Nuclear Engineering and Design 241 (2011) 4456–4463

Contents lists available at ScienceDirect

Nuclear Engineering and Design

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

CATHARE 2 V2.5_2: A single version for various applications

G. Geffraye*, O. Antoni, M. Farvacque, D. Kadri, G. Lavialle, B. Rameau, A. Ruby

CEA, DEN, DER, F-38054 Grenoble, France

ARTICLE INFO

Article history:
Received 16 March 2010
Received in revised form 31 May 2010
Accepted 2 June 2010

ABSTRACT

This paper presents the new capabilities of CATHARE 2 as a multi-purpose multi-reactor concept system code. The CATHARE 2 code was originally devoted to best estimate calculations of thermal–hydraulic transients in Water-Cooled Reactors such as PWR, VVER or BWR. Recently, in the framework of the Generation IV International Forum, CEA launched several feasibility studies of future advanced reactor concepts including Gas-Cooled Reactors, Sodium-Cooled Fast-Breeder Reactors, Supercritical Water-Cooled Reactors. The 2-fluid model with non-condensable gases transport equations was first easily extended to Gas-Cooled Reactor applications with very few modifications. At the same time CEA seized opportunity to use CATHARE 2 to perform studies for non-nuclear industrial applications such as cryogenic rocket engines. New capabilities were implemented allowing passage from supercritical pressure to subcritical conditions and these features were then easily applied to Supercritical Water-Cooled Reactors. New developments were also necessary to extend the code to Sodium-Cooled Reactors. CATHARE 2 can now describe several circuits with various fluids either in single-phase gas or liquid, or in two-fluid conditions possibly with noncondensable gases, which allows simulating any kind of reactor concept and any kind of accidental transient.

The development method for the extension to new fluids is presented with an overview of the most striking functional and modelling features that have been implemented in the new CATHARE 2 V2.5_2 version to be released mid-2009 for industrial applications.

1. Introduction

The V2.5_2 version of the CATHARE 2 code is the outcome of more than 30 years of joint development effort by CEA (French Atomic Energy Commission), EdF (Electricité de France), AREVA-NP and IRSN (Radio-protection and Nuclear Safety Institute). CATHARE 2 was originally conceived for safety studies of PWR systems (Bestion and Geffraye, 2001).

In recent years, in the framework of the Generation IV International Forum, CEA launched a wide range of feasibility studies of future advanced nuclear reactors to develop the next generation nuclear energy systems, more specifically about Gas-cooled Fast Reactors (GFR), Sodium-cooled Fast Reactors (SFR) and Super Critical Light Water Reactors (SCLWR). At the same time, the CEA also decided to take the opportunity to use CATHARE 2 to perform studies for non-nuclear industrial applications such as rocket cryogenic engines.

In that context, there was a strong need to allow CATHARE 2 to take into account not only water but also other fluids and to extend CATHARE 2 capabilities to other concepts than light water reactors, including circuits with either single-phase gas or single-phase liquid flows, at both subcritical and supercritical pressures.

Rather than branching off separate versions of CATHARE 2 corresponding to each reactor concept, it was decided to integrate the new capabilities as independent options in a unique standard version of the code, respecting the same stringent procedures for Quality Assurance, in order to benefit from a maximum reusability and to minimize development and maintenance costs.

CATHARE 2 has thus evolved in a reliable unique system tool capable to study a large number of concepts in the scope of a best-estimate code used for thermal–hydraulic nuclear safety analyses.

The paper describes first the development method for extending CATHARE 2 to new fluids and then, it gives an overview of the most striking functional and modelling features that have been implemented in the new V2.5_2 version. New developments for PWR, extensions to SCLWR, new capabilities for GFR and SFR and developments for cryogenic fluids are successively presented.

2. The main principles of a single version

2.1. A single thermal–hydraulic kernel

CATHARE 2 has a flexible modular structure for the thermal–hydraulic modeling in applications ranging from simple

* Corresponding author.
E-mail address: genevieve.geffraye@cea.fr (G. Geffraye).

0029-5493/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.nucengdes.2010.09.019

Nomenclature

ADS	Automatic Depressurization Systems
DHR	Decay Heat Removal
GFR	Gas-cooled Fast Reactor
GFR-STREP	GFR-Specific Targeted Research Project
GUI	Graphical User Interface
HPLWR	High Performance Light Water Reactor European project
HTR	High Temperature Reactor
LB-LOCA	Large Break Loss of Coolant Accident
LOCA	Loss of Coolant Accident
LPSI	Low Pressure Safety Injection
QA	Quality Assurance
RAPHAEL	ReActor for Process Heat, Hydrogen and Electricity generation
SCLWR	Super Critical Light Water Reactor
SFR	Sodium-cooled Fast Reactor
SMFR	small innovative SFR
SPX	Superphenix

experimental test facilities to large and complex installations like Nuclear Power Plants. The main hydraulic components or elements are pipes (1D), volumes (0D), a 3D vessel and boundary conditions, connected to each other by junctions. Other sub-modules feature pumps and turbo-machines, control valves, T-junctions, sinks and sources, breaks and many other ones. All CATHARE modules are based on a six-equation two-fluid model (mass, energy and momentum equations for each phase), with additional optional equations for non-condensable gases and radio-chemical components. A specific treatment of the residual phases exists in order to manage their appearance and disappearance while minimizing convergence problems (Bestion et al., 1999) and with a quasi-perfect mass and energy conservation.

The discretization of all terms of the equations is fully implicit in 1D and 0D modules and semi-implicit in 3D elements including inter-phase exchange, pressure and convection terms, and the resulting nonlinear equations are solved using an iterative Newton solver. The code allows efficient use of several processors in parallel.

Although CATHARE was originally conceived for safety studies of PWR systems, it has many advantages to be extended easily to other applications. The numerical solver is reliable, efficient and generic. The existing tools for pre- and post-processing can be used for all applications. Basic modeling features, like circuits with heat exchangers, various hydraulic elements, valves, walls, already exist, are well consolidated, and can be reutilized.

In order to extend the code to other applications, development efforts could thus be limited to minor modifications of existing capabilities and addition of some new specific features for each application.

2.2. A new Graphical User Interface

A Graphical User Interface called GUITHARE has been developed over the last few years. It is developed for both windows and linux platforms. When it is used for pre-processing, GUITHARE is a helpful interface to create an input deck and “visualize” the circuit (see Fig. 1). Existing input deck can also be imported and modified. All these functionalities are interactive. Calculations can be launched from the GUI. For post-processing, GUITHARE is also an interactive tool, very helpful to analyse results of calculations. It can be used for all the applications of the V2.5_2 version.

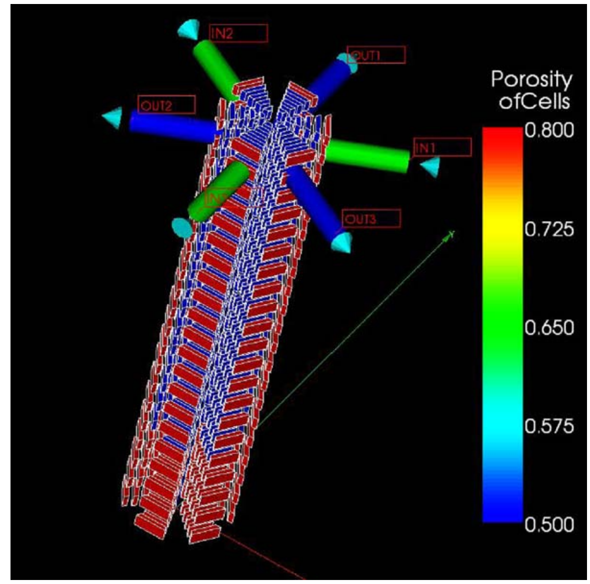

Fig. 1. GUITHARE view, 3D CATHARE modelling of a reactor vessel.

2.3. Common Quality Assurance procedures

The same QA procedures, well consolidated by application to all CATHARE previous versions (Bestion, 2000), are now applied to all the applications. The main procedures are described hereafter.

The developing methodology of CATHARE 2 includes non-regression tests for any new version or new release of updates. The objective is to trace the origin of any evolution of the results. The non-regression tests, which are sampled from the assessment matrices, test all physical models, all modules and submodules and any type of transient. In addition, before each code new version delivery, portability tests ensure that the code predictions do not depend on the computer.

The physical model developing methodology (Geffraye and Brun, 1999) is based on:

- Developments of models from separate effect tests or from literature, with possible adjustment of some coefficients (identified as revision).
- Systematic assessment of the physical closure laws against a large matrix of Separate Effect Tests.
- Extensive assessment on Integral Effect Tests in order to validate the general consistency of the set of physical closure laws.

As far as possible the same process is applied for the physical modeling for new applications. It will be detailed in the next paragraphs.

An extensive documentation is produced to describe the modules and submodules, to explain how to create an input deck and how to model the different reactor components. An important effort has been put on the “User’s Guidelines” document to specify the domain of application of the hydraulic and thermal components of the common kernel so that any user be aware of the conditions to be verified before using a common functionality.

And, at last, there is a unique team for maintenance and user support. This makes the maintenance process more efficient at least for all the software subroutines which are common to the various applications.