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Nuclear Engineering and Design 236 (2006) 491–501

Nuclear Engineering and Design

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Verification and validation of the HTGR systems CFD code Flownex

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Received 6 October 2004; received in revised form 16 November 2005; accepted 16 November 2005

Abstract

Regulatory requirements prescribe extensive verification and validation (V&V) of computer codes that are used in the design and analysis of accident conditions in nuclear plants. Flownex is a dynamic systems CFD code used as the primary thermal-fluid simulation code by the Pebble Bed Modular Reactor Company (PBMR).

Stringent quality assurance processes have been implemented to ensure that the code conforms to the set standards. These processes include the comparison of Flownex with analytical results as well as with experimental data.

The results of this process are summarized in this paper. Analytical solutions are used to verify Flownex's element models so as to ensure that the basic theory is correctly implemented in the computer code. As part of the analytical V&V effort various well-defined problems are solved using numerical methods implemented in independent computer codes.

Comparison with experimental and plant data is a very important feature of the V&V program to validate that the chosen theory is fit for purpose. For this, validation data from the pebble bed micro model (PBMM) is used. In addition to the PBMM experimental data Flownex is compared to a number of small thermal-fluid experiments in which certain specific component phenomena is validated. These experiments were developed in collaboration with North-West University (previously Potchefstroom University).

1. Introduction

Flownex (Anon., 2004; Landman and Greyvenstein, 2004) is a dynamic systems CFD code that enables users to perform detail analysis and design of complex thermal-fluid systems such as power plants and thermal-fluid networks. It is based on an implicit pressure correction method (IPCM) (Greyvenstein, 2002) that solves the momentum equation in each element and the continuity and energy equation at each node in large arbitrary structured networks for both steady-state and dynamic analysis. This gives the code a pseudo CFD capability, which allows it to predict complex phenomena such as pressure and temperature waves in pipes and buoyancy effects in packed beds.

According to Greyvenstein and van Ravenswaay (2002) the code has the ability to perform both steady-state and dynamic analyses. The solver, that is optimized for steady-state and transient flows, can deal with both fast and slow transients. Fast simulation speeds allow real time simulations to be performed on standard desktop computers. The code features the ability to simultaneously solve multiple gas and liquid networks that are connected through heat exchangers. The fundamental principle approach that has been used allows the prediction of phenomena such as choking, natural convection and Joule heating. It features a model builder that enables users to build advanced discretized re-usable models of complex components or sub-systems such as gas-cooled nuclear reactors and heat exchangers.

Standard component models in Flownex include: a comprehensive pipe model, a reservoir model, orifice models, a turbine model, a compressor model, various heat exchanger models (i.e. recuperator, shell and tube and finned tube), two reactor models (pebble and block fuel), a PID controller, valve models and pump models.

Flownex Nuclear is being developed to perform thermal-fluid analyses on a high-temperature gas-cooled reactor coupled to a direct, recuperated Brayton cycle in an implicit way. Since it is the first software product of its kind, a diverse number of verification and validation methods are used to qualify the software. The fact that Flownex Nuclear is the first software product of its

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doi:10.1016/j.nucengdes.2005.11.025

Nomenclature

BM	benchmark
FNX	Flownex
HPC	high-pressure compressor
HPT	high-pressure turbine
HS	heat source
IC	inter-cooler
LPC	low-pressure compressor
LPT	low-pressure turbine
PBMM	pebble bed micro model
PBMR	Pebble Bed Modular Reactor (Pty) Ltd.
PC	pre-cooler
PT	power turbine
RXLP	recuperator low-pressure side
RXHP	recuperator high-pressure side
V&V	verification and validation

kind should be stressed as it impacts on the availability of independent software products and experiments that can be used for V&V activities.

At PBMR, Flownex Nuclear is used to predict mass flows, heat transfer and pressures in the reactor core and the Brayton cycle during expected operational modes and states, as well as under accident conditions. It is used for both steady-state and transient simulations. Simulation results are fed back into the design process, where it dictates plant layout, material selection and operating philosophies. The accuracy of these simulations is crucial in determining the safety of operation, economic viability and protection of the plant.

In order to ensure the accuracy of these simulations a rigorous verification and validation (V&V) process has been implemented to guarantee the integrity of engineering analyses and to satisfy statutory requirements regarding the licensing and operating of nuclear plants in South Africa and abroad.

The process developed for the V&V of the code includes various control mechanisms and procedures that ensure that the whole development process is of the highest quality. This includes regression testing, automated testing, code reviews and validation of the code against benchmark data. The V&V process will described next.

2. Overview of the Flownex V&V process

The meaning of the two words “Verification” and “Validation” are not universally agreed upon. In the V&V process of Flownex, “Verification” is the process of ensuring that the controlling physical equations have been correctly translated into computer code or in the case of hand calculations, correctly incorporated into the calculation procedure. Validation is defined as the evidence that demonstrates that the code or calculation method is fit for purpose. This includes the confirmation that the results from the verified model agree with the benchmarks.

To ensure that all phenomena for each component in Flownex Nuclear are validated for the various extremities is a comprehensive exercise. Furthermore, V&V of the individual components as well as integrated systems of components for both steady-state and dynamic analysis are required.

The main focus of the Flownex V&V process is to perform effective V&V of complicated phenomena using the least possible validation cases. This is all done in a transparent and traceable manner according to regulatory guidelines and relevant international standards.

V&V forms part of the overall Flownex Nuclear development process and includes the verification activities that form part of the software engineering process, as well as all related verification that is done as part of the derivation and implementation of the theory for component models or model enhancements.

Fig. 1 shows a diagram of the V&V process for Flownex Nuclear. Tools used in the verification of Flownex include an implemented ISO 9001:2000 quality management system at M-Tech Industrial, the code developers, test plans and procedures, code reviews, user testing, automated testing and regression testing. Validation of Flownex Nuclear is performed by comparing the results of the implemented theoretical models in Flownex Nuclear with benchmark data obtained from appropriate methods or sources such as analytical data, experimental data, plant

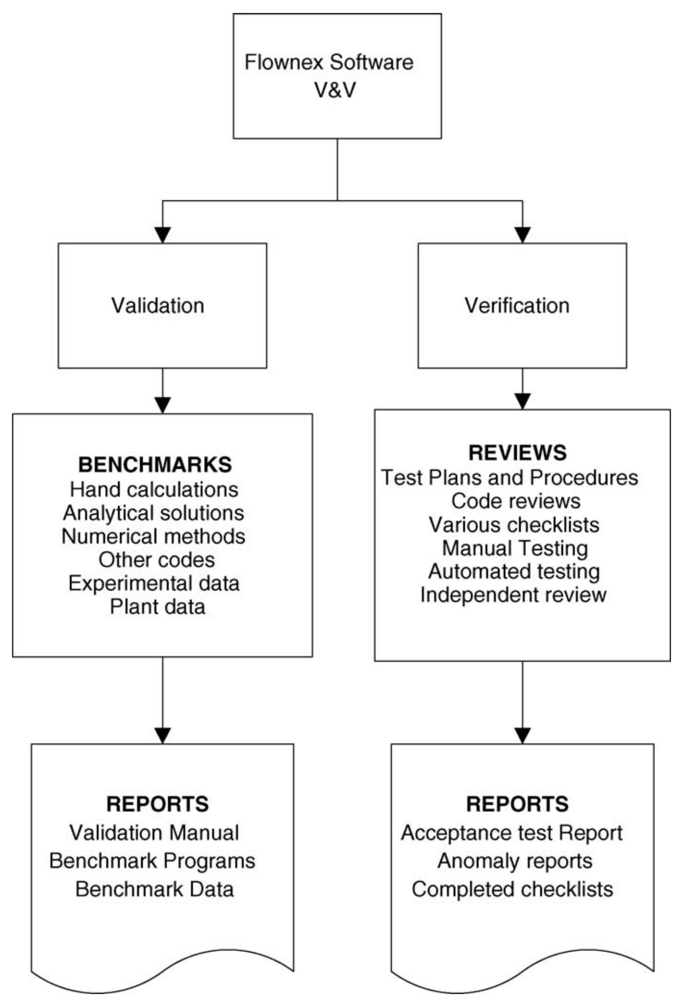

Fig. 1. Flownex Nuclear software V&V diagram.