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Main results of the European PASSAM project on severe accident source term mitigation

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ABSTRACT

The PASSAM (Passive and Active Systems on Severe Accident source term Mitigation) project was launched in the frame of the 7th framework programme of the European Commission. Coordinated by IRSN, this four year project (2013–2016) involved nine partners from six countries: IRSN, EDF and university of Lorraine (France); CIEMAT and CSIC (Spain); PSI (Switzerland); RSE (Italy); VTT (Finland) and AREVA GmbH (Germany).

It was mainly an R&D project of experimental nature aimed at investigating phenomena that might enhance source term mitigation in case of a severe accident in a Nuclear Power Plant (NPP). Both existing systems (i.e., water scrubbing and sand bed filters plus metallic pre-filters) and innovative ones (i.e., high pressure sprays, electrostatic precipitators, acoustic agglomerators and, advanced zeolites and combined wet-dry filtration systems), were experimentally studied in conditions as close as possible from those anticipated for severe accidents.

This paper presents the main experimental results of the project which represent a significant extension of the current database on these existing or innovative mitigation systems. Application of some of these data for improving existing models or developing new ones should eventually enhance the capability of modelling Severe Accident Management measures and developing improved guidelines.

1. Introduction

After the TEPCO Fukushima accident of March 2011, one of the main concerns of the nuclear industry has been the search for improved atmospheric source term mitigation systems. The motivation underneath stems from two major factors: venting of the containment building might be an essential accident management measure in order to prevent the loss of its mechanical integrity, but this containment venting might result in substantial radioactive releases if no efficient source term mitigation system is implemented.

Some countries like Sweden, Switzerland, Finland, Germany and France, had already implemented Filtered Containment Venting Systems (FCVS) in the early 1990's as a means to enhance the safety of their Nuclear Power Plants (NPPs). The Netherlands, China and Bulgaria followed before the Fukushima accident. Many other countries have considered, and several of them decided on the implementation of FCVS more recently, in the post-Fukushima context.

This renewed interest for FCVS has stimulated new national R&D programmes on this topic in several countries and new coordinated international activities, like writing a status report by a working group on the Analysis and Management of Accidents of the CSNI (Committee on the Safety of Nuclear Installations) of the OECD-NEA (Jacquemain et al., 2014), or launching the European Commission (EC) project on "Passive and Active Systems on Severe Accident source term Mitigation" (PASSAM) presented in this paper.

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After a short overview of the context, objectives and main features of the PASSAM project, this paper presents the various experimental studies which have been performed and highlights some of the major results obtained.

2. PASSAM context, objectives and main features

The industrial FCVS are essentially based on two approaches: "dry" and "wet" systems. In dry systems, large trapping surfaces are provided either by gravel or sand beds, or by metal fibers or by molecular sieves. In wet systems, trapping occurs in a liquid (water plus additives) pool as a consequence of several removal mechanisms the efficiency of which depends strongly on thermal-hydraulic conditions. These systems can be enhanced by including venturi scrubbers: water droplets injected into the gas stream capture aerosol particles and make them more easily trapped by subsequent filter systems.

In 2012, when launching the PASSAM programme, these systems, some of which were installed on NPPs, had been well characterized as regards aerosol retention efficiency, but to a far lesser extent as regards volatile iodine retention, including organic iodides. Indeed, more recent tests had been performed on FCVS for trying to improve the systems as regards organic iodide retention in water pools. Nevertheless the research on this specific aspect needed to be complemented. A lack of knowledge also appeared clearly for organic iodine retention in dry systems.

In parallel, several alternative and innovative approaches were appearing in the literature or are even already proposed by some vendors. Electric filtration systems were already widely used for many industrial applications, out of the nuclear field. Solutions based on molecular sieves (improved zeolites, metal organic frameworks, etc…) were also widely used as filter in many industrial processes. Many kinds of zeolite exist; a key point consisted of finding the most efficient zeolite for iodine species in severe accident conditions. Another promising innovative solution relied on the combination of wet and dry filter systems. Besides, as it is well known that, generally speaking, the filtration systems are less efficient for aerosol particles of some tenths of microns, some systems were being developed, aiming at agglomerating aerosol particles in order to get bigger particles which would be better filtered (acoustic systems, high pressure sprays …). Implementing such a device upstream of a filtration system could overcome the decrease of filtration efficiency of sub-micron particles.

Another subject which had poorly been studied is the stability of the trapped fission products on the medium and long term (up to some days) following a nuclear accident. Indeed, the trapped fission products may be re-vaporized and/or re-entrained due to surrounding conditions relevant to an accident and more especially, due to continuous irradiation, coupled to continuous flow-rate (if the venting system remains open), and to high temperature and humidity. Indeed the re-entrainment of trapped aerosols was tested in different small scale facilities and, at larger scale, in the international ACE programme (Allelein et al., 2009) where the aerosol loaded filters (dry and wet filters) were operated with clean gas and the aerosol concentrations of the gas downstream of the filters were measured. Nevertheless, no data on delayed release, under typical FCVS conditions (including irradiation) both for trapped aerosols and gaseous iodine forms, could be found in the open literature.

In this context, the PASSAM project was proposed to explore potential enhancements of existing source term mitigation devices and check the ability of innovative systems to achieve even larger source term attenuation. Heavily relying on experiments, the PASSAM project aimed at providing new data on the capability and reliability of a number of systems related to FCVS: pool scrubbing systems, sand bed filters plus metallic prefilters, acoustic agglomerators, high pressure sprays, electrostatic precipitators, improved zeolites and combination of wet and dry systems. Nonetheless, the scope of some of the PASSAM research topics – such as fission products and aerosol retention in water pools - goes beyond FCVS and might be applied for accident situations other than containment venting, e.g. for fission product scrubbing in the wetwell of a BWR or for Steam Generator Tube Rupture (SGTR) accidents with a submerged secondary side.

Besides an extension of the existing experimental database on existing and innovative filtration systems, the focus was put on trying to get a deeper understanding of the phenomena underlying their performance and to develop models/correlations that allow modelling of the systems in severe accident analysis codes, like ASTEC (Chatelard et al., 2015).

So, the PASSAM project was launched under the 7th framework programme of EURATOM for four years, formally from January 2013 to December 2016, and practically up to March 2017. Gathering 9 organizations (IRSN, EdF and University of Lorraine, France; CIEMAT and CSIC, Spain; PSI, Switzerland; RSE, Italy; VTT, Finland; and AREVA GmbH, Germany) and coordinated by IRSN, the project involved about 400 person-months and the associated cost was more than 5 M€.

The PASSAM project planning was rather linear as a whole, with three conceptual phases:

- set-up of organizational bases and of experimental facilities (2013);
- execution of experimental campaigns (mid 2013 to end 2016);
- in depth analysis of the experimental results and project wrap-up (mid 2015 to early 2017).

The first phase included a literature survey on the existing and innovative systems to be experimentally studied in the project (Herranz et al., 2013). This survey confirmed, with more details, the anticipated gaps of knowledge and so it allowed optimizing the test matrices for each experimental work-package (Herranz et al., 2014a). It ended up with an open workshop held in Madrid (Spain) in February 2014 (PASSAM, 2014).

The experimental studies, which constitute the largest part of the PASSAM activities, are described in the next section of this paper together with the rationale for exploring each of the system studied and a selection of some major results.

The last phase of PASSAM consisted mainly of two points. An in-depth analysis of the experimental results allowed developing some models and/or correlations from the experimental results. The corresponding outcomes are presented together with the experimental results in the next section of this paper.

In parallel, the project outputs were optimized so that nuclear community could easily benefit from the research conducted: a final PASSAM workshop was organized on February 28th and March 1st, 2017 in Paris (France), the final synthesis report of the project was made available in the open literature and several PASSAM papers were issued in scientific journals and conferences by the PASSAM partners.

3. PASSAM experimental studies and selected major results

3.1. Experimental studies of pool scrubbing systems (leader PSI)

Severe accidents in nuclear power plants are characterized by a damage of the reactor core, and subsequent potential for release of radioactive substances into the environment. In certain sequences, the radioactivity in the aerosol or gas form may be transported through a liquid pool, in which a large fraction of the radioactivity