Annals of Nuclear Energy 74 (2014) 165–172

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Generic Containment: Detailed comparison of containment simulations performed on plant scale

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ARTICLE INFO

Article history:
Received 12 December 2013
Accepted 7 July 2014
Available online 5 August 2014

Keywords:
Severe accident
SARNET
Containment flows
Hydrogen distribution and mitigation
User effect

ABSTRACT

One outcome of the OECD/NEA ISP-47 activity was the recommendation to elaborate a 'Generic Containment' in order to allow comparing and rating the results obtained by different lumped-parameter models on plant scale. Within the European SARNET2 project (http://www.sar-net.eu), such a Generic Containment nodalisation, based on a German PWR (1300 MW_{el}), was defined. This agreement on the nodalisation allows investigating the remaining differences among the results, especially the 'user-effect', related to the modelling choices, as well as fundamental differences in the underlying model basis in detail. The methodology applied in order to compare the different code predictions consisted of a series of three benchmark steps with increasing complexity as well as a systematic comparison of characteristic variables and observations.

This paper summarises the benchmark series, the lessons learned during specifying the steps, comparing and discussing the results and finally gives an outlook on future steps.

1. Introduction

In case of a severe accident, the containment is the ultimate barrier against release of fission and activation products to the environment. In order to describe containment thermal-hydraulic processes, hydrogen distribution and accident management measures to ensure containment integrity, reliable simulation tools are required. In the frame of the OECD/CSNI ISP-47 (Allelein et al., 2007) (2002–2007) on containment thermal-hydraulics, different codes have been applied. The best and the worst results (in the sense of agreement between experimental and calculated results) have been achieved by the same lumped parameter (LP) code but different users. This confirms the strong impact of user dependent choices, the so-called 'user-effect' and led to the recommendation to develop a 'Generic Containment' including

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http://dx.doi.org/10.1016/j.anucene.2014.07.006
0306-4549/

all important components enabling harmonisation of different users inputs with the aim to achieve a more reliable comparison of different calculations. For this purpose, a Generic Containment nodalisation was developed in the frame of the European Network of Excellence SARNET2 project (Severe Accident Research Network, 2009–2013), based on a German pressurised water reactor (PWR) with 1300 MW_{el}. It is used to compare and rate analyses being performed with different LP codes and models and can be applied for testing new model developments on a commonly available and accepted basis on plant scale in future.

The ‘Generic Containment’ code-to-code comparison is fundamentally different from any classical benchmark. Usually, the goal of such an exercise is to compare single theoretical models using experimental results of separate or coupled effect tests as a reference. Within this generic containment benchmark exercise, a comparison of results of complex code systems, containing the interaction of many single models, describing the different physical phenomena and technical systems was performed, but without reference to experimental results. In order to clearly separate the different contributions to the deviations among the results, a benchmark series with systematically increasing complexity was performed. In total, 14 European organisations and the Indian Bhabha Atomic Research Centre (BARC) applying 11 different LP codes contributed to this activity with 22 results for each step (see Table 1).

The benchmark consisted of three steps: run-0, run-1 and run-2. In the frame of the initial benchmark step, ‘Generic Containment-run-0’, the main focus was set on the preparation of the input decks, their verification and the transferability of assumptions and specifications among the different codes. A simple test-case, i.e. only the containment thermal-hydraulics of the in-vessel phase during a small break loss-of-coolant accident (SB-LOCA) was compared. The subsequent run-1 extended the transient and included H_2, CO and CO_2 releases and mixing during the ex-vessel phase. It aimed at identifying and reducing the user-dependent uncertainties to a well understood minimum, in order to achieve an understanding of sensitive modelling choices and their effects. The remaining deviations and their sources were investigated in detail. Based on this detailed understanding, the developed Generic Containment was applied as a basis for testing different passive auto-catalytic recombiner (PAR) modelling approaches in the benchmark step run-2.

2. Generic Containment definition

The general specification and the nodalisation of the Generic Containment have been prepared on the basis of an existing COCOSYS nodalisation of German PWR with 1300 MW_{el}, provided by GRS (Bönigke et al., 1998). The reactor system consists of four primary coolant loops with vertical U-tube steam generators. The reactor cooling system (steam generator, pumps etc.) is housed in separated equipment rooms. Burst discs will open in case of overpressure in the component rooms, enabling atmospheric flow to the dome and to the annular compartments. The reactor building consists of an inner steel shell (design pressure ~8 bar, volume ~70000 m^3), which houses the reactor system, as well as an outer concrete building, which contains the safeguard compartments (volume ~42000 m^3). Fig. 1 shows the division of the reactor building (R) into control volumes (the 3D view provides a clearer picture of the model, although simulations were of course 1-D).

The rooms and compartments of the reactor and auxiliary building have been grouped in 16 control volumes (zones) in order to devise a simple generic nodalisation. Also, real structures and flow paths have been merged in order to limit the model complexity. The four loops have been grouped; therefore, there are two steam generator compartments R-SG12 and R-SG34 as well as the corresponding annular compartments and stair cases behind the cylindrical missile shield R-ANN12 and R-ANN34. Associated with these rooms are the compartments U-12 and U-34 within the safeguard compartments (annulus). There are a common dome and sump zones R-DOME and R-SUMP within the containment and the safeguard building (U) U-DOME and U-SUMP. The reactor cavity R-CAVITY as well as the pipe duct R-DUCT is represented by means of a single zone, respectively. In order to take into account the design leakage from the inner steel shell to the safeguard compartments, there is a connection to the lower nuclear auxiliary building (AB) AB-SUMP. Gas can distribute within the two compartments AB-UP1 & 2, leak or be vented by the exhaust chimney AB-CHIM to the surrounding environment ENVIRON. The source terms representing the release from the primary circuit and later MCCI are defined for the steam generator compartment R-SG12 and R-CAVITY, respectively.

The Generic Containment zones are connected by means of single atmospheric (gas) and drain (liquid) junctions. In order to reduce complexity, doors, rupture discs and pressure relief flaps have been merged and are considered in a simple way by means of a rupture disc model. Fig. 2 gives an overview of the connections between the control volumes.

The Generic Containment nodalisation is thus indeed strongly simplified; however, the total heat capacity and the heat transfer area have been preserved. In order to have a common representation, especially of the total heat capacities, the properties of concrete and steel are predefined. Each zone contains both steel and concrete structures, which represent the overall heat exchange

Table 1
Participating organizations and applied codes.

Organisation	Code	Organisation	Code
AREVA	GOTHIC (v7.2b) (George et al., 2009) [a]WAVCO (2009_1) (AREVA, 2005)	NUBIKI	ASTEC (v2.0) (Chatelard and Reinke, 2009)
BARC	ASTEC (v2.0) (Chatelard and Reinke, 2009)	RUB	COCOSYS (v2.4) (Allelein et al., 2008)
ENEA	[a]MELCOR (v1.8.6YV) (Gauntt et al., 2005) [b]MELCOR (v2.1) (Gauntt et al., 2008)	RSE	MELCOR (v1.8.6YN) (Gauntt et al., 2005) ECART (v.4W0Q) (Parozzi and Paci, 2006) ASTEC (v2.0) (Chatelard and Reinke, 2009)
GRS	COCOSYS (v2.4) (Allelein et al., 2008) ASTEC (v2.0) (Chatelard and Reinke, 2009)	UJV	COCOSYS (v2.4) (Allelein et al., 2008) MELCOR (v1.8.6YV) (Gauntt et al., 2005)
JSI	ASTEC (v2.0) (Chatelard and Reinke, 2009) [a]CONTAIN (v2.0) (Murata et al., 1997)	UNIPI	ECART (v4W0P) (Parozzi and Paci, 2006) MELCOR (v1.8.6) (Gauntt et al., 2005) FUMO (Manfredini et al., 1992)
IRSN	ASTEC (v2.0) (Chatelard and Reinke, 2009)	VTT	APROS (v5.09) (Silde and Ylijok, 2010)
JÜLICH	COCOSYS (v2.4) (Allelein et al., 2008)	VUJE	MELCOR (v2.1) (Gauntt et al., 2008)
NRG	MELCOR (v1.8.6) (Gauntt et al., 2005) SPECTRA (v3.60) (Stempniewi, 2010)		

[a] Contributed only to run-0.
[b] Contributed only to run-1.