Available online at www.sciencedirect.com
ScienceDirect
Progress in Nuclear Energy 48 (2006) 746–763
PROGRESS IN NUCLEAR ENERGY
An International Review Journal
www.elsevier.com/locate/pnucene

Impact of cross-section generation procedures on the simulation of the VVER-1000 pump startup experiment in the OECD/DOE/CEA V1000CT benchmark by coupled 3D thermal-hydraulics/neutron kinetics models

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Abstract

In the framework of joint effort between the Nuclear Energy Agency (NEA) of OECD, the United States Department of Energy (US DOE), and the Commissariat a l'Energie Atomique (CEA), France a coupled three-dimensional (3D) thermal-hydraulics/neutron kinetics benchmark was defined. The overall objective of OECD/NEA V1000CT benchmark is to assess computer codes used in analysis of VVER-1000 reactivity transients where mixing phenomena (mass flow and temperature) in the reactor pressure vessel are complex. Original data from the Kozloduy-6 Nuclear Power Plant are available for the validation of computer codes: one experiment of pump start-up (V1000CT-1) and one experiment of steam generator isolation (V1000CT-2). Additional scenarios are defined for code-to-code comparison. As a 3D core model is necessary for a best-estimate computation of all the scenarios of the V1000CT benchmark, all participants were asked to develop their own core coupled 3D thermal-hydraulics/neutron kinetics models using the data available in the benchmark specifications and a common cross-section library. The first code-to-code comparisons based on the V1000CT-1 Exercise 2 specifications exhibited unacceptable discrepancies between two sets of results. The present paper focuses on the analysis of the observed discrepancies. The VVER-1000 3D neutron kinetics models are based on cross-section data homogenized on the assembly level. The cross-section library, provided as part of the benchmark specifications, thus consists in a set of parameterized two group cross sections representing the different assemblies and the reflectors. The origin of the observed large discrepancies

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doi:10.1016/j.pnucene.2006.06.003

was found mainly to lie in the methods used to solve the diffusion equation. The VVER reflector properties were also found to enhance discrepancies by increasing flux gradients at the core/reflector interface thus highlighting more the difficulties in some codes to handle high exponential flux gradients. This paper summarizes the different steps applied to analyze the neutronic codes and their predictions as well as the impact of cross-section generation procedures.

Keywords: V1000CT; Benchmark; VVER; Coupled; Cross section; HELIOS

Nomenclature

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
ADFs	Assembly discontinuity factors
ARO	All rods out
CEA	Commissariat à l'Energie Atomique
DFs	Discontinuity factors
DOE	Department of Energy
FA	Fuel assembly
FEM	Finite element method
FZR	Forschungszentrum Rossendorf
HP	Hot power
HZP	Hot zero power
LWR	Light water reactor
MSLB	Main steam line break
NEA	Nuclear Energy Agency
PSU	The Pennsylvania State University
PWR	Pressurized water reactor
T-H	Thermal-hydraulic

1. Introduction

During the second OECD/DOE/CEA V1000CT benchmark (Ivanov et al., 2002) workshop conducted in Sofia, Bulgaria, in April 2004 (OECD, 2004), it was discovered that two clusters of participants' results for normalized radial power distribution were formed for both hot power (HP) conditions and hot zero power (HZP) conditions. The observed difference between these two clusters is approximately in the range of ±11%, while the difference within each of the clusters is in the range of ±1.5%. Compared to the results of PWR MSLB benchmark (Ivanov et al., 1999a) these deviations are not acceptable. Therefore, steps for understanding this problem were taken, which were described in detail in the paper presented at the AER Symposium (Ivanov et al., 2004).

Two representative results from each cluster were chosen to illustrate the deviations for HZP. The comparison of the PSU (TRAC-PF1/NEM) and CEA (CRONOS/FLICA-IV) HZP results for normalized radial power distribution have shown deviations that varies from 11.40% in the periphery of the core to −11.76% in the center of the core. It was decided that the possible sources of the observed deviation could be as follows:

- Differences of the interpolation procedures used for extracting the cross-section values from the cross-section library based on two-dimensional (2D) tables as a function of moderator density and fuel temperature.
- The fixation of the thermal-hydraulic (T-H) feedback could also be a possible source of deviations if it is not set up properly. Fixing the T-H feedback means that each node in the 3D neutronics model should have constant values for $T_f = 552.15$ K and $\rho_{mod} = 767.1$ kg/m^3.