R2CA Newsletter

Issue 4

15/01/2024

Last news from R2CA

Most of the last year was devoted to updating accident sequence calculations using improved calculation chains and simulation tools (benefiting of the implementation of some refined models developed during the project itself), and to assessing the gains obtained in terms of radiological consequences by comparing these latest calculation results with the initial calculation results. As expected, due to the reduction of some of the conservatisms used in the initial calculations for most of the re-assessed reactor accidental scenarios the radiological impact was reduced.

The synthesis of all this work, currently underway, is feeding the formulation of recommendations for the harmonization of radiological consequences evaluation methodologies also in progress.

A great part of work has also been carried out in the work-packages dedicated to innovation, with a particular emphasis on optimizing accident management procedures in SGTRs and finalizing the development of a prototype expert tool based on neural networks, dedicated to the early diagnosis of defective fuel rods to improve their management. All this work has been and continues to be carried out under the best possible conditions, thanks to the 4-month extension granted to the project by the European Commission.

Finally, this last period was also rich in terms of communication and knowledge dissemination, notably with a well-attended summer school on DBA & DEC-A for LWRs held in July 2023 in Bologna and the preparation of 18 dedicated open papers to be published on-line in a R2CA special issue of Annals of Nuclear Energy.

To close the project, its most important outcomes and main advances will be presented and discussed during an open workshop organized at the end of November in IRSN headquarters in Paris.

Nathalie Girault (IRSN)

TASK 2.5: Main outcomes of second set of reactor calculations

The main outcomes from the first set of reactor calculations were used to identify the needs in terms of code/model improvements, to reduce some of the conservatisms in modelling assumptions and to upgrade calculation chains by including for example more detailed (mechanistic) computer codes. The results of the first set of the simulations served as a reference point for a second set of simulations of the same LOCA and SGTR transients performed after the improvements and was used to quantify the gains in terms of radiological consequences (RC) of the updated calculation methodologies.

The improvements made were of two kinds:

- Modelling improvements. For LOCA transient calculations, partners were improved thermomechanical models for clad ballooning and burst, new clad burst criteria were built. Also core nodalization was improved (made in more details or reorganized based on best practice and results of parametric analyses). For SGTR transient calculations, partners dedicated improvements on fission product modelling: initial primary contamination and FP transient spiking releases, dilution in RCS, transport, scrubbing, partitioning, atomisation, speciation etc. Partners also improved their thermohydraulic model using refined model for the relief/safety valves of the steam generators (SG) or optimizing the Emergency Operating Procedures (EOPs).
- Improvements in the calculation chains. Detailed (mechanistic) computer codes were also used in partners calculations, often as a support of less detailed codes. For LOCA calculations for instance, detailed fuel performance codes were used to reflect fuel thermal and thermomechanical processes. Also detailed codes, coupling thermal hydraulics and thermomechanics models have been used to better predict clad ballooning and burst at subchannel level. For SGTR calculations, more detailed codes were also used for modelling spiking FP releases from defective fuel rods at transient onset, primary FP transport and chemistry and phenomena occurring at water/steam jet location (flashing…). Some partners used different modelling approaches from those used in the first calculation set.

In total 34 accidental scenarios (both LOCA and SGTR) were calculated in the second set of calculations on different kinds of reactor designs (VVERs, PWRs, EPR and BWR), covering both DBA and DEC-A conditions.

Mentioned improvements mainly concerned, for LOCA, thermal mechanical phenomena in fuel rods (LOCA) and, for SGTR, FP releases, transport and behaviour in primary circuit and in the failed steam generator. Thus, in the second calculation set, there was no significant change in thermo-hydraulics results, for most partners. The major changes were made in clad thermomechanics and in FP releases and behaviour.

For LOCA scenarios, most of the partners achieved significant lower fuel rod burst percentage after provided improvements. This directly involved a significant reduction of the primary contamination and FP activity transport to containment and environment. Thus, when very conservative assumptions were used in the first calculation set, a reduction of almost 99% the environmental activity has been observed, while this reduction didn't exceed 22% when more realistic assumptions and/or more detailed simulation tools have been used. - Also, the results of second calculation set were found to be less scattered, especially for PWR type reactors, where the environmental activities differed by one order of magnitude compared to two in the first calculation set.

For SGTR scenarios as explained earlier, partners improved their simulation scheme mainly on the FP inventory and transport aspects. Therefore, except for two partners who also improved their thermohydraulic part as well, there is no change on the calculated cumulative steam/liquid water released in environment. Thanks to more realistic models for FP transport and interaction in the RCS and

SG, partners achieved a reduction of the activity releases in the environment between 17 to 97 %. Nonetheless, two partners calculated higher activity releases with the second set of calculations.

Radiological consequences were evaluated for the first and second sets of calculations. The results are consistent with what is observed with the activity releases to the environment: radiological consequences are reduced in the second set of calculations compared to the first one, except for two SGTR transients.

The calculated doses for all analyzed transients (both LOCA and SGTR) and conditions (DBA and DEC-A) always stayed under acceptance criteria.

T. Kaliatka (LEI), P. Foucaud (TE), N. Girault (IRSN)

TASK 2.6: Towards harmonization of the RC evaluation methodologies

Several "recommendations" were expressed in order to sustain the evolution of the methodologies through more realistic (less conservative) results in terms of RC of LOCA and SGTR. These recommendations are sorted considering each barrier based on the structure of the initial review of the existing RC evaluation methodologies performed within the project. The choice was made to promote recommendations based on their impact on quantitative results in terms of RC.

Without being exhaustive, here is an overview of the recommendations:

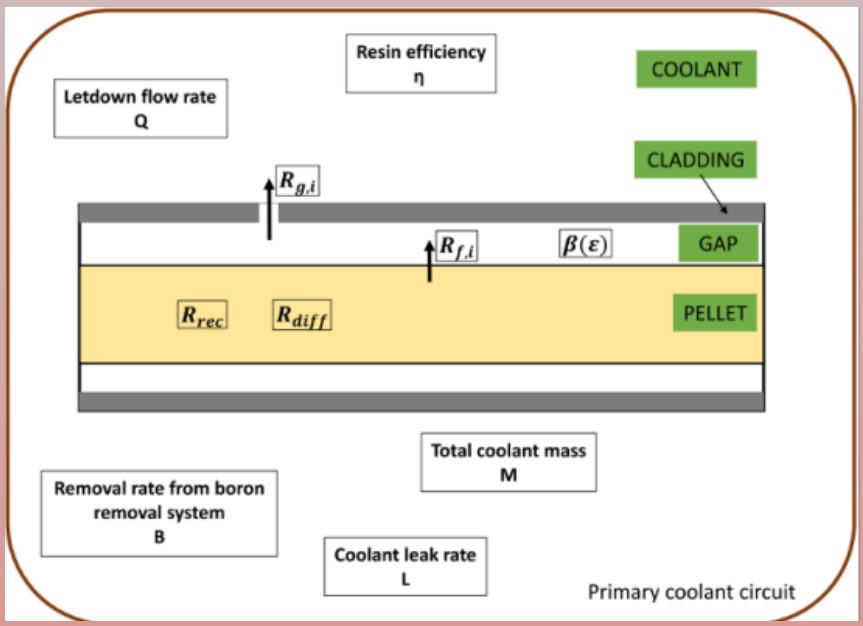
- LOCA. Fuel source term: regarding fuel rod burst failure, using a 3D core model appears to be crucial for asymmetric transient like LOCA; refining the evaluation of the FP's inside the gap inventory appears to be important; coupling Thermohydraulics and thermo-mechanics; expressing specific rods initial conditions (internal pressure, burnup…); using more realistic criteria of cladding bust as developed during the project. Transfer from containment to environment: as important information, noble gasses represent at the same time the most dominant contributor and their behavior is easier to treat than other FP's; valuable to evaluate the time dependent speciation of iodine in the containment in order to quantify their amount in each phase; selecting adapted hypotheses about containment venting and filtration is important as well as considering FP retention on its surfaces.
- SGTR. Fuel source term: regarding gap release, the project illustrated the importance of the initial RCS contamination and spiking model, a large choice of best-fitted spiking correlations exist from the most simple to the most advanced, supported by codes or not. Transfer to and in affected SG: using more realistic value for the part of break flow which is transformed into aerosols based on test facility results for uncovered break scenarios; valuable to evaluate iodine speciation in the primary to better estimate iodine flashing and partitioning. Transfer to environment: distinguishing phases with their own activities in the secondary appears valuable in order to not directly release flashed part of the break flow.

Parmentier Francois (BELV)

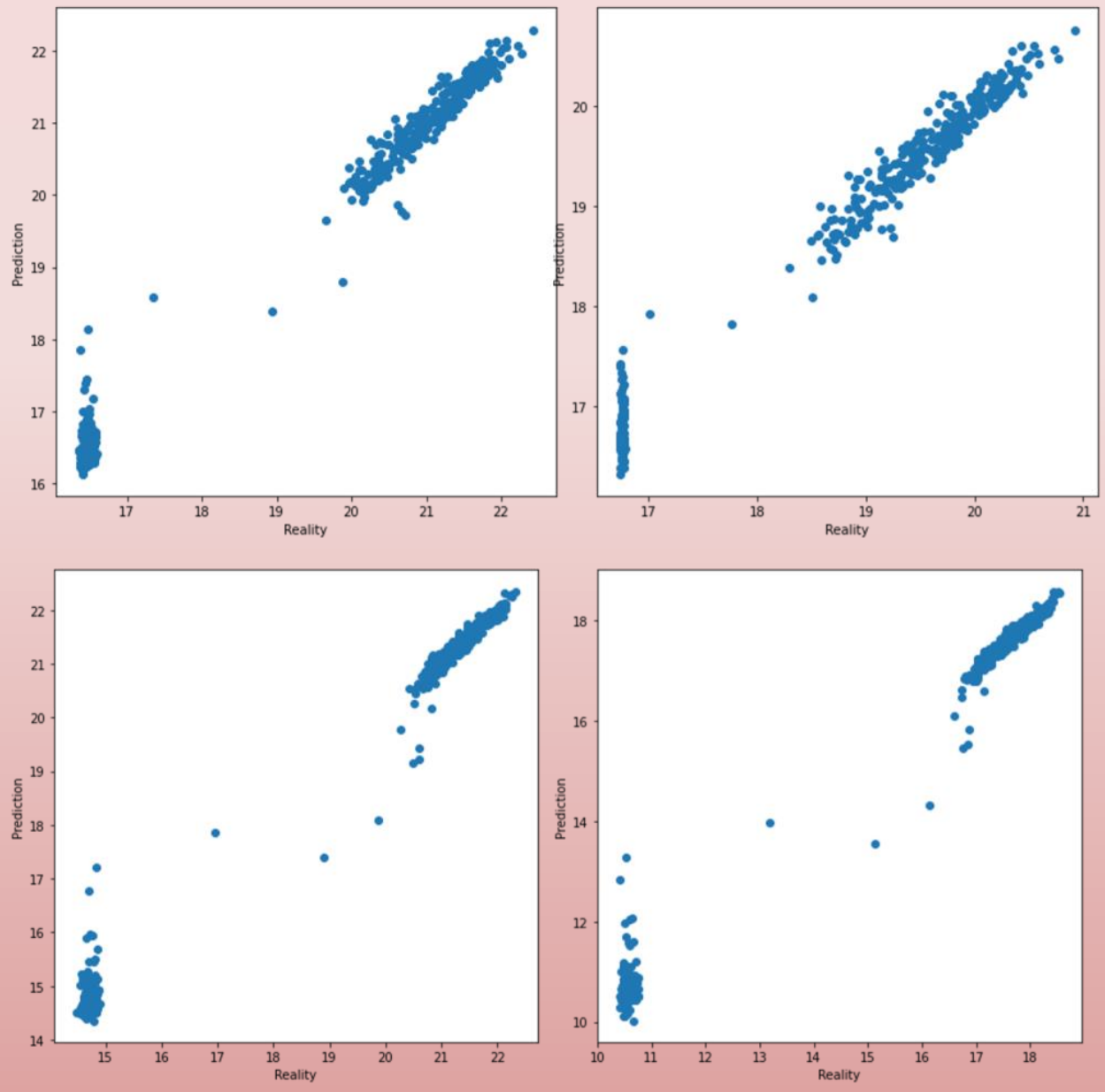
WP5 (Artificial Neural networks for detection of defective fuel rods)

During normal reactor operations, the fuel rod cladding acts as a barrier to prevent the fission products (FP) generated within the nuclear fuel to be released to the reactor primary circuit. Some part of fission gases and volatile FP may be released from the fuel matrix, but they are retained within the fuel-cladding gap as long as the cladding layer is intact. The cladding may, however, be damaged during reactor operations due to the influence of various phenomena, such as stress corrosion cracking (SCC), grid-to-rod fretting (GTRF), debris induced failure, among others. Subsequently, the high-pressure coolant water enters the fuel-to-clad gap through the defect site, causing the FP retained within the gap to escape into the primary coolant, and oxidation of the fuel which may further enhance FP release. The released radionuclides can interact with the coolant and may cause serious corrosion problems to the fuel cladding or other reactor structures. Further deterioration of the defective fuel elements can also occur with continued operation due to secondary hydriding of the Zircaloy cladding. Such deterioration and activity release may affect the power plant economically, such as from lost burnup due to early discharge of the fuel at power. The detection of defective fuel rod is thus of primary importance. Different approaches have been adopted for fuel failure detection: (i) using the operating limit of the specific activity in the coolant (ii) using the release to birth ratio (R/B) slope versus decay constant in a log–log figure; (iii) using the fitted escape rate coefficient, which directly represents the degree of fuel failure. Due to drawbacks of these approaches, data-driven methods such as Artificial Neural Networks (ANN) have gained momentum in the recent years. In the framework of the R2CA project, a physical model for FP release from defective fuel rod has been developed at IRSN and used in conjunction with an artificial neural network for diagnosis and characterization of defective fuel rods.

The physical model considers the release from fuel pellet by diffusion and recoil, a generalized diffusion and first-order kinetic model for the FP in the gap region, and a first-order kinetic model in the coolant region, as illustrated below.



The physical model was run for a large set of input parameters to generate a computation database, which was then used to train and test the ANN. This ANN was designed to be a meta-model of the physical model, predicting isotopes activities in the coolant from the inputs of the physical model. The results obtained with this ANN on never-seen-before data, represented below on Prediction (ANN) vs Reality (Physical model) curves for normalized activity of 4 isotopes of interest, are satisfactory. The normalized activity values are regrouped in two sets which represent situations with and without defect, resulting in high and low activity, respectively. Based on these encouraging results, further work is being carried out to design a new ANN for predicting the occurrence of a defect from the coolant activity levels, and/or the time elapsed since the defect occurrence, hence providing interesting tools for the detection of defective rod during reactor operations.



Kremer Francois (IRSN)

COMUNICATION AND DISSEMINATION

Final Open Workshop of the R2CA project

The final Open Workshop of the R2CA project, held the 29-30 November in IRSN headquarters Fontenay-aux-Roses, France, discussed the main results and outcomes of the project dedicated to Design Basis and Design Extension of Loss-Of-Coolant and Steam Generator Tube Rupture Accidents, Accident Management and Procedures, Innovative Tools and Devices.

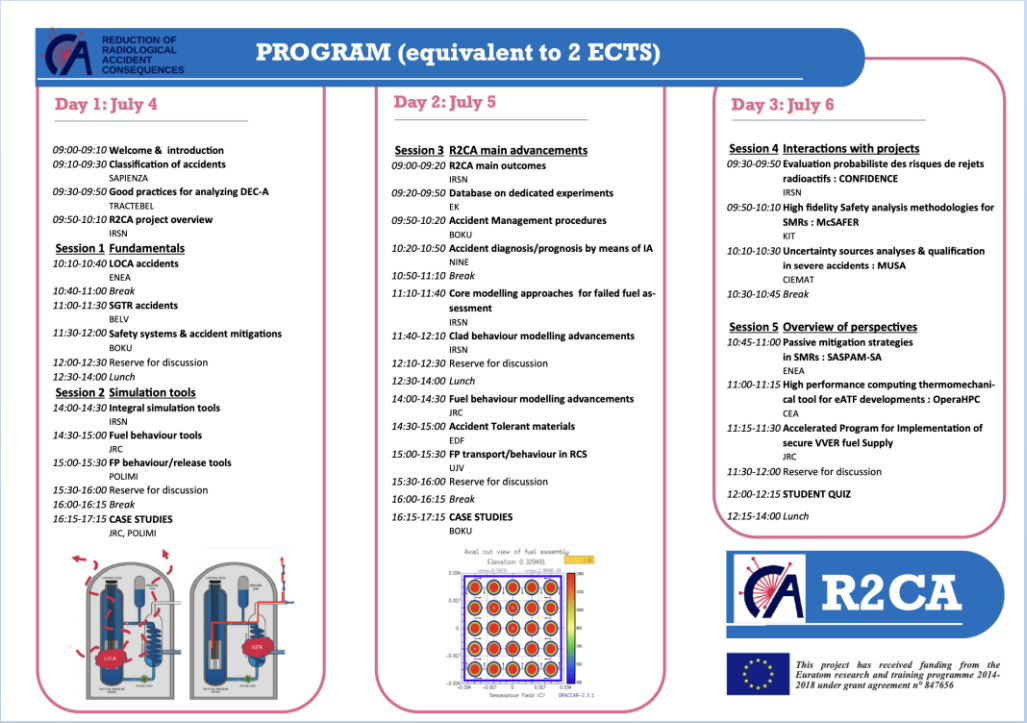
Main topics addressed were the Fuel/clad thermomechanics, the fission products behaviour in fuel, fission product transport from primary to secondary circuit and behaviour Accident Tolerant Fuels, accident prevention & management procedures, methodologies for radiological consequence assessments.

Nathalie Girault (IRSN), Fulvio Mascari (ENEA)

R2CA Summer School

From the 4th to the 6th of July, 2023, a Short Summer School has been organized by ENEA and IRSN in Bologna. The main target of the summer school is to disseminate the knowledge consolidated and gained along the R2CA project to Masters and PhD students, young researchers and engineers involved in nuclear energy and reactor safety analyses. Along the school the main safety aspects related to DBA and DEC-A of LOCA and SGTR accidents has been discussed focusing the attention on the phenomenology, experimental knowledge available and current numerical modeling. Main advancements within the R2CA project served as a background to show the current state of art and the new ideas. The school targeted both fundamental knowledge, current nuclear safety best practices and innovation. A video has been done to summarize the event.

Participants to the R2CA summer school hosted in Bologna (July 4 th-6th 2023)



REDUCTION OF RADIOLOGICAL ACCIDENT CONSEQUENCES

PROGRAM (equivalent to 2 ECTS)

Day 1: July 4

09:00-09:10 **Welcome & introduction**
09:10-09:30 **Classification of accidents**
SAPIENZA
09:30-09:50 **Good practices for analyzing DEC-A**
TRACTEBEL
09:50-10:10 **R2CA project overview**
IRSN

Session 1 Fundamentals

10:10-10:40 **LOCA accidents**
ENEA
10:40-11:00 Break
11:00-11:30 **SGTR accidents**
BELV
11:30-12:00 **Safety systems & accident mitigations**
BOKU
12:00-12:30 Reserve for discussion
12:30-14:00 Lunch

Session 2 Simulation tools

14:00-14:30 **Integral simulation tools**
IRSN
14:30-15:00 **Fuel behaviour tools**
JRC
15:00-15:30 **FP behaviour/release tools**
POLIMI
15:30-16:00 Reserve for discussion
16:00-16:15 Break
16:15-17:15 **CASE STUDIES**
JRC, POLIMI

Day 2: July 5

Session 3 R2CA main advancements

09:00-09:20 **R2CA main outcomes**
IRSN
09:20-09:50 **Database on dedicated experiments**
EK
09:50-10:20 **Accident Management procedures**
BOKU
10:20-10:50 **Accident diagnosis/prognosis by means of IA**
NINE
10:50-11:10 Break
11:10-11:40 **Core modelling approaches for failed fuel assessment**
IRSN
11:40-12:10 **Clad behaviour modelling advancements**
IRSN
12:10-12:30 Reserve for discussion
12:30-14:00 Lunch
14:00-14:30 **Fuel behaviour modelling advancements**
JRC
14:30-15:00 **Accident Tolerant materials**
EDF
15:00-15:30 **FP transport/behaviour in RCS**
UJV
15:30-16:00 Reserve for discussion
16:00-16:15 Break
16:15-17:15 **CASE STUDIES**
BOKU

Day 3: July 6

Session 4 Interactions with projects

09:30-09:50 **Evaluation probabiliste des risques de rejets radioactifs : CONFIDENCE**
IRSN
09:50-10:10 **High fidelity Safety analysis methodologies for SMRs : McSAFER**
KIT
10:10-10:30 **Uncertainty sources analyses & qualification in severe accidents : MUSA**
CIEMAT
10:30-10:45 Break

Session 5 Overview of perspectives

10:45-11:00 **Passive mitigation strategies in SMRs : SASPAM-SA**
ENEA
11:00-11:15 **High performance computing thermomechanical tool for eATF developments : OperaHPC**
CEA
11:15-11:30 **Accelerated Program for Implementation of secure VVER fuel Supply**
JRC
11:30-12:00 Reserve for discussion
12:00-12:15 **STUDENT QUIZ**
12:15-14:00 Lunch

R2CA

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n° 847656

Agenda *R2CA of summer school hosted in Bologna (July 4 th-6th 2023)*

TRANSURANUS *SCIANTIX /MFPR-F TRAINING

On June 26-30, we have organized another in person training on TRANSURANUS, but this time coupled with SCIANTIX 2.0 version from POLIMI and the MFPR-F code from IRSN, both developed within the R2CA project. The training course took again place in Karlsruhe for 8 participants. The training provided an introduction on the three codes, focusing on the SCIANTIX capabilities and its functioning as a fission gas behavior module within the TRANSURANUS fuel performance code, complemented with an online introduction about the fission product chemistry capabilities of the MFPR-F code. The participants had the opportunity to employ the coupled code suite TRANSURANUS-SCIANTIX to analyse representative LWR fuel rods and investigate the code calculations in terms of integral fission gas release provided by SCIANTIX.

*Participants to the TRANSURANUS *SCIANTIX /MFPR-F training hosted in Karlsruhe (Junee 26-30, 2023)*

R2CA special issue

A dedicated special issue on the Annals of Nuclear Energy Journal has been organized in order to collect all the outcomes of R2CA project and enhance the visibility of the activity maximizing the impact of the project. The special issue is under finalization. The guest editors are Nathalie Girault, Fulvio Mascari, Lelio Luzzi.
(https://www.sciencedirect.com/journal/annals-of-nuclear-energy/special-issue/105M36PSDR6)

Here the papers currently published:

- F. Feria, L.E. Herranz, Assessment of hydride precipitation modelling across fuel cladding: Hydriding in non-defective and defective fuel rods, Annals of Nuclear Energy, Volume 188, August 2023, 109810
- G. Zullo, D. Pizzocri, L. Luzzi, F. Kremer, R. Dubourg, A. Schubert, P. Van Uffelen, Towards simulations of fuel rod behaviour during severe accidents by coupling TRANSURANUS with SCIANTIX and MFPRF, Annals of Nuclear Energy Volume 190, 15 September 2023, 109891
- de Lara, A. Schubert, E. Shwageraus, P. Van Uffelen, Towards preliminary design calculations with TRANSURANUS for application of Hastelloy cladding material, Annals of Nuclear Energy, Volume 192, November 2023, 109973
- Z. Hózer, M. Adorni, A. Arkoma, V. Busser, B. Bürger, K. Dieschbourg, R. Farkas, N. Girault, L.E. Herranz, R. Iglesias, M. Jobst, A. Kecek, C. Leclere, R. Lishchuk, M. Massone, N. Müllner, S. Sholomitsky, E. Slonszki, P. Szabó, T. Taurines, R. Zimmerl,Review of experimental database to support nuclear power plant safety analyses in SGTR and LOCA domains, Annals of Nuclear Energy, Volume 193, 1 December 2023, 110001
- Berezhnyi, A. Krushynskyi, D. Ruban, S. Sholomitsky, Conservative evaluation of radionuclides release for VVER-440 and VVER-1000 type reactors, Annals of Nuclear Energy, Volume 194, 15 December 2023, 110105
- Tadas Kaliatka, Tomas Kačegavičius, Algirdas Kaliatka, Mantas Povilaitis, Andrius Tidikas, Andrius Slavickas, Methods for the radioactive release estimation under DEC-A conditions, Annals of Nuclear Energy,Volume 195, 2024,110143
- F. Feria, P. Aragón, L.E. Herranz, Assessment of cladding ballooning during DBA-LOCAs with FRAPTRAN, Annals of Nuclear Energy, Volume 195, 2024,110194
- Bousbia Salah, M. Di Giuli, P. Foucaud, R. Iglesias, A. Malkhasyan, M. Salmaoui, L.E. Herranz, Iodine source term assessment under DBA SGTR accident scenario, Annals of Nuclear Energy, Volume 196, 2024,110201
- L. Giaccardi, M. Cherubini, G. Zullo, D. Pizzocri, A. Magni, L. Luzzi,Towards modelling defective fuel rods in TRANSURANUS: Benchmark and assessment of gaseous and volatile radioactive fission product release, Annals of Nuclear Energy, Volume 197, 2024,110249
- P. Foucaud, M. Di Giuli, M. Salmaoui, A. Bousbia Salah, R. Iglesias, A. Malkhasyan, L.E. Herranz, Iodine source term assessment as result of iodine spiking and mass transfer phenomena during a SGTR transient using MELCOR 2.2 and CATHARE 2 codes, Annals of Nuclear Energy, Volume 198, 2024, 110305

R2CA Members

17 Organizations
(11 Countries)

Duration

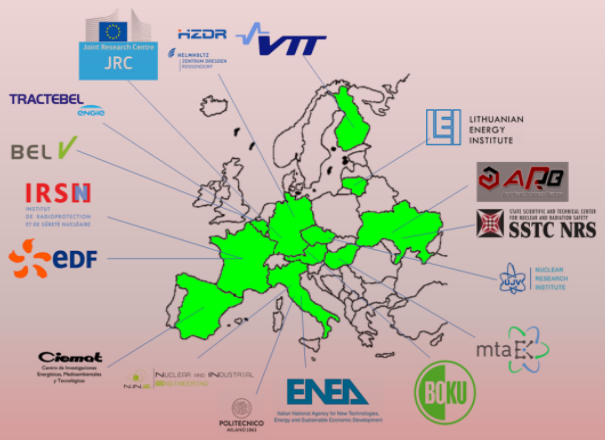
01.09.2019 – 31.08.2023

Commitment

522 person/months

Overall Budget

€ 4.2 M€ (~ ¾ funded by EU)



THE CONSORTIUM

FOLLOW & CONTACT US:

Project Coordinator: nathalie.girault@irsn.fr
http://r2ca-h2020.eu
www.linkedin.com/groups/12404880/

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n° 847656