IRIS_2010 – PART I: GENERAL OVERVIEW OF THE BENCHMARK

J.-M. Rambach[1], N. Orbovic[2], F. Tarallo[1]
[1]Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Fontenay-aux-Roses, France
[2]Canadian Nuclear Safety Commission (CNSC) - Commission Canadienne de Sûreté Nucléaire (CCSN), Ottawa, Canada
E-mail of corresponding author: mathieu.rambach@irsn.fr

ABSTRACT

The benchmark IRIS_2010 is an exercise in OECD/NEA/CSNI framework. This paper is the 1st of a series of 5 companion papers that present the objectives, the experiments to be simulated, the simulations of tests with punching failure, the simulation of tests with bending failure and the lessons and recommendations. The aim of this paper is to describe the origin, the objectives, the process followed for the selection of the tests, the schedule and the whole organization.

IRIS is the acronym for the title of an activity initiated inside CSNI/IAGE working groups: "**I**mproving the **R**obustness assessments, methodologies for structures **I**mpacted by missile**S**". The aim of the benchmark is to find a place and an approach where a potentially sensitive matter, like the analysis of the effect of an impact of commercial aircraft on NPP, can be openly discussed by worldwide specialists of simulation in mechanics. This goal has been reached taking into account these two limitations: only mechanical effects are considered and the objects to be tested and numerically simulated are of reduced size compared to NPP's structures. Once acted by the NEA, the activity is launched under a benchmark among member state representatives of the concrete sub-group of the IAGE. A structure is put in place, approved during a 1st meeting, with an Organizing Committee, a Scientific Committee and a Website. The Organizing Committee pilots the project and organizes a 2nd meeting where the tests to be simulated are selected. The elementary structure to be tested is a reinforced concrete square slab, simply resting along its 4 edges, impacted on its centre by a missile. Three different simulations are proposed: a 1st one is chosen from the literature, whose results are well known. The 2 others proposed are with unknown results (blind simulation). The two main types of failure are considered: by punching and by bending. The Organizing Committee and the Finnish company VTT fund and design the dedicated tests and VTT carries out the tests. The latter are repeated, in order to discriminate the expected results discrepancy of experimental nature from the discrepancy of modeling origin. The simulation regarding the punching rupture is proposed according to the results of impacts on 3 slabs as identical as possible. The simulation regarding the bending or flexural rupture is proposed according to the results of impacts on 2 identical slabs. The results are obviously concealed until the transmitting of the results of the numerical simulations. In order to ease the treatment of the results, a rigid formatting of the result presentation (under spreadsheets) is imposed to the participants and even the Numerical Simulation Reports, requested from the participants, are proposed with an imposed structure. The 28 participating teams proposed their simulations (24 with the complete set of 3 simulations, 2 with only 2 simulations and 2 with only 1 simulation). They come from Asia (3 countries), Europe (5), North America (2), they belong to different institutions (vendors, utilities, TSO, regulators, academics). The presentation of the tests (design, carrying out and results) is made in the 2nd companion paper, the presentation of the simulations of tests with punching failure and their synthesis is made in the 3rd one, the simulation of tests with bending failure and their synthesis is made in the 4th one and lastly the 5th paper deals with the lessons gained from this collective exercise and with the recommendations that constitute a guidance aiming to improve the analysis of the mechanical effects of the impact of aircraft on concrete structures.

INTRODUCTION

IRIS_2010 is the project name of the benchmark of simulation of impacts on reinforced concrete slabs by missiles at medium velocity that occurred in 2010. This benchmark was initiated and supported by the IAGE (Working Group dealing with the Integrity of Components and Structures inside the Committee on the Safety of Nuclear Installation – so-called CSNI) that impulses the reflection about all topics regarding the management of the safety of existing nuclear installations among the member states belonging to the Nuclear Energy Agency (NEA) from OECD organization. This paper is the first in a series of five companion papers (see Ref. [1] to [4]) that respectively present the objectives of this benchmark, the tests to be simulated, the simulations of tests with punching failure, the simulation of tests with bending failure and, last but not the least, the lessons and

recommendations. The aim of this paper is to describe the objectives, the organization, the process followed for the selection of the tests, the development of the benchmark and the concluding workshop.

OBJECTIVES OF IRIS_2010

Public acceptance of existing and new nuclear installations depends partially on demonstrating the adequate structural robustness of the installation and the effectiveness of emergency response strategies to avoid or mitigate the effects of some unexpected events (and therefore not considered in the initial design): the 11 September 2001 terrorist attack outlines the risk of a voluntary aircraft crash on a Nuclear Power Plant (NPP). The Fukushima accident, following the 11 March 2011 earthquake and tsunami, outlines in other domains the necessity for each nuclear installation to resist beyond design aggressions.

The IAGE launched by the end of 2008 a CSNI Activity Proposal Sheet (CAPS) under the label "**I**mproving **R**obustness assessment of structures **I**mpacted by missile**S**" whose acronym is IRIS_2010. Its objective "*is to suggest a mean to facilitate technical exchanges* […] *without producing detrimental results. It is then proposed to compare the assessment of typical impacts on well known structures, the emphasis being on effects description rather than on justification. In order to avoid any malevolent use of NPP's robustness evaluation, the idea is to consider similar structures encountered on NPP site but at reduced size* […]. *The technical exchanges are based on numerical simulations rather than on effective tests on real mock-ups.*"

It is recalled that an aircraft crash on a nuclear installation does not only involve a mechanical response of the directly impacted structure: the vibrations propagating throughout the whole structure and the explosion and fire due to kerosene and all other burnable material may affect the operability of the safety classified systems and components. In order to avoid a technical exchanges process within a framework restricted for confidentiality reasons for such potentially sensitive data and results, the benchmark domain (open to OECD/NEA member states) was intentionally limited to the analysis of the mechanical effects of an aircraft crash on the safety related structures.

The IRIS_2010 benchmark has been, since the beginning, thought as the 1st of a series of 3 benchmarks: a 2nd benchmark was envisaged to consider more complicated RC structures (always at reduced scale) resembling to those used in NPPs design (box shaped, cylindrically and spherically shaped) and a 3rd benchmark was envisaged to consider the induced vibrations inside the structure. For each of these intended benchmarks the way of progress in the knowledge and in the reliability in structure designing is the simulation of the mechanical behaviour of some tested structures: the comparison of the time history of strains and displacements recorded by sensors with computed values of strains and displacements at same location provides data of high interest on the quality of the simulation.

The CSNI/IAGE then initiated a benchmark study as a means of validating the evaluation techniques used in the assessment of the integrity of structures impacted by missiles. In the proposed IRIS_2010 round robin study, the different computer codes, modelling approaches methods and results were to be compared to data and other codes used to determine effective means of analyzing the structural effects of a postulated missiles impact on civil structures. When numerous teams are participating in the benchmark, an additional piece of information is provided by such a collaborative approach: the epistemic uncertainty of the simulation results or, in other words, the quotation of the unavoidable scattering induced by the people in charge of the simulations, all along the process of simulation. This might be considered as a pedagogic issue. The participants were encouraged to use a wide range of simulation tools, model refinements, material laws, from the simplest analytical model (few degrees of freedom) up to the more sophisticated finite element models (millions of degrees of freedom). As a general rule, the treatment of the results shall keep its statistical interest: the point is not to find the best team that would have found the best approximation.

As nowadays the NPPs of 3rd generation are sized to resist large aircraft impact, it is necessary to gain a better confidence in the modelling capability and in the relevance, robustness and accuracy of the computational results, in terms of resistance displacement and deformation. This is a major issue addressed to the NPP Operators and their designers (if any) involved in the justification of the adequacy of the structures that shall resist the direct action of the impact and of the systems and components that shall ensure a satisfactory safety level during and after the impact. This issue is also addressed to the Regulators and the TSOs (if any) involved in the definition of the protection level required from the installation and in charge of the assessment of the justification, from the methodology up to the criteria. The simulation of aircraft impact deals with dynamic phenomena beyond elastic behaviour domain: this double constraint induces a certain sensitivity to the assumptions which are necessary to be appreciated.

A series of two meetings were held by the representatives of the IAGE/Concrete subgroup in year 2009: the first one in April, where the organization and the rules have been adopted and the second one in October where the number and the type of simulations have been settled and adopted.

BENCHMARK ORGANIZATION

An Organizing Committee, headed by IRSN and CNSC-CCSN, is created: its role is to specify all necessary data, rules and pace ensuring the development of the project. The number of active Organizing Committee members shall be sufficiently large for a good sharing of efforts and for a higher benefice from the differences of opinion but this number shall be sufficiently reduced for keeping a good reactivity. A number of 5 people were initially foreseen, but the Organizing Committee was run by only 3 people.

A Scientific Committee is created: its role is to provide guidance to the Organizing Committee, in the selection of the tests to be simulated, in the definition of the play rules, in the analysis of results and in selection and writing of the recommendations. Furthermore, they are asked to provide lectures in workshop session. More than 5 internationally recognized experts kindly and generously accepted to help the Organizing Committee by their comments, lectures and guidance.

A dedicated website is created in order to facilitate the exchange of heavy numerical files and to guarantee the same level of information for all participants. The website was hosted by the NEA website. It has been observed however that the practice was that all data, modifications and periodic reporting etc., initiated by the Organizing Committee were directly transmitted by e-mail to each participant and that all the results from the participants were directly sent by e-mail to the Organizing Committee members. However, in our opinion, the dedicated website remains necessary: it is a practical way to ensure the completeness and correctness of all the data, play rules and results.

TESTS SELECTION

The tests are selected in such a way they address the behaviour of typical part of NPP's outer structures (i.e. reinforced concrete wall or slab) damaged by missile at medium velocity (in 100 to 200 m/s range). It was excluded to consider some NPP mock-ups impacted by an aircraft mock-up for this main reason: the reliability of such tests would be questioned due to the reduced size. It has been considered wiser to start by a kind of analytical approach where simple structures are impacted by simple missile. The considered structure is a simply supported square slab made of reinforced concrete and the considered missile is a more or less deformable steel pipe.

Two main distinct features of the slab damaging are considered, either by bending or by punching. The tests to be simulated were initially supposed to be found in the literature, but there were no available tests exhibiting distinctly the bending mode failure and moreover it was considered as more interesting (and exciting) to benchmark blind simulations.

It has then been decided:

- to simulate one test among the tests performed in Germany at Meppen's testing facility and whose results are known and well described in different papers,
- to simulate one new test with bending rupture mode,
- to simulate one new test with punching rupture mode,
- to repeat those new tests: 2 identical bending rupture tests and 3 identical punching rupture tests, in order to have better confidence in what is supposed to be the reality.

The new tests are performed by the Finnish company VTT, they are financed by VTT (40%), IRSN (40%) and CSNC-CCSN (20%).

BENCHMARK DEVELOPMENT AND NUMERICAL SIMULATION

The Organizing Committee defines and pilots the overall scheduling and prepares the data that could be useful in the simulations. The Organizing Committee, with the help of VTT, defines the slabs to be tested (dimension, reinforcement, concrete resistance, supporting conditions) and the missile to be launched (dimension, velocity). Special dispositions are taken in order the results remain concealed. The Organizing Committee defines the formatting of the simulation results (figures and report) in order to ease their further treatment.

The main steps of the benchmark are recalled as follows:

- beginning February 2010: official launching with definitive input data,
- April and May 2010: the new tests are performed and the measured concrete properties and the effective missiles velocities are then transmitted to the participants,
- mid June 2010: the templates (formatted spreadsheets) for expressing the computational results are transmitted to the participants,

- September 2010: the results from the participants are collected,
- end of October 2010: the numerical simulation reports are collected,
- beginning of November 2010: the tests results are revealed and transmitted to the participants,
- beginning of November 2010: the Organizing Committee makes available to each participant, through the website, the results obtained by each team,
- Mid-December 2010: the Workshop is held in OECD premises.

The Organizing Committee used the period from October up to Workshop date for the whole analysis and tried to give sense to all those numerical results.

THE WORKSHOP

The Organizing Committee organized the 3-day workshop (13 to 15 December at NEA Headquarters), where each participant was invited to present its 3 simulations during 20 min and where ample time was devoted to discussion and technical exchanges.

A total of 28 teams from 20 different institutions (NI suppliers, Utilities, Safety Authorities, TSOs, Research Institutes) and from 11 different countries from Europe, North America and Asia (plus 2 international organisations) were participating in the workshop (see hereafter table). Among those 28 teams, 24 performed all the 3 simulations requested, 2 only 2 simulations and 2 only 1 simulation. Some institutions presented several teams with different modelling options.

Participant	Europe	North America	Asia	International
Nuclear Island suppliers	AREVA	AECL		
Utilities Engineering	EDF, FORTUM, COB[+], SPI[++]			ITER
Regulators	ENSI	CNSC(2), NRC(2)		
Technical Support Organizations	GRS, IRSN(4)		BARC, JNES, KINS	
Research Institutes	CEA(2), VTT(3), NRI, UJF[+++]			JRC

The figure after some participant acronym means the number of participant teams in the same company

[+]: COB stands for Coyne&Bellier that belongs to Tractebel Engineering which is a part of GDF-SUEZ group

[++]: SPI stands for Stangenberg und Partner Ingenieur

[+++]: UJF stands for Université Joseph-Fourier that belongs to the University of Grenoble (France)

At the end of the workshop, the Organizing Committee submitted its own analysis, conclusions, recommendations and proposals for further activities.

CONCLUSION

The objectives of IRIS_2010 are to improve the ability of robustness assessment of structures impacted by aircrafts. The way to manage open discussions about this potentially sensitive topic is to improve the ability in modelling the mechanical behaviour of simple structures of reduced size impacted by missile by comparing the simulations results with the test results. This collaborative approach gives in addition a certain idea of the scattering due to different modelling tools, meshes, material laws and all other necessary assumptions. The comparison of the whole results of simulation with the recorded values of the tested structures allows good practices in modelling assumptions to appear

The papers referenced [1] to [4] develop the outcomes of this exercise.

REFERENCES

[1] Vepsä, A., Saarenheimo, A., Tarallo, F., Orbovic, N., and Rambach, J.-M., "IRIS_2010 – Part II: Experimental data", *SMiRT_21 Proceedings*, New Dehli, India., SMiRT-21, November, 2011

[2] Orbovic, N., Benboudjema, F., Colliat, J.-B., Berthaud, Y., Tarallo F. and Rambach, J.-M. "IRIS_2010 - Part III: Numerical simulations of Meppen II-4 test and VTT-IRSN-CNSC Punching tests", *SMiRT_21 Proceedings*, New Dehli, India., SMiRT-21, November, 2011

[3] Berthaud, Y., Benboudjema, F., Colliat, J.-B., Tarallo, F., Orbovic, N. and Rambach, J.-M., "IRIS_2010 - Part IV: Numerical simulations of Flexural VTT-IRSN tests", *SMiRT_21 Proceedings*, New Dehli, India., SMiRT-21, November, 2011

[4] Tarallo, F., Orbovic, N., Rambach, J.-M., Benboudjema, F., Colliat, J.-B. and Berthaud, Y., "IRIS_2010 - Part V: Lessons learned, recommendations and tracks for future works", *SMiRT_21 Proceedings*, New Dehli, India., SMiRT-21, November, 2011.