Nuclear Engineering and Design 275 (2014) 69–79

Contents lists available at ScienceDirect

Nuclear Engineering and Design

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

ASSERT-PV 3.2: Advanced subchannel thermalhydraulics code for CANDU fuel bundles

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HIGHLIGHTS

- Introduction to a new version of the Canadian subchannel code, ASSERT-PV 3.2.
- Enhanced models for flow-distribution, CHF and post-dryout heat transfer prediction.
- Model changes focused on unique features of horizontal CANDU bundles.
- Detailed description of model changes for all major thermalhydraulics models.
- Discussion on rationale and limitation of the model changes.

ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form 21 April 2014
Accepted 22 April 2014

Keywords:
ASSERT-PV
Subchannel analysis
CANDU bundles
Thermal hydraulics
Code development
Numerical modeling

ABSTRACT

Atomic Energy of Canada Limited (AECL) has developed the subchannel thermalhydraulics code ASSERT-PV for the Canadian nuclear industry. The most recent release version, ASSERT-PV 3.2 has enhanced phenomenon models for improved predictions of flow distribution, dryout power and CHF location, and post-dryout (PDO) sheath temperature in horizontal CANDU fuel bundles. The focus of the improvements is mainly on modeling considerations for the unique features of CANDU bundles such as horizontal flows, small pitch to diameter ratios, high mass fluxes, and mixed and irregular subchannel geometries, compared to PWR/BWR fuel assemblies. This paper provides a general introduction to ASSERT-PV 3.2, and describes the model changes or additions in the new version to improve predictions of flow distribution, dryout power and CHF location, and PDO sheath temperatures in CANDU fuel bundles.

1. Introduction

ASSERT-PV (Carver et al., 1990; Carlucci et al., 2004; Rao and Hammouda, 2003) is a subchannel thermalhydraulic computer code developed by Atomic Energy of Canada Limited (AECL). Designated as an IST (Industry Standard Toolset) code, ASSERT-PV is the only subchannel code qualified for thermalhydraulic analysis of CANDU reactor fuel bundles in support of new fuel design and safety analysis in the Canadian nuclear industry. The code is based on the subchannel concept widely used for fuel bundle and fuel assembly thermalhydraulic analysis, where subchannels are the coolant flow areas bounded by the fuel elements and imaginary planes linking adjacent element center lines. The two-phase flow model used in ASSERT-PV is based on an advanced drift flux model, a five equation model that can consider thermal non-equilibrium and the relative velocity of the liquid and vapour phases. Equations of mass, momentum and energy are solved for each subchannel while taking into account inter-subchannel interactions. The subchannel solutions provide detailed single- and two-phase flow distributions, such as subchannel flows (axial and cross flows), enthalpy or quality, and void fraction. The code also calculates fuel sheath temperature distribution, pressure distribution, and local critical heat flux (CHF), from which dryout power is determined.

Abbreviations: CANFLEX®, CANadian FLEXible, a registered trademark of AECL and the Korea Atomic Energy Research Institute (KAERI); AECL, Atomic Energy of Canada Limited; AFD, Axial Heat Flux Distribution; ASSERT-PV, Advanced Solution of Subchannel Equations in Reactor Thermalhydraulics, Pressure-Velocity solution; BLA, boiling length average; BWR, boiling water reactor; CANDU®, CANada Deuterium Uranium, a registered trademark of AECL; CHF, critical heat flux; HTC, heat transfer coefficient; LUT, look-up table; PCD, pitch circle diameter, diameter of an element ring in CANDU bundles; PDO, post-dryout; PWR, pressurized water reactor; RFD, radial heat flux distribution; RMS, root-mean-square; SL, Stern Laboratories; TM, turbulent mixing, inter-subchannel; V3R1, Version 3 Revision 1, equivalent to v3.1.

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http://dx.doi.org/10.1016/j.nucengdes.2014.04.016

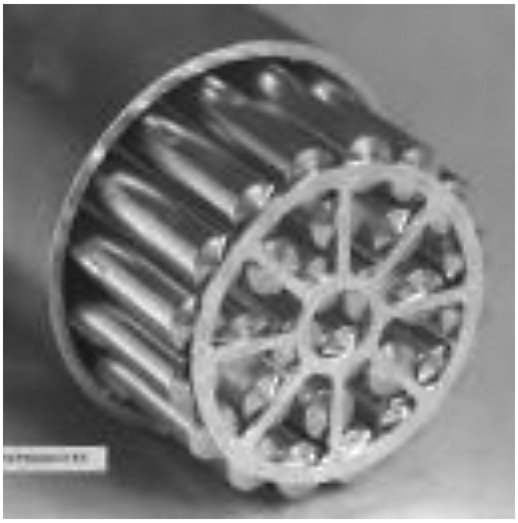


Fig. 1. Image of a 28-element bundle in pressure tube.

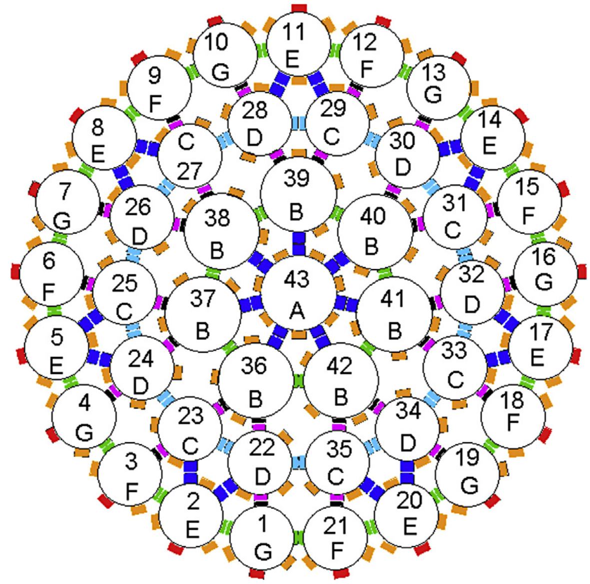


Fig. 2. Schematic of a 43-element bundle with appendages.

The main use of ASSERT-PV is to compute thermalhydraulic conditions in a horizontal CANDU fuel channel, including: pressure drop, CHF location, dryout power, and post dryout (PDO) fuel sheath temperature, for steady state or slow transients. It is the primary tool used to assess the effects on channel dryout power of parameters such as Axial heat Flux Distribution (AFD), Radial heat Flux Distribution (RFD), axial pressure tube creep profile, and bundle geometry variations resulting from dimensional design tolerances, manufacturing non-conformances, and reactor operation. Results from such assessments can help optimize the design of new fuels, and provide support for front line licensing codes such as CATHENA (Hanna, 1998) in the safety assessment of existing and new fuel designs.

This paper provides a general introduction to ASSERT-PV 3.2, and describes the model changes or additions in the new release version, compared to the previous version ASSERT-PV V3R1 (the format of the code version identifier has changed during the course of new code development). The focus is placed on the enhanced models for better prediction of flow-distribution, CHF and post-dryout heat transfer in horizontal CANDU bundles. The theory and rationale behind the model changes, as well as the limitation of the new models, are also discussed.

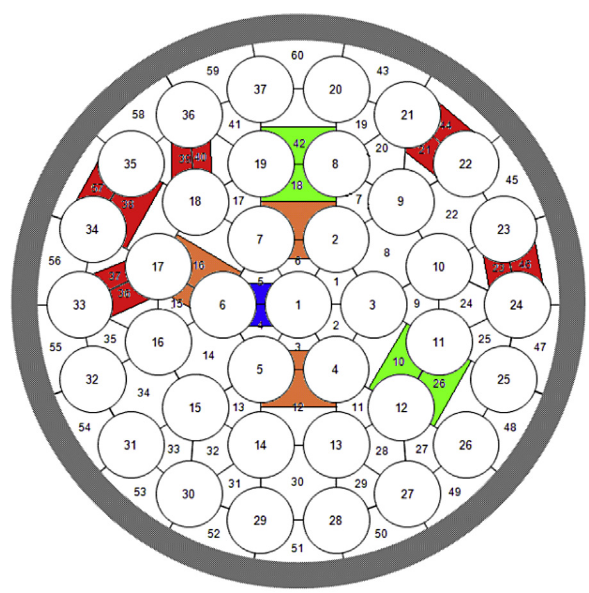
Assessments of the improved capabilities for flow distribution, dryout power and CHF location, and PDO sheath temperature predictions have been completed using experiment data sets, including the Stern Laboratories' 28-, 37- and 43-element bundle experiments. Significant improvement has been confirmed for all key output parameters and for all three CANDU bundles. The assessment results for the flow-distribution prediction are presented in the second paper (Nava-Dominguez et al., 2014), whereas those for the CHF and PDO predictions are included in subsequent papers (Rao et al., 2014; Cheng et al., 2014).

Subsequent sections in the paper are arranged as follows: (i) development of ASSERT-PV; (ii) flow-distribution model; (iii) CHF model; (iv) PDO model; and (v) concluding remarks.

2. Development of ASSERT-PV

2.1. ASSERT-PV applications

ASSERT-PV models the subchannel flow and phase distribution in horizontal CANDU channels. Figs. 1–3 show respectively an image of a 28-element bundle in a pressure tube (CANTEC, 2014), a schematic of a 43-element bundle with appendages (spacers, buttons and bearing pads); and a cross-sectional view of an ASSERT-PV model of a string of 37-element CANDU bundles in a pressure tube. Note that in Fig. 2, numbers 1–43 show the number assigned to each of the 43 fuel elements, whereas letters A–G show each of the groups of elements that have an identical design of appendages (spacers, buttons and bearing pads). Fig. 4 shows schematically a test section simulating a bundle string of 12 CANDU bundles in a horizontal pressure tube used in many CANDU bundle experiments. Although ASSERT-PV has been developed mainly for horizontal CANDU fuel channels, the code is general enough to accommodate other geometries and orientations, including PWR and BWR designs, in both vertical and horizontal orientations.



Green: uniform square-square array
Blue: uniform triangle-triangle array
Brown: square-triangle subchannel pair
Red: not characterized.

Fig. 3. ASSERT model of 37-element bundle in pressure tube.