REDUCTION OF RADIOLOGICAL ACCIDENT CONSEQUENCES

Overview of the EU H2020 R2CA project:

Reduction of Radiological Consequences of Accidents

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R2CA Final Open Workshop, 29-30 November, 2023

IRSN

Commission européenne

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847656.

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Origin & Context

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- More challenging safety objectives worldwide targeted for NPPs (decrease of radiological consequences, more restrictive safety criteria)
  - For DBA RC reduction down to levels where no more population protection measures necessary (evacuation, sheltering)
  - Considering scenarios more severe than DBA (DEC-A) and implementation of the associated safety measures/provisions
- After FKS large R&D efforts on evaluation of Severe Accident progression and consequences lead to increase the predictability of SA progression and improve their management/mitigation
  - Less efforts paid on ***DBA/ DEC-A leading to reduce the differences in risks associated to DBA and BDBA***
- DBA largely studied and modeled for establishing safety criteria to fulfill safety objectives, but evaluations usually done with very conservative deterministic assumptions/decoupled approaches and fewer efforts paid to best estimate evaluation of RC
  - Conservative evaluations of safety limits not related to bounding scenarios but to ranges of postulated scenarios
  - For LOCA safety objectives often related to clad integrity/core coolability and RC evaluated with specific decoupled assumptions (i.e. in France 33% of the fuel rods assumed to fail)

Framework: HORIZON-2020 (NUGENIA)

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- R2CA devoted to research & development of generic methodologies to assess the safety margins of accidents within DBA and DEC-A domains was fully in line with H2020 framework and was certified by NUGENIA
  - "…update/development of simulation tools to improve safety features and AM strategies for GEN II, III and III+"
  - "…ST re-assessments incl. a particular emphasis on innovative accident management strategies…"
  - "…the results should be reflected in the SAMGs and recommendations should be formulated to improve EP&R…"

- R2CA was especially intended to answer or provide useful information to the following questions:
  - How accurate are the simulations and what should be done to improve them?
  - To what extent accident management strategies could be improved?
  - When possible new safety or mitigation device could be proposed?
  - What are the outcomes that should influence the design of future concepts?

NUGENIA
NUclear GENeration II & III Association

CERTIFICATE
NUGENIA LABEL

Date of certificate issuance: *09/07/2018*
Certificate number: *2018NUG0051*

The NUGENIA Executive Committee during its meeting held on *13-14 June 2018* awarded the NUGENIA Label to the project idea identified as *Reduction of Radiological Consequences in design basis Accident (R2CA)* with the technical content reviewed and published through NUGENIA Open Innovation Platform on the *09/04/2018*.

Signed for and on behalf of the NUGENIA Executive Committee.

NUGENIA
Nuclear Gen II&III Association

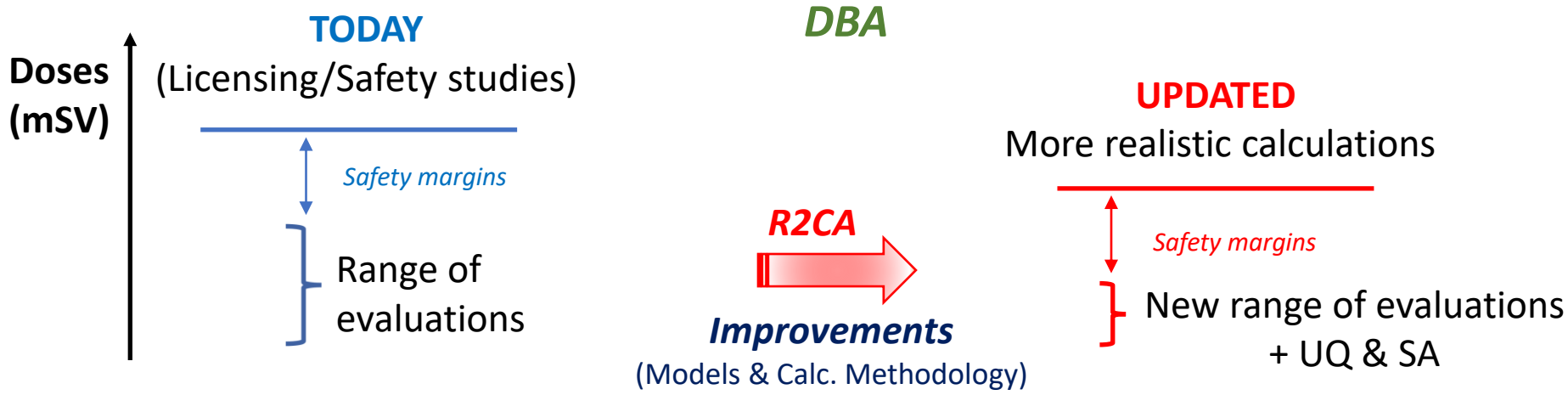
Steve Napier
Executive Committee Chair

NUGENIA LABEL

Motivation

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Refine the assessments of radiological consequences of explicit DBA and DEC-A accidental scenarios **in Gen II, Gen III and Gen III+ NPPs focusing on the 2 main important scenarios (LOCA & SGTR)**



- Increase the level of NPP safety by more realistic evaluations of DBA RC decreasing some of the conservatisms/decoupling factors used can
  - Help better quantification/consideration of potential changes to come in operating conditions (fuel burn-up increase, ATF…)
  - Highlight higher risks exhibited by knowledge improvements (clad embrittlement through Ilary hydriding, higher FP releases from high fuel burn-up or Mox fuel…)
  - Benefit to development of innovative measures, devices or tools to prevent these accidents and strengthen their management
- Strengthen assessments of NPP safety levels considering situations more severe than those integrated in plant designs (DEC-A domain ↔ wo "*significant fuel melting*")

Objectives & Methodology

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- General objectives of R2CA for a best estimation of LOCA & SGTR radiological consequences
  - Upgrade models, simulation tools (integral, detailed) & improve calculation schemes (coupling…)
  - Quantify gains through two set of full range of reactor simulations up to FP releases in environment
  - Provide recommendations towards harmonization of calculation methodologies for more realistic RC evaluations
  - Optimize accident management procedures (development of new/improved algorithms…)
  - Evaluate innovative systems (ATF, safety devices, algorithms…)
  - Develop innovative tools based on expert system for earlier diagnosis of defective rods and (SGTR) accident anticipation

Focus on : PWRs/EPR/VVERs/BWR, LOCA/SGTR, DBA/DEC-A, Radiological Consequences, AMPs

Methodology

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- LOCA reactor calculations

Select Accidental Scenarios for each reactor type

Perform simulations according to **own used approaches** (regulatory practices in each country, safety studies, DEC-A analyse EU/IAEA standards…) generally conservative/with decoupling factors esp. for DBAs

1- Improve failed rod number prediction: statistical approach, core modelling refinement (extension approach)

2- Improve fuel rod failure models: clad burst criteria update

3- Improve FP-release/transport models: consideration of HBS, fuel oxid./frag…

Improvements

Reduction of conservatisms (decoupling factors)

Perform simulations according to a **more realistic** (≈ **Best-Estimate) approach**

same scenarios with improved models & calc. schemes

Quantify the gains through RC evaluation comparison of initial/new calc. methods

Evaluate innovative systems (ATF, new AMPs…)

Sensitivity Analyses & Uncertainty evaluation

Expected outcomes

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Updated/advanced knowledge, understanding & modelling (beyond SoA) of radiological source term
  - Dedicated experimental database associated to phenomena occurring in LOCA/SGTR within DBA/DEC-A conditions
  - Upgraded reference simulation tools with improved (more mechanistic) models re-assessed on the database
  - Advanced tool coupling and integral calculation chains (for LOCA & SGTR) from initiating events to FP envt releases
  - Databases of updated LOCA/SGTR DBA/DEC-A calculation results
- Generic evaluation methodologies for safety margin re-assessments of LOCA/SGTR in DBA & DEC-A domains applicable to existing European NPP designs or to be used for safety studies future reactor design safety studies
  - Reinforcement of competences on reactor safety and on evaluating radiological consequences
  - Support the integration of DBA and DEC-A accident risks in the design phase of future LWR concept
- Innovative actions to pave the way to the design & implementation of new approaches/devices as possible back fitting options for the operating fleets or for the future concepts
  - Demonstration of the ability of expert system (e.g. neural networks) for accident prognosis/prevention (e.g for identification/location of defects in fuel rods)
  - Proposals for accident management strategies optimization & evolutions in reactor designs
  - Derivation of some principles for EP&R action optimization

Expected outcomes

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Public Dissemination

WP1	D1.5	First yearly activity report	IRSN
	D1.6	Second yearly activity report	IRSN
	D1.7	Third yearly activity report	IRSN
	D1.8	Final project synthesis activity report	IRSN
WP2	D2.1	LOCA and SGTR DBA and DEC-A available evaluation methodologies	BEL V
	D2.2	LOCA and SGTR available simulation codes	VTT
	D2.3	LOCA and SGTR available experimental data	MTA EK
	D2.4	Minutes of the Senior Expert Group meeting	IRSN
	D2.6	Uncertainty analyses	NINE S.R.L.
	D2.7	Reassessment of reactor tests cases	LEI
	D2.8	Updated harmonized methodologies	BEL V
WP3	D3.2	Final report on fission product relase during LOCA	NRI
	D3.4	Final report on rod cladding failure during LOCA	IRSN
	D3.6	Final report on fuel rod behaviour during LOCA	JRC
WP4	D4.2	Final report on fission product release during SGTR	CIEMAT
	D4.4	Final report on rod cladding failure during SGTR	POLIMI
	D4.5	Failure criteria for defective fuel rods during SGTR	IRSN
WP5	D5.1	Report on Pro and Cons of innovative devices and management approaches	NINE S.R.L.
	D5.2	Report on innovative diagnosis tools and devices	IRSN
	D5.3	Report on Pro and Cons of ATF	EDF

- Shared reactor calculation database

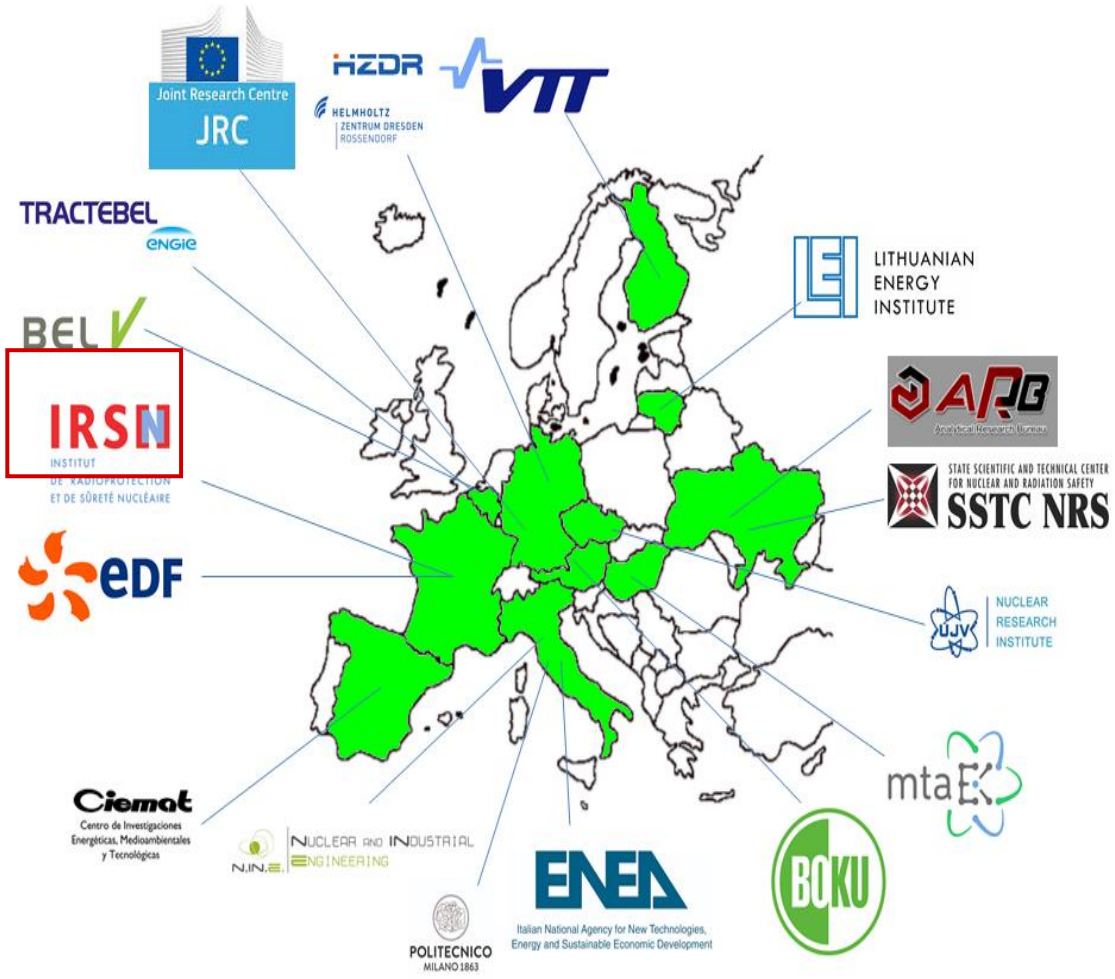
– 20 reports (on Zenodo-R2CA community and R2CA external website (https://r2ca-H2020.eu))

– 4 News letters posted on R2CA website and social networks

Structure

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Ressources 17 organisations
- Time frame 01.09.2019 – 31.12.2023



Promote the dialog between:

- Industrials, R&D & academic partners, TSOs
- Eastern/werstern european countries with different NPP concepts, regulatory practices
- Fuel safety and source term/accident consequence communities

Structure

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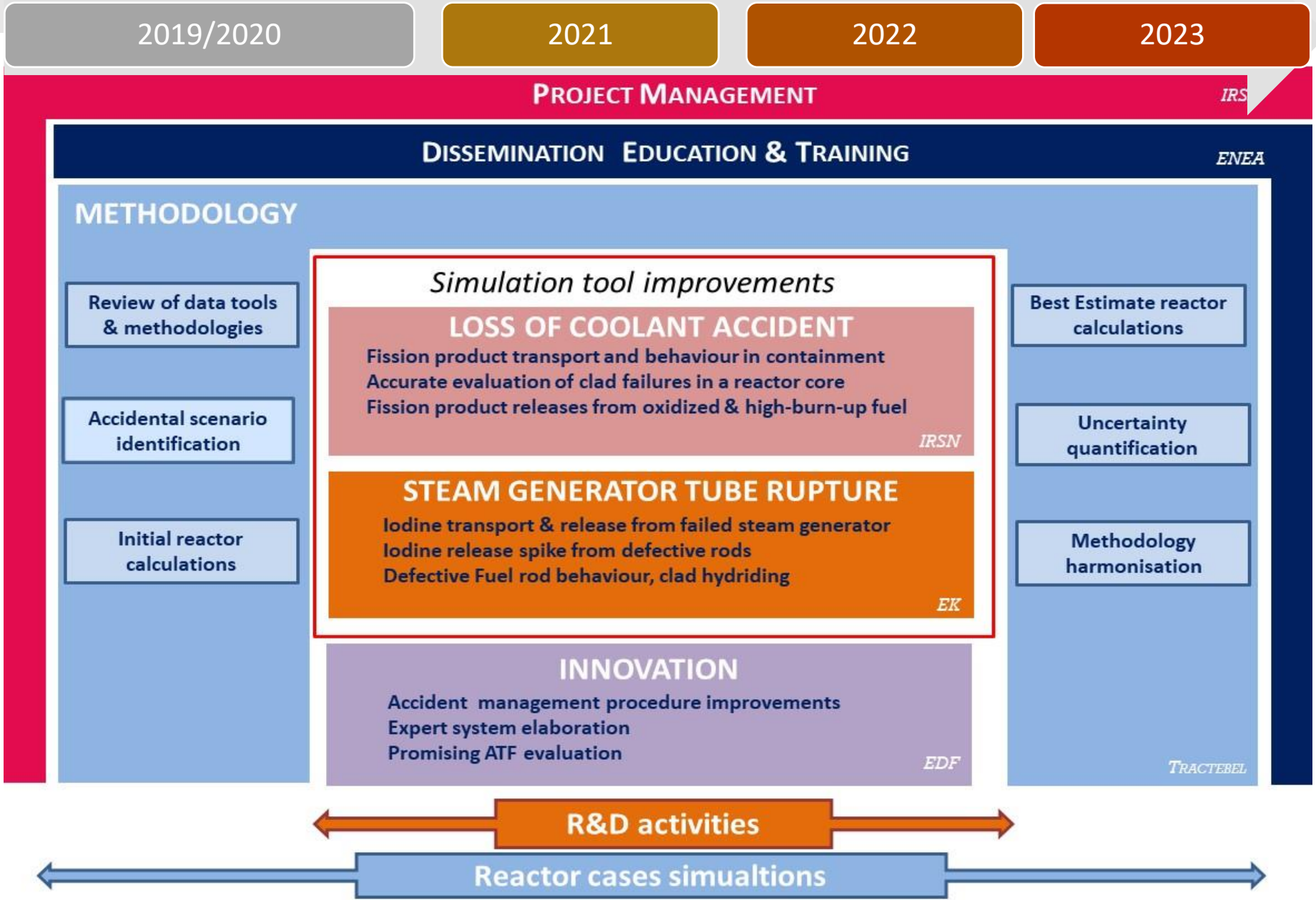
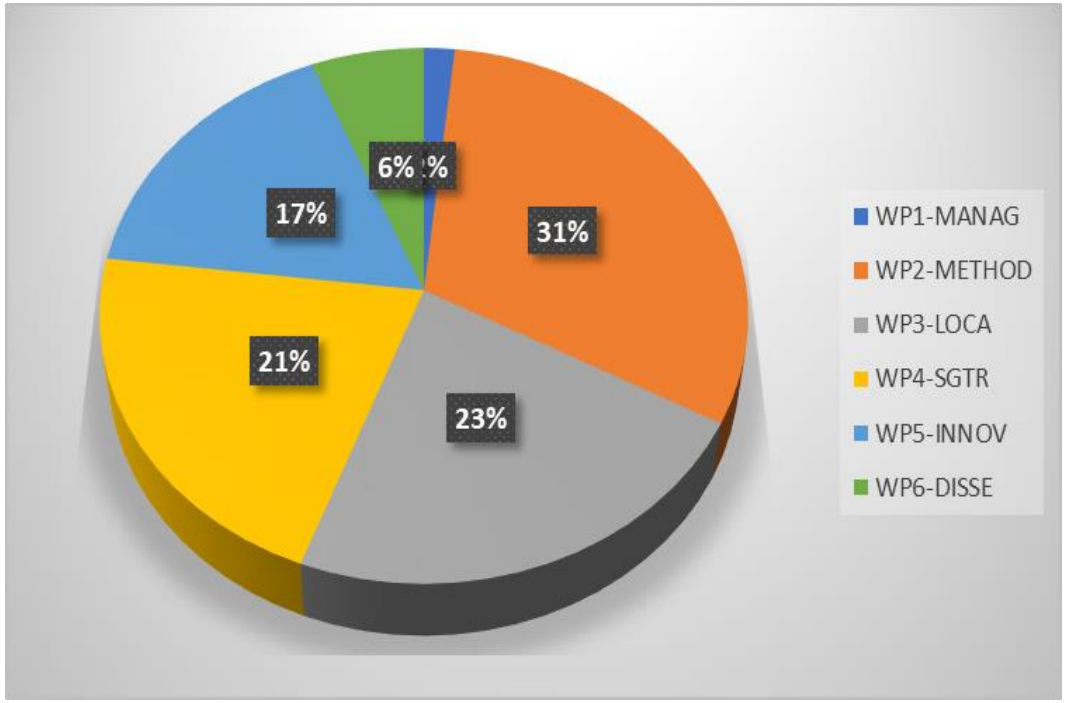


Structure

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Ressources distribution



Total ressources : ~ 535 pm

Total budget : ~ 4157 k€ (76% EU funded)

Specific R&D objectives: WP3-LOCA

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Develop/upgrade of models, simulation tools, calculation schemes in support of more realistic evaluations of LOCA DBA & DEC-A Radiological Consequences

- Identifying main relevant phenomena where model improvements are needed
- *Developing models & coupling tools to reduce conservatisms/decoupled factors*
- *Verifying/validating models & tools within range of DBA/DEC-A conditions based on R2CA built exp. database*

T3.1 «FP releases from primary circuit»

AMBITION

Better evaluation of envirt ST for more appropriate decisions in EP&R.

OBJECTIVES

Model refinements for FP behaviour in I^{ary} circuit & containment (esp. Iodine)

T3.2 «Clad burst failure»

AMBITION

More accurate evaluation of number of failed fuel rods for better evaluation of I^{ary} circuit contamination

OBJECTIVES

Improvt/Elaboration of new clad burst models/criteria + improved core modelling approaches

T3.3 «Fuel rod T/M & FP releases»

AMBITION

Refined evaluations of FP release kinetics for better evaluation of fuel rod gap inventory

OBJECTIVES

Upgrading of FP release models/tools + coupling to fuel T/M tools

Specific R&D objectives: WP4-SGTR

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Developt/upgrade of models, simulation tools, calculation schemes in support of more realistic evaluations of SGTR DBA & DEC-A Radiological Consequences

- Identifying main relevant phenomena where model improvements are needed
- *Developing models & coupling tools to reduce conservatisms/decoupled factors*
- *Verifying/validating models & tools within range of DBA/DEC-A conditions based on R2CA built exp. database*

T4.1 «FP releases from primary circuit»

AMBITION

Better evaluation of envirt ST for more appropriate decisions in EP&R.

OBJECTIVES

Upgrading of models for primary/secondary FP transfer (e.g. iodine flashing, carry-over)

T4.2 «FP releases from defective rods»

AMBITION

More accurate evaluation of primary circuit contamination in N.O. & transients

OBJECTIVES

Devpt/refinemt of models for FP releases from defective fuel rods (e.g. activity spike)

T4.3 «Clad secondary hydriding & failure»

AMBITION

Evaluation of the risks of defective fuel rod failure

OBJECTIVES

Devpt of models for clad secondary hydriding in defective fuel rods & clad failure criterion

Specific objectives: WP5-INNOV:

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Develop technological innovations for reduction of RC in LOCA/SGTR DBA & DEC-A

- *Accelerating* integration of technological breakthroughs (providing *global and long-term vision)*
- Identifying/tackling *technological and scientific challenges*

T5.1 « Pro and Cons of innovative devices and management approaches »

AMBITION

Best measurement at the right spot for better decisions, SA prevention

OBJECTIVES

Optimization of AMPs (SGTR)

T5.2 « Innovative diagnosis tools and devices »

AMBITION

In real time, collect/analyze, harvest values of plants operating param. for earlier diagnosis/increase safety

OBJECTIVES

Elaboration of a prototype expert system for rod defect identification/location

T5.3 « E-ATF Anhanced accident tolerant fuel »

AMBITION

Give all nuclear power plants benefit of a fuel that can better withstand accidents.

OBJECTIVES

Evaluation of promising ATF (Cr-coated Zr clad, Cr-doped fuels

Summary

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- R2CA project devoted to elaboration of generic & more realistic calculation methodologies for radiological consequence evaluations of LOCA/SGTR transients in DBA & DEC-A conditions focussed on:
  - Upgrading, & validation of reference tools (detailed and/or integral) from fuel behaviour to environmental FP releases
  - Recommendations for Harmonization of calculation methodologies applicable to all existing European LWR designs (PWR, BWR, VVER)
- Innovative actions also investigated for their potential applications to reduce the radiological consequences of LOCA/SGTR within those conditions
  - Evaluation of near-concept ATFs for LOCA with updated calc. schemes (sensitivity analyses on material base properties)
  - Investigation/evaluation of innovative devices/systems (algorithms), optimisation of accidental management procedures (additional water injection, dedicated instrumentation…)
  - Use of “Expert system based” on ANN for anticipation of SGTR accidental sequences (turn prognosis tools into diagnosis ones for early detection of defective fuel rods)

Thank you!

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