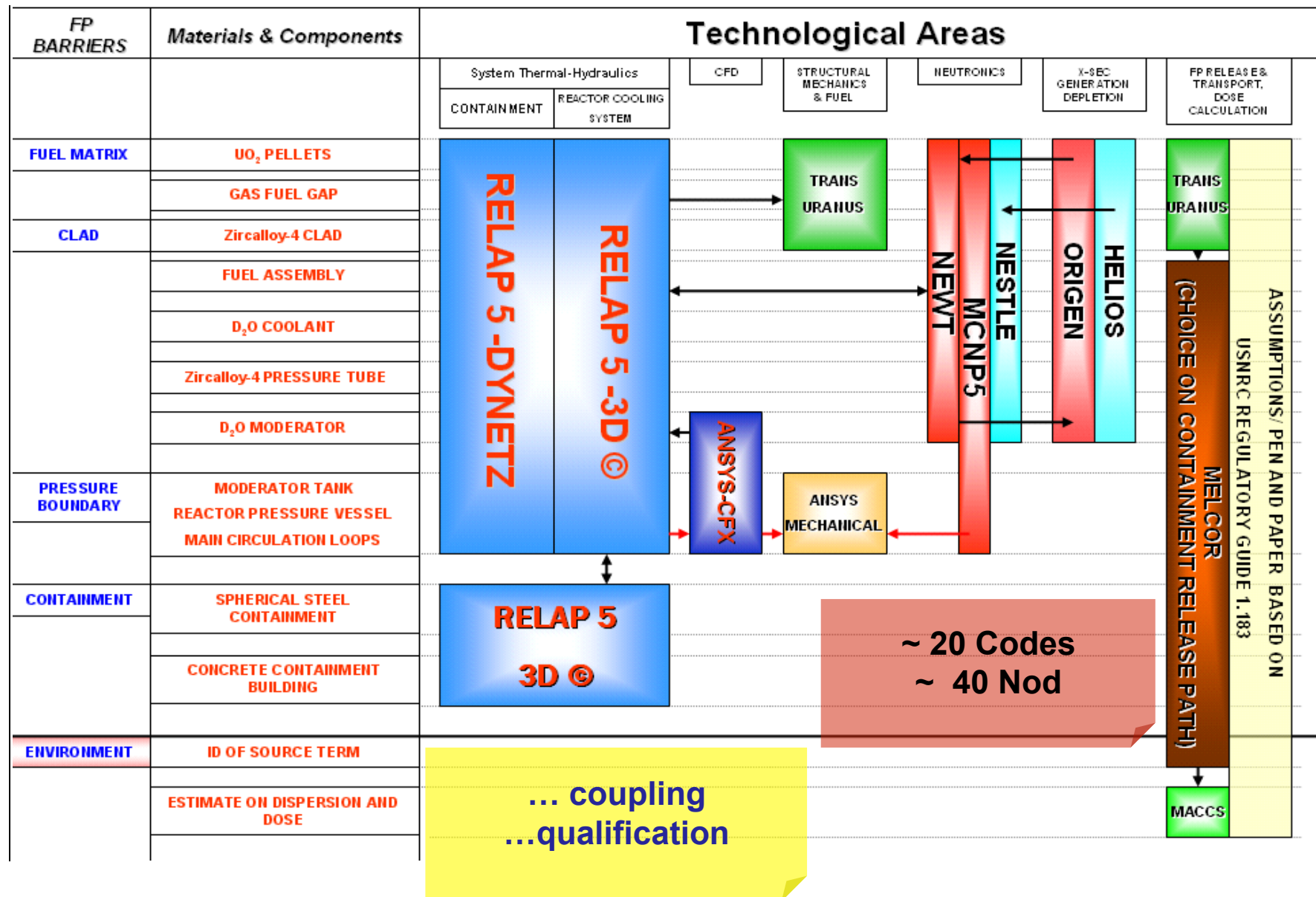
83 NPP
SCENARIOS

No	Transient	Section FSAR	Adopted Evaluation Model	Class of Accident
Increase in Heat Removal by the Secondary System		15.1		
2	FW System Malfunctions that result in an Increase in FW Flow (Stuck Open FW Control Valve)	15.1.2	CSA	AOO
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
9	Inadvertent Closing of the Moderator Cooler Bypass CV	15.1.7	CSA	AOO
36	Uncontrolled CR Withdrawal at the particular Power Level that yields the most Severe Results	15.4.2	CSA	AOO
41	Spectrum of Rod Ejection Accidents	15.4.7	CSA	DBA
Spectrum of SGTR		15.6.3		
46	Single SG Tube Rupture ("Bordihn": SG Tube Failure)	15.6.3.1	CSA	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
72	Leakage on the Refueling Machine and Auxiliary Equipment	15.8.2	RCA	DBA
Anticipated Transients Without Scram (ATWS)		15.9		
74	Mechanical Failure of the Control Rods in case of Emergency Power Mode	15.9.1	CSA	SBDBA



THE BEPU PROCESS

THE COMPUTATIONAL TOOLS

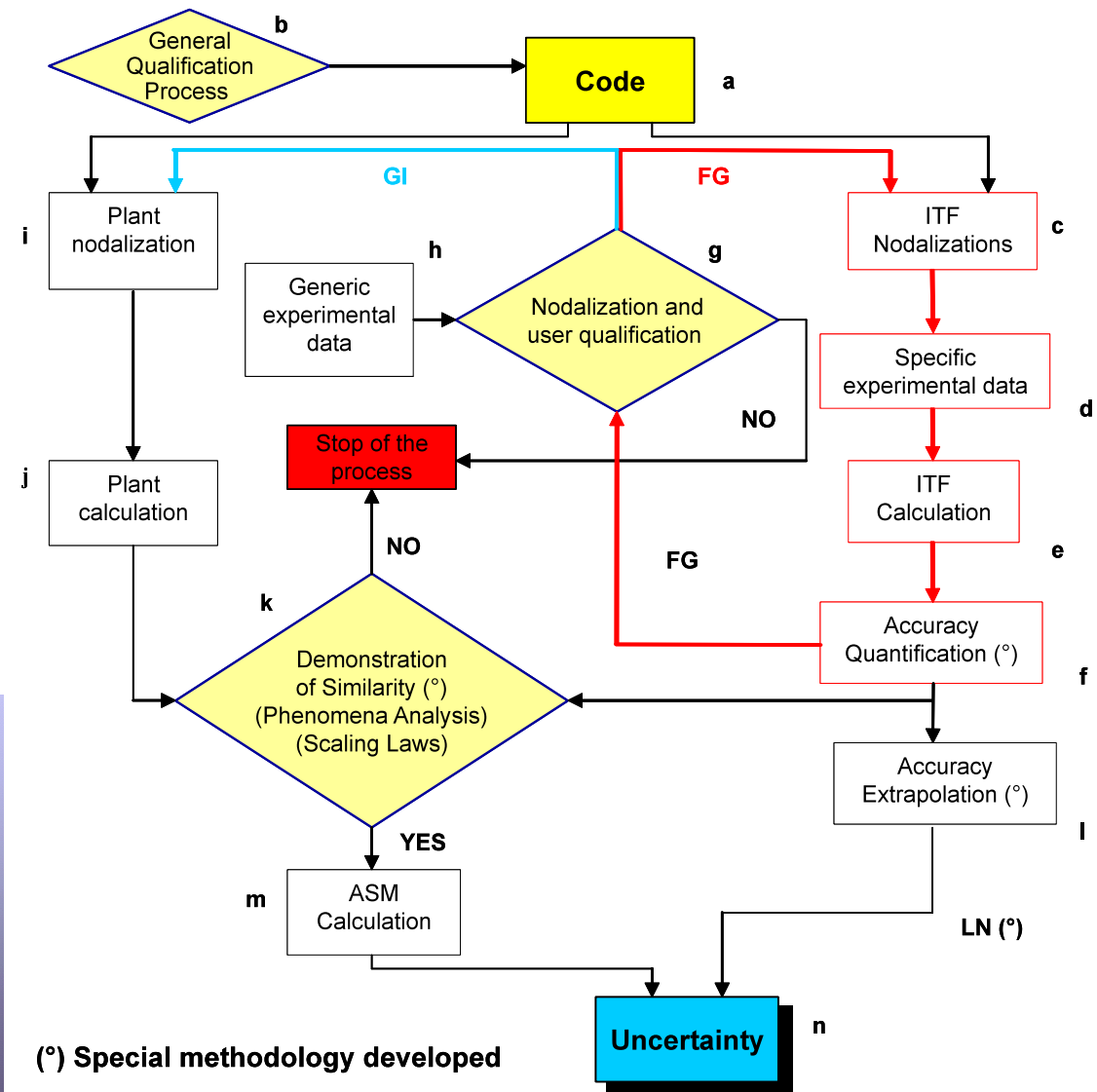
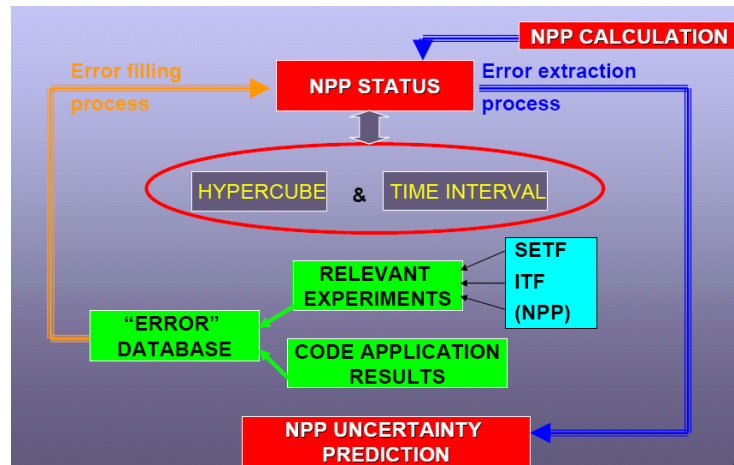




THE BEPU PROCESS

THE UNCERTAINTY METHOD

**THE ACCEPTABILITY
THRESHOLDS**
*(for the use of the uncertainty
method)*





THE BEPU PROCESS

THE CASE 'A' AND THE CASE 'B'



Related to each Transient

For DBA (logic diagram)

Case A (BE): All I&C considered functioning (except PIE) serves to demonstrate the realistic accident course – **4 redundancies working**.

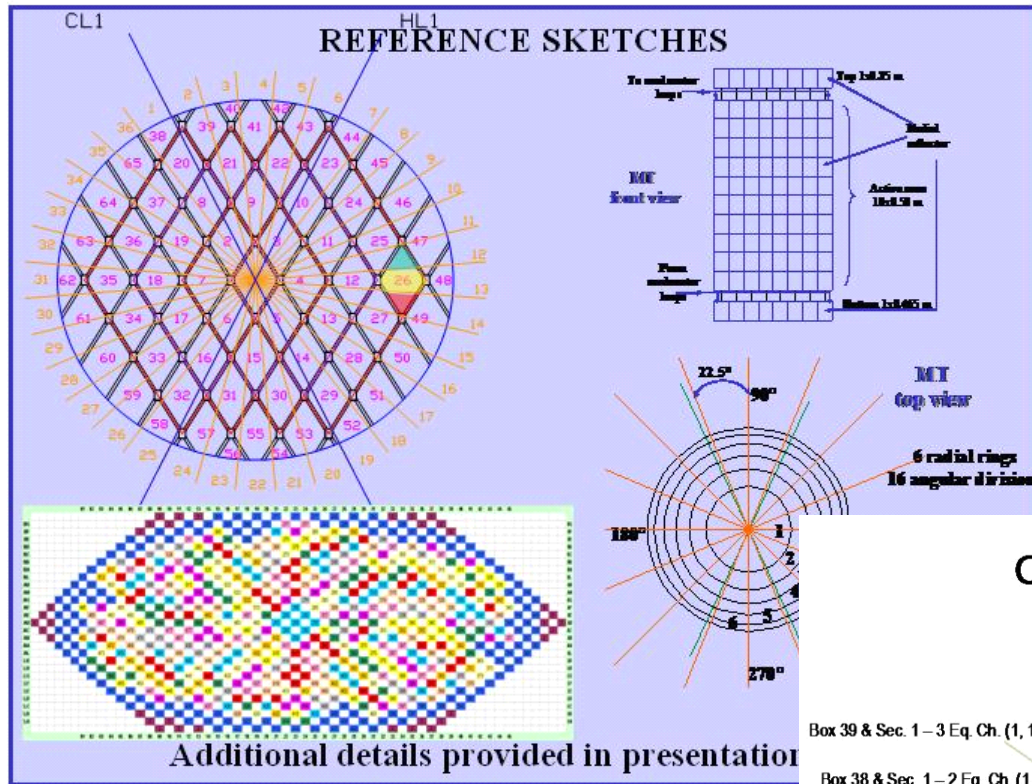
Case B (Conservative Case): Controls having favorable influence are not considered. All limitation systems are assumed to be available and a failure of the first reactor trip system is postulated (**single failure & repair case for most effective redundancies**).



Selected Outcomes from FSAR Chapt.

INPUT DECK

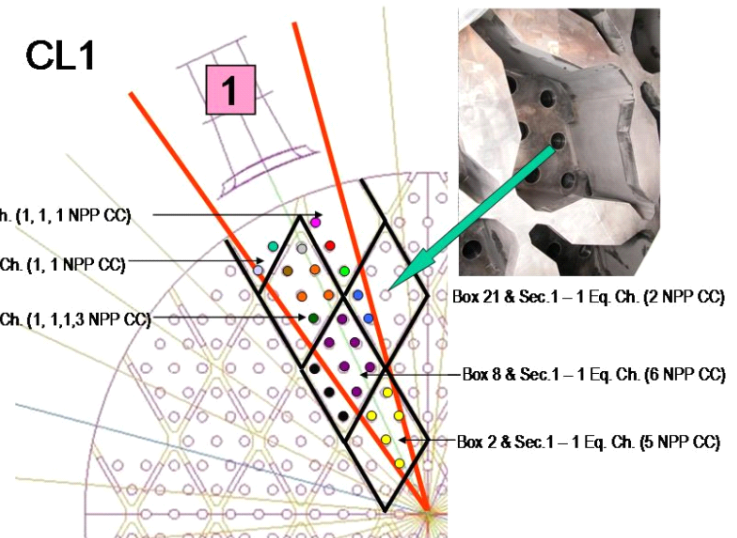
IDENTIFICATION OF NODALISATIONS UNIP1_280CH_3D-MT_3DNK



RESOURCES

No of hydraulic nodes 6342
No of mesh points 53334
No of trips 10
No of lines of the input file 115918

THE COMPLEXITY OF INPUT DECKS

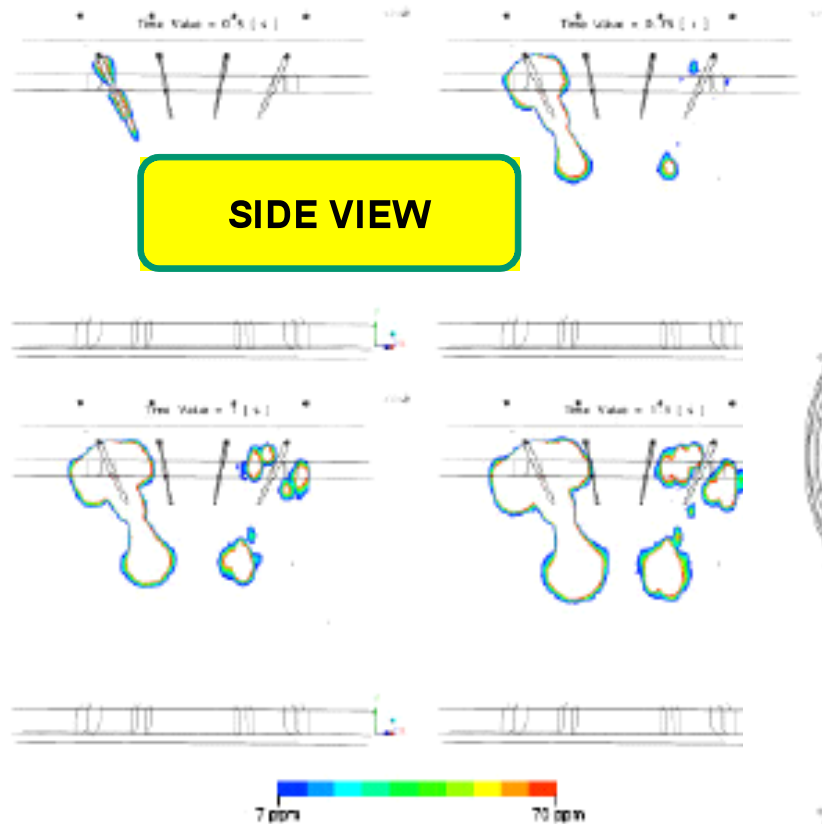




Selected Outcomes from FSAR Chapt.15

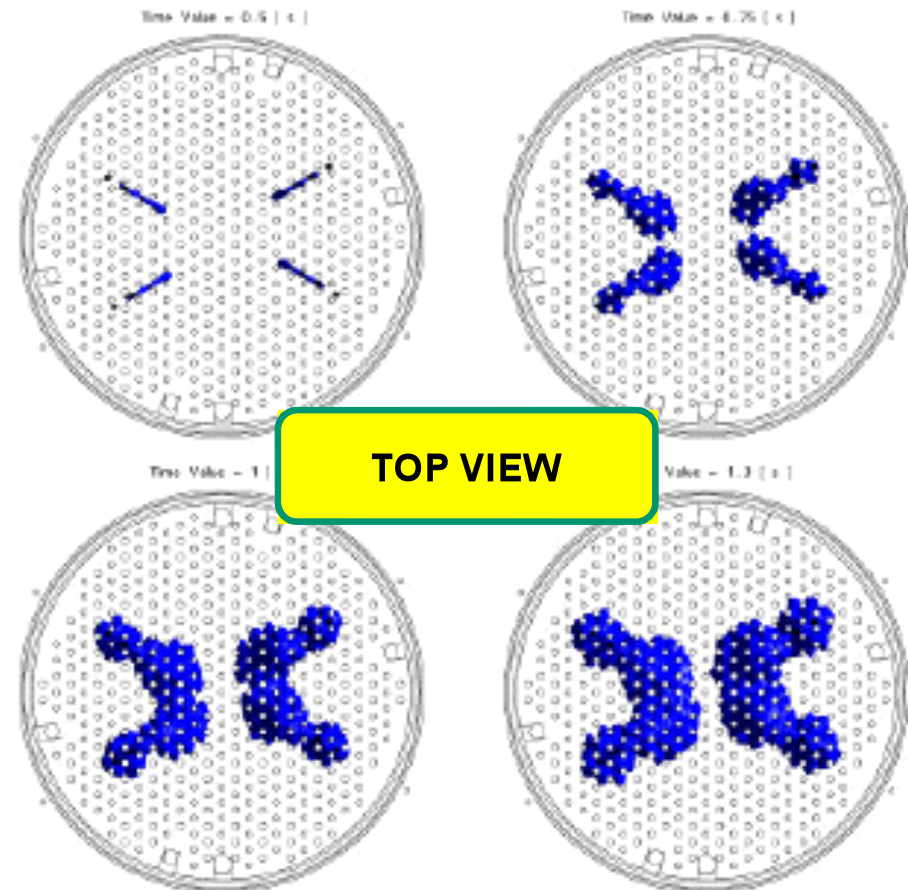
CFD

SIDE VIEW



**BORON INJECTION IN THE
MODERATOR TANK**

TOP VIEW



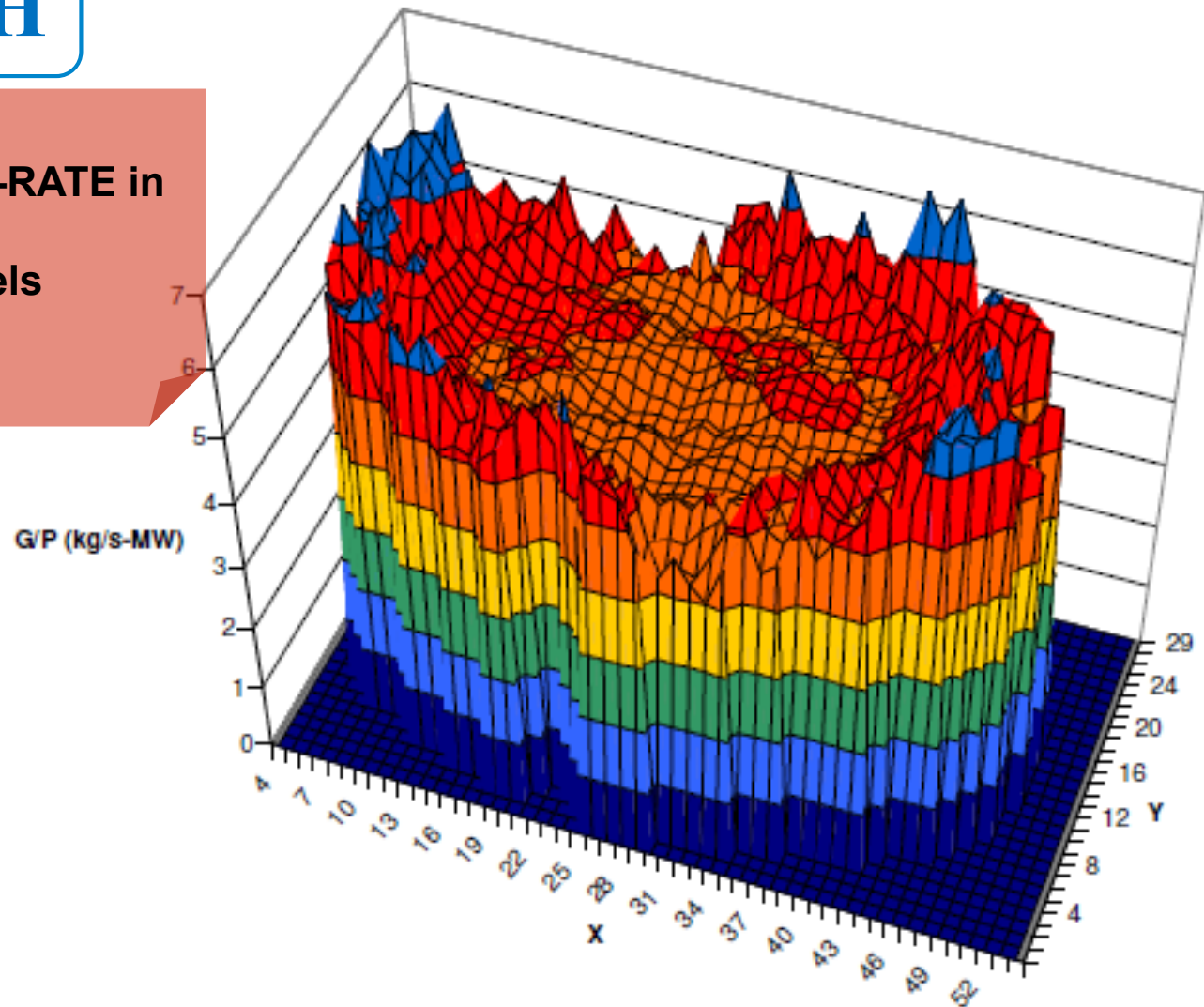


Selected Outcomes from FSAR Chapt.15



3D NK & TH

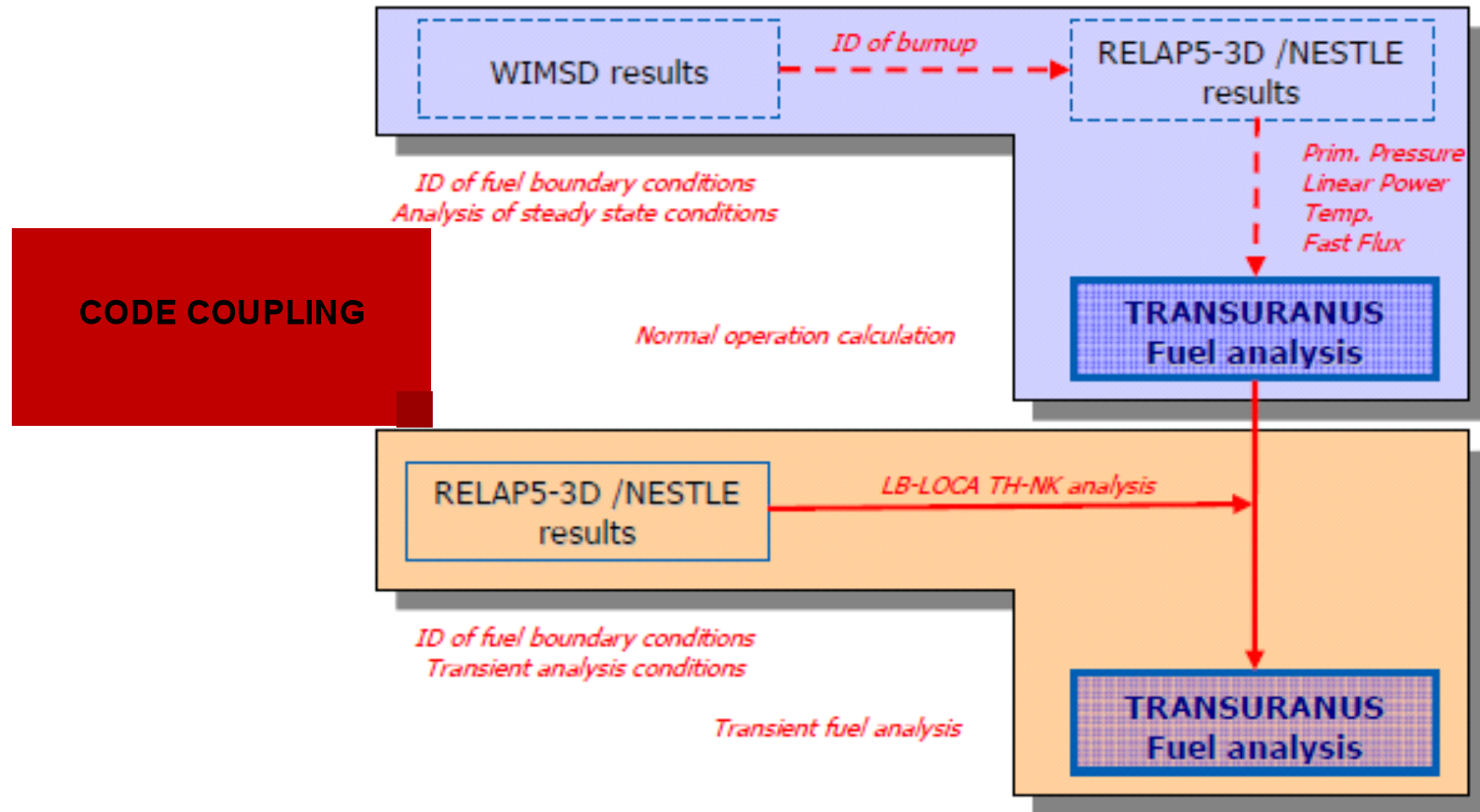
**THE POWER & FLOW-RATE in
each of
451 Fuel Channels**





Selected Outcomes from FSAR Chapt.15

FUEL ANALYSIS



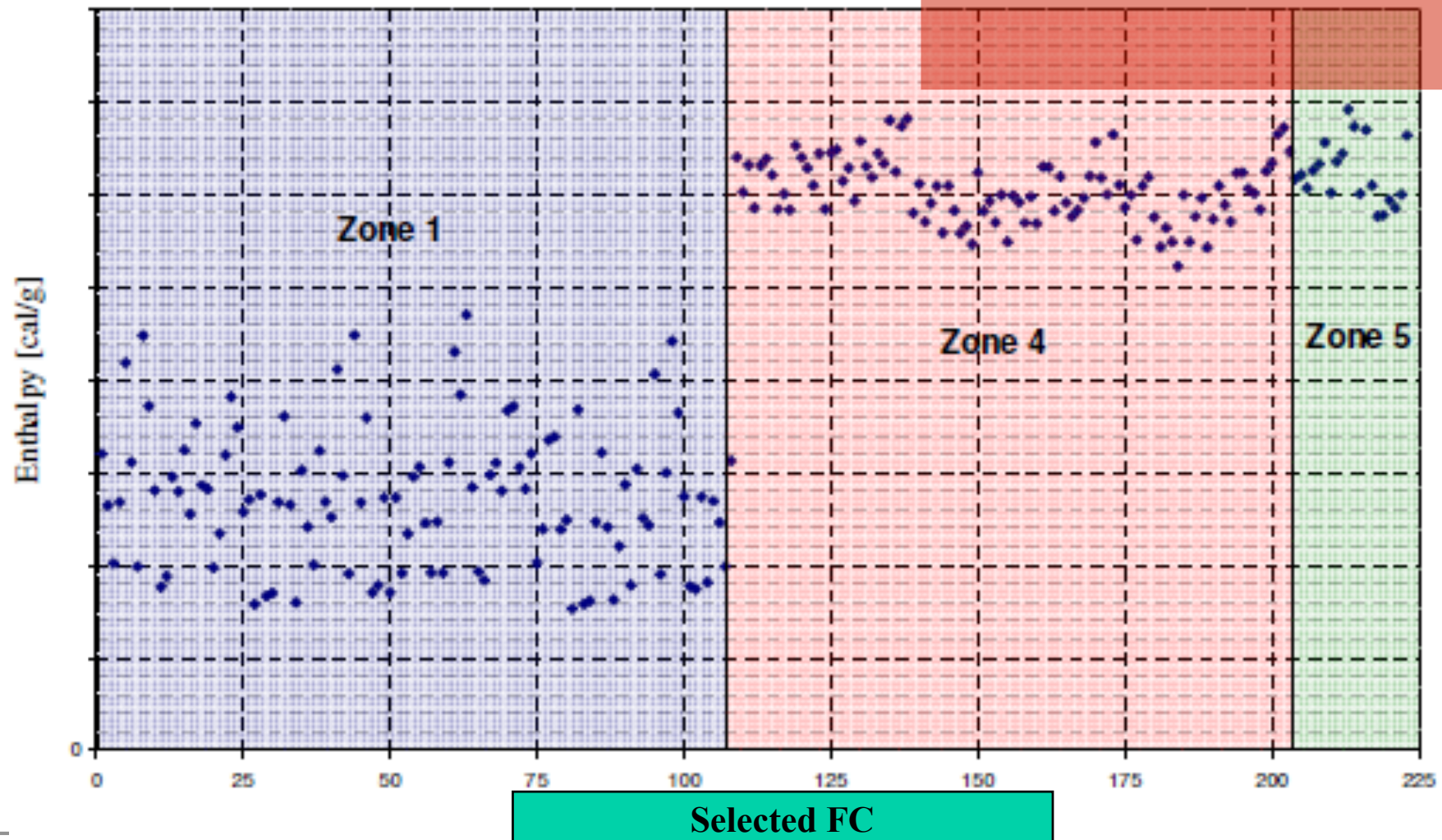


Selected Outcomes from FSAR Chapt.15



FUEL ANALYSIS

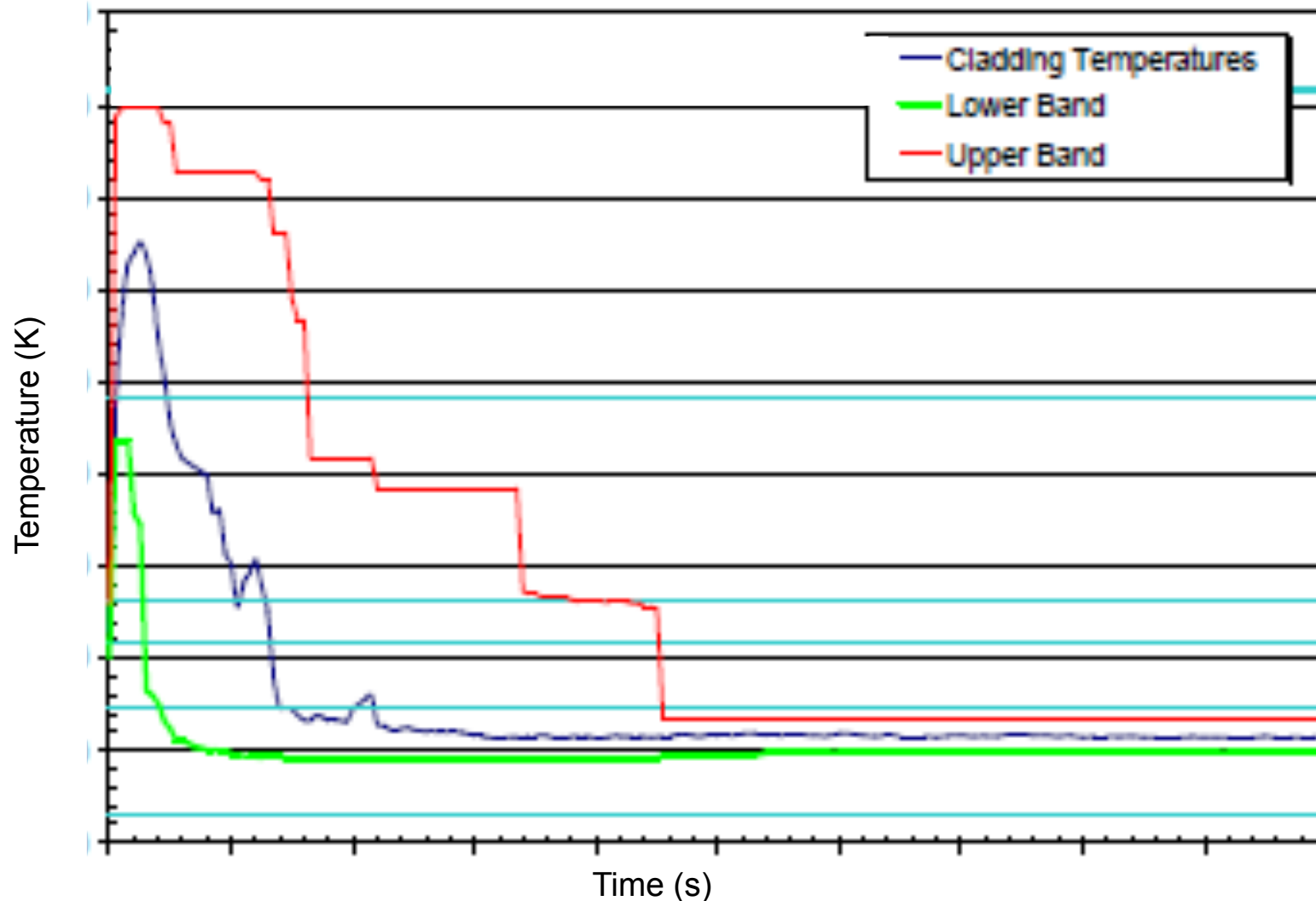
ENTHALPY RELEASE TO THE
FUEL DURING LBLOCA





Selected Outcomes from FSAR Chapt.15

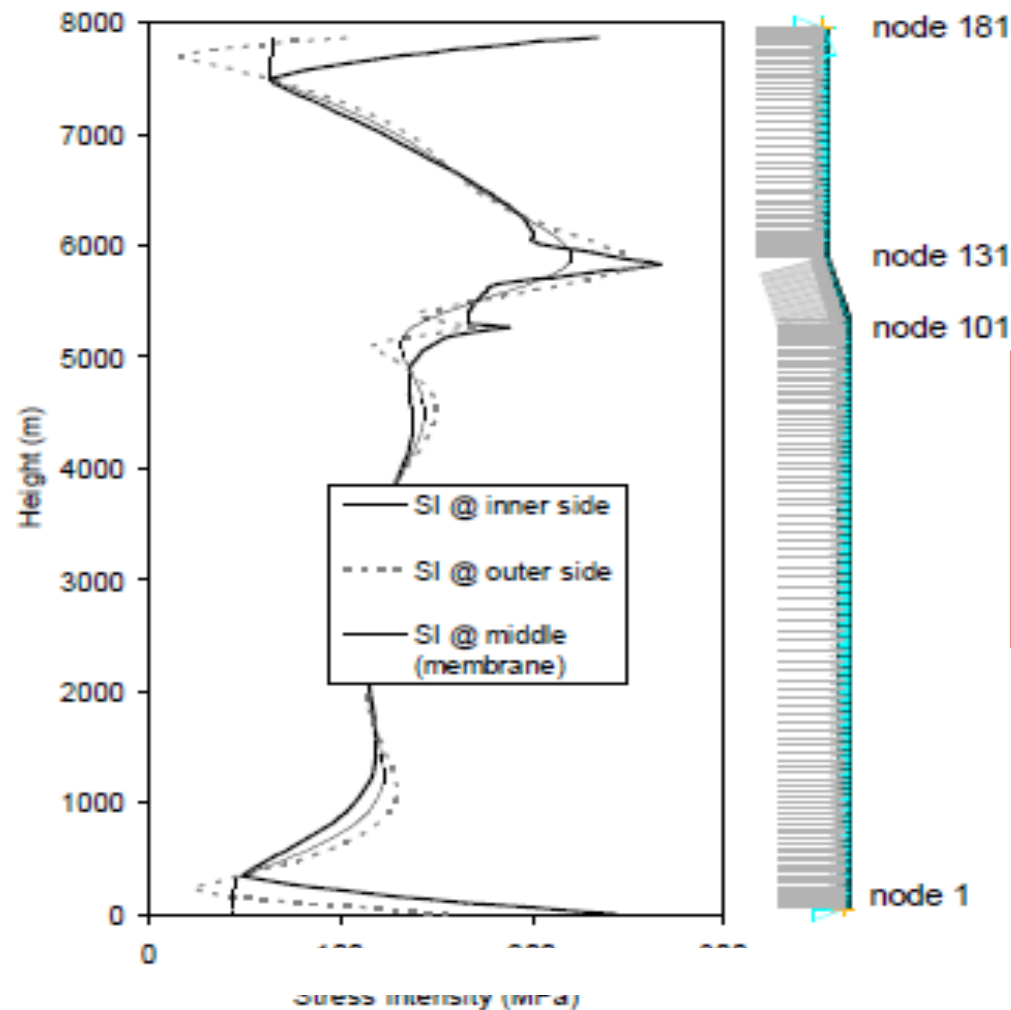
APPLICATION OF UNCERTAINTY





Selected Outcomes from FSAR Chapt.15

MECHANICAL LOADS



**STRESS ON RPV
INTERNALS DURING
LBLOCA**



Selected Outcomes from FSAR Chapt.15

RADIOLOGICAL IMPACT

**Fuel Rupture &
Coolant Radioactivity**



**The Radioactivity in
Primary Circuit**



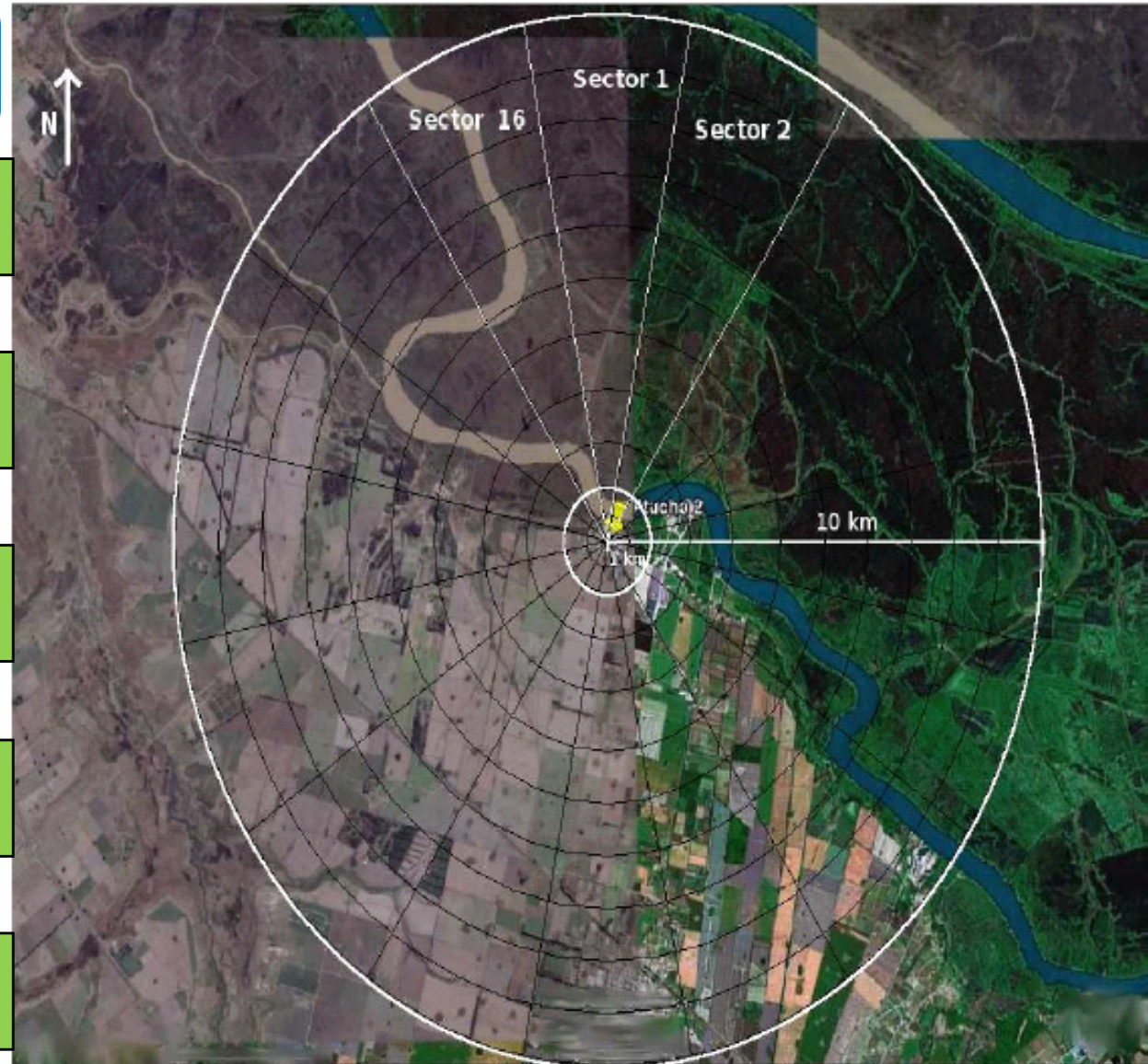
**The Radioactivity in
Containment**



**The Radioactivity in
Environment**



The Doses





THE ATUCHA-2 FSAR CHAPT. 15 PAPER FORMAT



5 VOLUMES

- 2500 pages
- 14 kg of paper
- 1/5 of a pine tree





CONCLUSIONS (1)



- ✓ CONSISTENT AND ADOPTED APPROACHES TO QUANTIFY UNCERTAINTY HAVE BEEN IDENTIFIED

The propagation of code input errors:

'GRS-method like', endorsed by industry and regulators.

The propagation of code output errors:

'CIAU approach', alternative to previous one already used for industrial

Data Adjustment and Assimilation:

With the support of ASAP/FSAP

- ✓ THE MATURITY OF THE FIRST TWO METHODS IS PROVED

(UMS, BEMUSE, INDUSTRIAL APPLICATIONS, REVIEW WITHIN IAEA AND OECD FRAMEWORKS).

- ✓ THE THIRD APPROACH IS INNOVATIVE: AN ESTABLISHED IDEA AND FRAMEWORK TO PURSUE A MATHEMATICALLY BASED ROAD TO EVALUATE THE UNCERTAINTY IN SYSTEM CODE PREDICTIONS, NOT YET A TECHNOLOGY.



CONCLUSIONS (2)



- ✓ The Atucha-2 (about 800 MWe) NPP is to be licensed by BEPU
- ✓ FSAR Chapt. 15 issued and delivered to ARN (Argentinean regulatory body)
- ✓ Challenges:
 - **simulation of control systems**
 - **use of CFD**
 - **use of 3D NK & Coupling**
 - **application of uncertainty method**
- ✓ Suitable safety margins calculated
(‘new’ computational methods applied to ‘old’ NPP design)



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a.petruzzi@nineng.com