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Top-down scaling methodology from the LSTF facility to a three loop PWR plant applied to a SBLOCA event – The ROSA 1.2 test

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ABSTRACT

The scaling methodology describes quantitatively the possible differences in the behavior between a reduced size experimental facility and a full scale commercial plant for a determined transient. Then scaling is an essential tool in the design and operation processes of a reduced size facility in order to be able to simulate the behavior of large commercial plants. Since, in this way, it is possible to advance in the development of safety systems, prediction of situations likely to produce accidental sequences, etcetera. Therefore the scaling calculations should be carried out from the earlier stages of the experimental facility conceptual design, so that its experimental data results could be directly extrapolated to a commercial plant. Evidently, the scaling analysis has to be carried out for the experimental test plans, in order to check the capacity to transpose the experimental data of the reduced size facilities to the commercial plants. Consequently, the major objective of the scaling methodology is to evaluate quantitatively the applicability of small size test facility data to predict the behavior of full size commercial plants.

The top-down scaling step of the H2TS scaling methodology, between the LSTF experimental facility and a Pressurized Water Reactor of Siemens-KWU type for the ROSA 1.2 test, has been carried out along this document to evaluate the global system behavior. In order to achieve this main purpose, the general description of both facilities, the transient scenario, and the results of the scaling analysis for a small break loss of coolant accident (SBLOCA) in the hot leg are shown. The scaling analysis methodology used is the top-down global system analysis, from which, it is intended to establish thermal–hydraulic similarity between a scaled facility and a full scale industrial plant. With this aim, the accidental sequence of the ROSA 1.2 test has been divided into its five main time phases, analyzing separately each of them. In each phase the similarity groups (π-monomials and π-monomial groups) have been defined and applied. In such a way that only a reduced number π-monomials are needed to develop the scaling methodology, in addition, many of these similarity groups appear in several phases.

The key aspect of this document is to show the applicability of the top-down scaling analysis methodology to a commercial plant of a different type to that of the reference NPP at which the experimental facility replicates, i.e., test carried out in a Westinghouse type experimental facility, scaling analysis applied to a Siemens-KWU type. In such a way that, it has been proved the possibility to use the measurements made in an experimental facility of different type of the reference plant for an accidental scenario, in particular, applicability of a SBLOCA test data from an experimental facility of type Westinghouse to a commercial plant of type Siemens-KWU.

1. Introduction

Scaling analysis has been traditionally an issue previous to the construction of new nuclear power plants, since its design and construction processes constitutes a very complex technological challenge. Due to the almost unavoidably problem to characterize the whole system performance under the design conditions previous to the plant construction. Then, consequently, the experiments aimed to understand this behavior are usually performed in small size prototypes. So the scaling methodologies have been traditionally of importance during the design process of these experimental facilities.

Several scaling methods has been developed and used in many technical fields from the 70 s up to nowadays, such the linear scaling, the power/volume scaling, the Ishii's scaling (Bestion, 2016). It was in the 90's when the Hierarchical Two-Tiered Scaling methodology, H2TS, appeared (Zuber, 1991). This methodology is the most widely used in

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Nomenclature

A	area
D_h	hydraulic diameter
E	total energy
f	friction factor
g	gravity constant
G	mass flux
h	enthalpy
H_0	total height
k	form loss coefficients
$\vec{k}$	unit vector in the z direction
L	liquid height
L_i	length of segment i
M	total mass
M_l	momentum of loop l
t	time
u	velocity
U	total internal energy
V	control volume
$\dot{m}$	mass flow rate
N_{nodes}	total number of nodes
$\vec{n_s}$	unit vector in the mixture velocity direction
p	pressure
$\dot{q}$	heat transfer
Q	volumetric flow rate
Ri	Richardson number
S	length along the loop
t	time
T	temperature
u	fluid velocity
W_m	mass flow rate of the gas-steam mixture
x_s	static quality

Greek symbols

α	void fraction
Δ	difference (as in ΔT, difference in temperature)
ε	stored energy per unit mass
ϕ	phase (1ϕ single-phase fluid, 2ϕ two-phase fluid)
μ	specific internal energy
Π_x	π-monomial of a magnitude x
ρ	density
τ	characteristic time
ν	specific volume
ω_x	transfer characteristic frequency of a given property
$\Xi_{x,y}$	π-monomial group of a property, x, which is changing caused by a property, y.
$\Xi_{x,y,Z}$	π-monomial group of a property, x, which is changing caused by a property, y, in the facility, Z.

Subscripts

0	reference
bg	begin of phase
end	end of phase
f	liquid phase
g	gas phase
in	inlet
l	loop
LSTF-ROSA	ROSA 1.2 test in the LSTF Facility
m	two-phase mixture
m-p	mid-point
net	total
out	exit
prz	pressurizer
RCS	reactor coolant system
sat	saturation conditions
TSK-PWR	Siemens-KWU PWR type, three loop 3010 MW_t
Westinghouse	PWR of Westinghouse type, four loop 3423 MW_t

Superscripts

*	dimensionless variable
—	mean value
·	variation per unit time t
→	vector

Acronyms

AIS	Accumulator Injection System
ATLAS	Advanced Thermal-hydraulic Test Loop for Accident Simulation
BD	Blow-Down
ECCS	Emergency Core Cooling System
H2TS	Hierarchical Two Tiered Approach
HPIS	High Pressure Injection System
HQMD	High Quality Mixture Discharge
JAERI	Japan Atomic Energy Research Institute
LBLOCA	Large Break Loss Of Coolant Accident
LOCA	Loss Of Coolant Accident
LSTF	Large Scale Test Facility
LWR	Light Water Reactor
NC	Natural Circulation
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
PKL	"Primärkreislauf", primary circuit
PRZ	Pressurizer
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
ROSA	Rig Of Safety Assessment program (carried out in LSTF)
RPV	Reactor Pressure Vessel
RR	Reactor Refilling
SBLOCA	Small Break Loss Of Coolant Accident
SCRAM	Safety Control Rod Axe Man
SG	Steam Generator
TPD	Two-phase Discharge
TRACE	TRAC/RELAP Advanced Computational Engine (Thermal-Hydraulic code of the U.S. NRC)
TSK-PWR	Pressurized Water Reactor of type Siemens-KWU

the industry, but over the last decade two new methodologies have been developed, the Fractional Scaling Analyses (FSA) and the Dynamical System Scaling (DSS). The FSA is quite similar to the H2TS methodology, in fact both were developed by Zuber and his coworkers (Zuber et al., 2007), and both methodologies have many similarities. As far as DSS is concerned, say that this approach examines the scale distortions over the transient duration (Reyes, 2015), but due to its short life it has not been applied to a complex system. All these last three methods are based in the determination of a hierarchical ordering of the phenomena involved in the studied transient.

In general, thermal-hydraulics calculations constitute one of the major points for the safety design analysis of the light water nuclear reactors (LWR's). In particular, the scaling analysis is a very important tool to extrapolate the results obtained in small size test facilities to the