



## Outcomes from the EURATOM–ROSATOM ERCOSAM SAMARA projects on containment thermal-hydraulics for severe accident management



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### HIGHLIGHTS

- Hydrogen distribution in the containment of PWR was investigated for scenario leading to stratification.
- The scenario was scaled from a generic PWR containment to four facilities.
- Effect of spray, cooler and heat sources was investigated experimentally and with LP and CFD.
- Code-to-code benchmarks aiming a scaling up the facilities to a large containment.

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### ABSTRACT

ERCOSAM and SAMARA are the acronyms for two parallel projects co-financed respectively by EURATOM and ROSATOM during the period 2010–2014 with the general aim to advance the knowledge on the phenomenology associated with the hydrogen and steam spreading and stratification in the LWR containment during a postulated severe accident. The important peculiarity of the projects was in experimental and analytical investigating the impact of systems such as spray, cooler and heat sources (simulating thermal effect of PARs) on the distribution of gas mixture (e.g. hydrogen, steam, air). This paper presents the main outcomes of the ERCOSAM–SAMARA projects.

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## 1. Introduction

The presence of a local accumulation of hydrogen (stratification) in a nuclear power plant (NPP) containment following a postulated severe accident is a safety concern. Pockets of hydrogen of high concentration could lead to a deflagration or detonation,

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which might damage safety equipment necessary for safety functions and even challenge the containment's structural integrity.

The analysis of various thermal-hydraulic processes leading to the stratification of steam and hydrogen and the potential destabilization or break-up of these layers by the operation of safety systems e.g. coolers, sprays, and passive autocatalytic recombiners (PARs) are very complex. The complexity arises from the fact that a large number of self-consistent phenomena should be taken in consideration in the analysis. For example, the phenomenology includes convective flows produced by jets and plumes, diffusion, buoyancy forces induced by density differences, condensation occurring on relatively cold walls or initiated by activation of cooler or sprinkler, and so on. Moreover, the functioning of active (e.g. spray, active cooler, etc.) or passive safety systems (e.g. PAR, passive cooler, etc.) would depend on the specific safety component design and as well on the thermal-hydraulic conditions in the containment and therefore would vary on different stages of the postulated accident.

Advanced lumped parameter (LP) and Computational Fluid Dynamic (CFD) codes are valuable tools for analyzing nuclear power plant containment behavior during postulated DBA (Design Basic Accident), BDBA (Beyond DBA) and SA (severe accident). These computational tools are continuously validated and improved taking into account the advantage of the continuing increase in computing power and in the accumulated knowledge about containment phenomenology. Experimental data needed for code validation now are obtained on experimental facilities with different scales and in general comparable to the real NPP by initial and boundary conditions. Account must be taken of the fact that for SA conditions large or full-scale facilities seem not to be available in the nearest future. In fact, due to the explosive nature of hydrogen, large steam/hydrogen discharge (with large amounts of released mass and energy, at high temperatures, pressures, radiation, etc.) would not be safe or would be extremely expensive and too technically complicated to be realized.

So, application of existing advanced small scale and middle scale facilities is the only and very important step forward allowing for insights on the phenomenology to be associated with investigated accident scenarios. Nonetheless, the development of methodology of scaling down from NPP conditions to experiment and following scaling up of obtained results is essential to minimize the impact of scaling distortions and to identify the effects, which could be facility dependent and therefore not to be expected in real plant containment.

In the last years, the research community has devoted several research projects (e.g. OECD/SETH1 [Paladino et al., 2012](#), SETH-2 [Studer et al., 2012](#), OECD/THAI [Royl et al., 2009](#), etc.), to the hydrogen issues (e.g. distribution, mitigation, combustion). The ERCOSAM-SAMARA projects have been conducted under the auspices of EURATOM and ROSATOM in the framework of a cooperation agreement during the period 2010–2014 to investigate the containment thermal-hydraulics of current and future LWRs for severe accident management ([Paladino et al., 2012](#)), with particular attention to the hydrogen distribution/stratification into the containment under various conditions. The ERCOSAM-SAMARA projects had two main objectives. The first was to establish, for a severe accident sequence chosen from existing plant calculations and representative of a LOCA in a LWR, the stability of hydrogen stratification, which can be established during part of the transient period, starting from the late blowdown until the end of hydrogen release from the reactor vessel into the containment. The second was to determine whether the hydrogen stratification, if established, can be broken down by the operation of SAM devices: sprays, coolers and heat release by PARs.

With respect to the previous projects devoted to the hydrogen issue, one of the peculiarities of the ERCOSAM-SAMARA projects

was to define tests with similar initial and boundary conditions in various thermal-hydraulics facilities and to carry out a systematic analysis aiming at assessing the computational tool capabilities to analyze scenarios at scales ranging from e.g. 7 m<sup>3</sup> to about 3181 m<sup>3</sup>.

The focus of the investigations was on hydrogen distribution (rather than on mitigation or combustion) and therefore for safety reasons helium has been used to simulate hydrogen.

The SAMARA project has been carried out with the contribution of the Russian Organizations: IBRAE RAN, JSC “Afrikantov OKBM” and SSC RF-IPPE. The Organizations contributing to the ERCOSAM project were: PSI (Switzerland), IRSN (France), CEA (France), JUELICH (Germany), KIT (Germany), NRG (The Netherlands). Moreover, AECL (Canada) and NRC (US) were associated in the ERCOSAM consortium as non-EU Countries and contributed with analytical activities to the projects.

A detailed overview on the experimental and analytical activities as well as the scaling methodology used to define the tests and the detailed synthesis of the test phenomenology has been reported in separate papers ([Benteboula et al., 2015](#); [Andreani et al., 2015](#); [Dabbene et al., 2015](#); [Malet et al., 2015](#)). The CFD analysis of all ERCOSAM-SAMARA tests performed within the SAMARA activities is reported in the paper ([Filippov et al., 2015](#)). The overview of SPOT experimental and analytical activities performed within SAMARA with the KUPOL code is reported in paper ([Kamnev et al., 2015](#)). The benchmark results for the analytical HYMIX tests are reported in paper ([Yudina et al., 2015](#)). During the project, project findings have been published in the papers ([Liang and Andreani, 2012a,b](#); [Paranjape et al., 2013, 2014](#); [Filippov et al., 2014a,b](#); [Grigoryev et al., 2014](#)).

This paper summarizes the main results of the ERCOSAM-SAMARA projects.

## 2. Project structure and methodology

### 2.1. Structure of the project work

The ERCOSAM-SAMARA parallel projects were structured in 5 separate but interlinked work packages (WPs). The global objectives of these WPs are outlined below:

- WP1 (Led by IRSN): to design the general conditions including scaling down methodology of the experimental test sequences.
- WP2 (Led by PSI): to provide analytical support in the definition of tests (scoping calculations) and to assess code capabilities in the test analysis (pre- and post- test analysis).
- WP3 (Led by CEA): to perform experiments aiming at project objectives.
- WP4 (Led by IRSN): to bring all experimental evidences and code outcomes into a common and harmonized context for synthesis purposes.
- WP5 (Led by PSI): to coordinate project activities and to highlight experimental and analytical findings. To interface with the EC and improve ERCOSAM and SAMARA cooperation.

### 2.2. Methodology to define experimental tests

Based on the collection of existing LOCA calculations for various nuclear power plant (NPPs) designs, the selected reference scenario was a Small Break LOCA in a LWR with dry containment, which generally constitutes the largest contribution to the core damage frequency. The considered NPPs characteristics have been used to define the containment of a generic NPP of about 1000 MW<sub>th</sub>. The generic containment has been determined by scaling down from a PWR configuration keeping the ratio between the

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