BWR TURBINE TRIP CALCULATIONS WITH THE CATHARE CODE

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ABSTRACT

This paper presents a boiling water reactor turbine trip transient computation performed with the CATHARE code. The calculation is carried out in the frame of an international benchmark [1] organized by OECD/NEA concerning boiling water reactors transient analysis using coupled 3D thermal hydraulic and kinetics codes. The transient addressed is a BWR turbine trip experiment performed at Peach Bottom Unit 2 that involves pressurization events in which the interactions between core phenomena and system dynamics are very important.
The benchmark is composed of three exercises and this paper deals with the first one. The purpose of this first calculation is to test the reactor thermal hydraulic system response and to initialize system models before coupling with 3D codes.
The first section presents the CATHARE modeling of the reactor. The second section describes the calculation results: the initial steady state conditions fully comply with the specifications, the transient results (core flow, reactor pressure..) are comparable to the RETRAN calculation results.
The final objective of the benchmark is to perform a complete coupled 3D kinetics/thermal hydraulic calculation for the core and 1D thermal-hydraulic modeling for the balance of the plant.

1. INTRODUCTION

The Nuclear Energy Agency of the OECD and the Pennsylvania State University have organized an international benchmark: the BWR TT Benchmark. A turbine trip transient performed in 1974 on the Peach Bottom 2 reactor has been selected to investigate the effects of the pressurization transient following the sudden closure of the Turbine Stop Valve on the neutron flux in the core. This event involves strong interactions between the core physics (neutronics and thermalhydraulics) and the system dynamics, thus enabling verification of the capability of coupled system thermal hydraulics and neutron kinetics codes.
The benchmark is made of three different exercises consisting in:
exercise 1 : thermal hydraulic calculation of the reactor with given axial power profile
exercise 2 : coupled 3D core/thermal hydraulic calculation with boundary condition modeling
exercise 3 : best estimate coupled 3D core/thermal hydraulic system modeling
The results of the calculation of the exercise 1 performed with the CATHARE 2 V1.5A code are presented in this paper. They are compared with the results of a RETRAN calculation, which can be considered as the benchmark reference calculation [2].

The objective of the first exercise is to test the thermal hydraulic system response and to initialize the system models in order to perform the final coupled exercise with the three codes CATHARE [3], FLICA4 [4] and CRONOS [5].
The second exercise of the benchmark has been calculated by the CEA with CRONOS and FLICA4 [6].

2. CATHARE MODELISATION OF THE PEACH BOTTOM REACTOR

The Peach Bottom reactor model represents the reactor vessel with its internal structures, the steam lines up to the turbine stop valve (TSV), and the steam by pass lines up to the condenser (Figure 1). The reactor geometry follows the benchmark specifications. A PB2 RETRAN skeleton input deck has been used to build the model (elevations, volumes…).

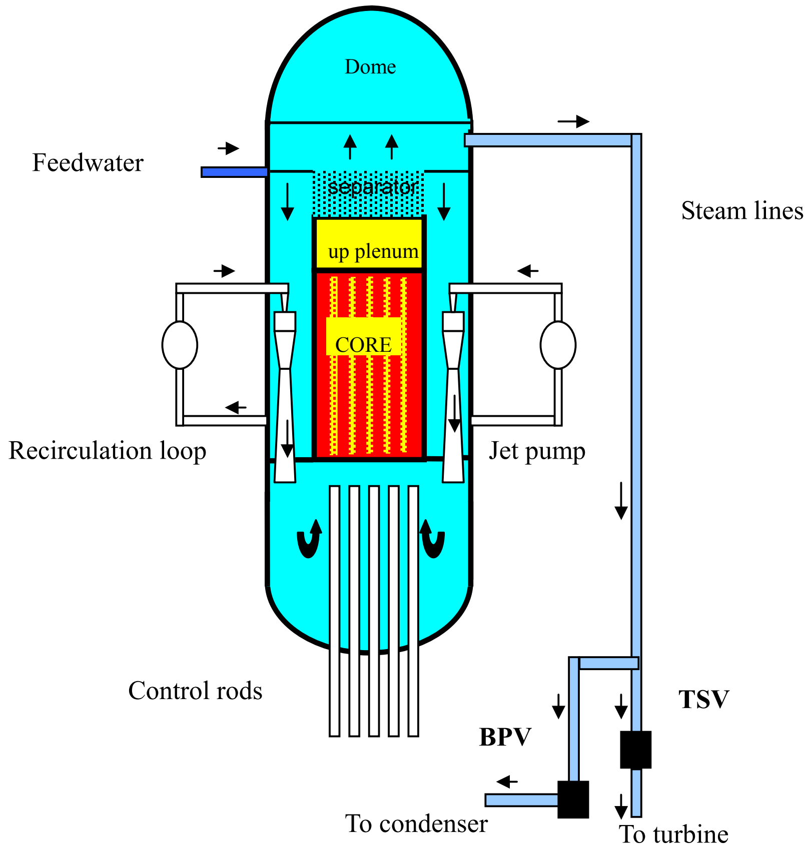

Figure 1. Peach Bottom reactor model

The modeling of the reactor is represented in Figure 2. There are 764 fuel assemblies in the core, represented by a 1D module with a weight 764. This module is divided into 24 axial meshes. The axial power profile is given as input of the calculation. A 1D module represents the core by-pass flow between the subassemblies. The downcomer, the standpipes are 1D modules, the two recirculation loops are modeled with 1D, Tee elements and 0D pump modules. The recirculation pump performance parameters are derived from the RETRAN model. Each recirculation loop drives 10 jet pumps lumped as one. There is no specific jet pump model in the CATHARE code: the jet pumps have been schematized with 1D modules and Tee modules connecting the recirculation loop and the downcomer (Figure 2).

The separator dryer is represented by a specific 0D module with carry under and carry over values set to 10^{-4}. The dome and the lower plenum are 0D modules.
The four main steam lines are lumped into one line: they are modeled with a 1D module of weight 4. The spatial discretization is about 300 meshes for a pipe length of 250 m with a maximum mesh length of 1m. The Turbine Stop Valves (TSV) and the Bypass Valves (BPV) are simulated with singular pressure loss coefficients.

The boundary conditions of the initial steady state are as follows :
Inlet condition : feedwater inlet in the upper downcomer, mass flow rate and temperature are given.
Outlet condition : pressure is imposed in the condenser, which is a very large section volume (P = 0.05 bars), downstream of the BPV an outlet pressure is imposed in order to obtain 68 bars in the dome.

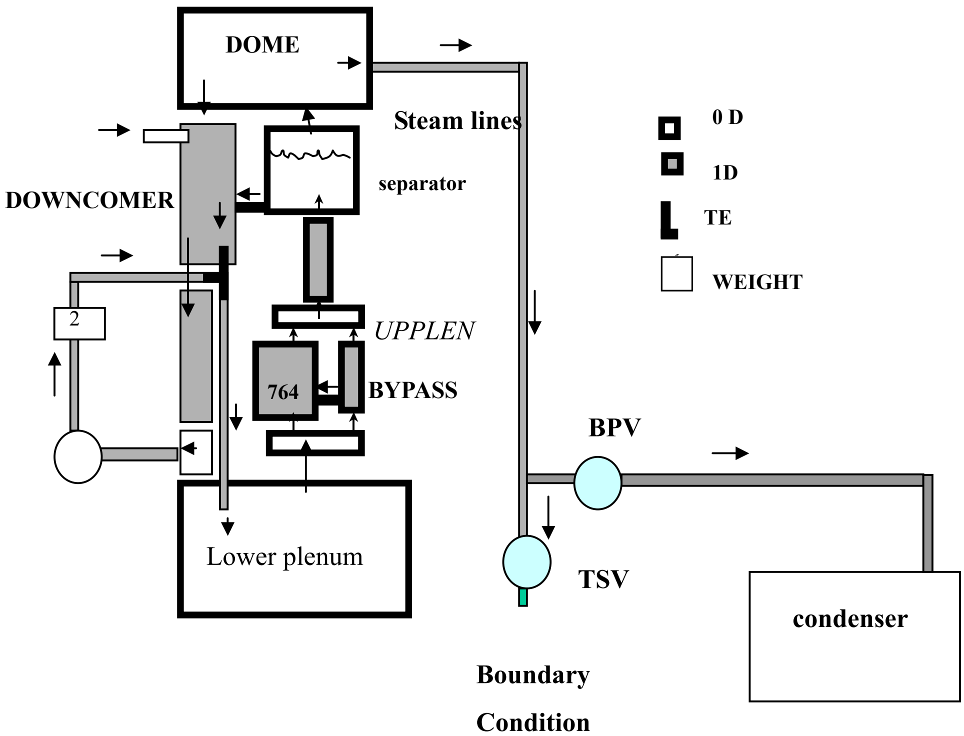

Figure 2. CATHARE modeling of the PB2 reactor

3. CALCULATION RESULTS

3.1 INITIAL STEADY STATE CONDITIONS

The initial steady state is calculated by fitting the singular pressure loss coefficients in the reactor in order to obtain the flow distribution in the main components (core, by-pass, recirculation loop, downcomer) corresponding to the specifications.
The steady state conditions calculated fully comply with the specifications. The main parameters are given in Table I

Table I

core thermal power (MW)	2030
initial power level, % of rated	61.65
feedwater flow (kg/s)	980.3
reactor pressure (Pa)	$798\ 10^5$
core flow (kg/s)	10445
inlet core subcooling (KJ/kg)	48
feedwater inlet temperature (C)	168.2
mass flow in a recirculation loop (kg/s)	1435.7
core average void fraction	0.3
core pressure drop (Pa)	$0.96\ 10^5$

The axial void fraction distribution in the core is represented in Figure 3. The maximum void fraction calculated at the outlet of the core is equal to 0.62, which corresponds to the value given in the benchmark specifications. The pressure profile in the core is represented in Figure 4: the core inlet pressure loss is nearly equivalent to the total fuel assembly friction pressure drop.

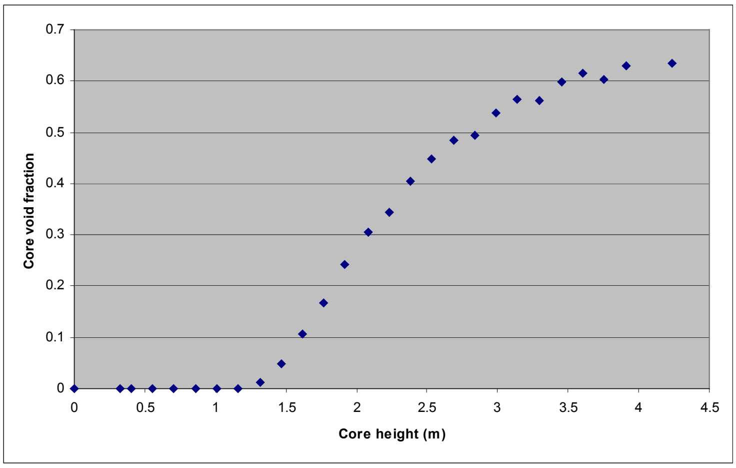

Figure 3. Axial distribution of core void fraction

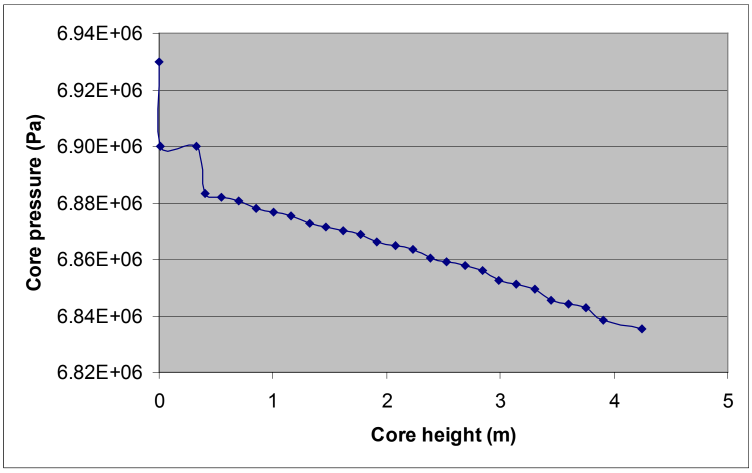

Figure 4. Core pressure drop

3.2 TRANSIENT CALCULATION

The first five seconds of the transient are calculated since the main phenomena occur during this time period.
The transient begins with the closure of the TSV.
The boundary conditions imposed during the transient are as follows:

- feedwater flow is given versus time, the temperature is kept constant
- the normalized relative fission power is given versus time (Figure 5)

  The power increases rapidly from 0.4s, reaches its maximum value at 0.72 s. This maximum value is about 5 times more than the initial value. Then the power decreases quasi instantaneously with the control rod insertion.
- the opening and the closure of the BPV and the TSV: the values of the singular pressure loss coefficient are calculated from the % of aperture according to the specifications.

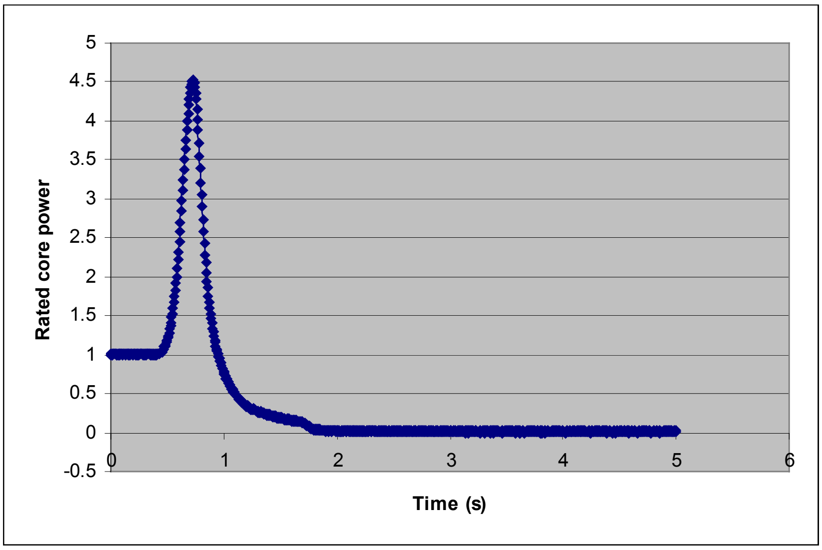

Figure 5. Core power evolution (input condition)

The main events are summarized in Table II.

Table II
TT2 event timing
(time delay given in ms)

TSV begin to close	0
BPV begins opening	60
TSV closed	96
Bypass valves full open	846
Vessel pressure initial response	329
Core exit pressure initial response	353
Dome first pressure peak	779
Maximum of reactor pressure	3914

The closure of the TSV initiates a pressure wave, which propagates in the steam lines with a velocity near to 500 m/s. The BPV begins to open before the TSV is completely closed and helps to relieve the pressure. The steam pressure increase reaches the reactor pressure vessel at 329 ms. The pressure wave reaches the core following two paths: a single phase (liquid) path through the downcomer, a two-phase path through the separator dryer and the upper plenum. The time needed to reach the core via each of these two paths differs, since the lengths are different and the velocities of propagations are not the same. The induced core pressure oscillations affect the core void fraction and the core mass flow rate.

Figure 6 shows the evolution of the core exit pressure calculated by CATHARE and by RETRAN, the total jet pump flow calculated by the two codes is represented in Figure 7. Comparisons between the CATHARE and RETRAN results are satisfactory.

The first peak of pressure increase calculated by CATHARE is more than 3 bars and is observed after 779 ms. The maximum pressure reached in the dome at about 4 s is more than 72 bars (initial dome pressure is 68 bars).

The oscillations of the total jet pump flow are more damped in the CATHARE calculation, but the maximum discrepancies on the amplitude are less than 10% and the period of the fluctuations is almost the same. CATHARE has no specific modeling for jet pumps, which are simply modeled with 1D and Tee modules. Moreover, the interfacial friction and condensation models are not the same in the two codes, which can explain the differences of pressure and flow oscillations.

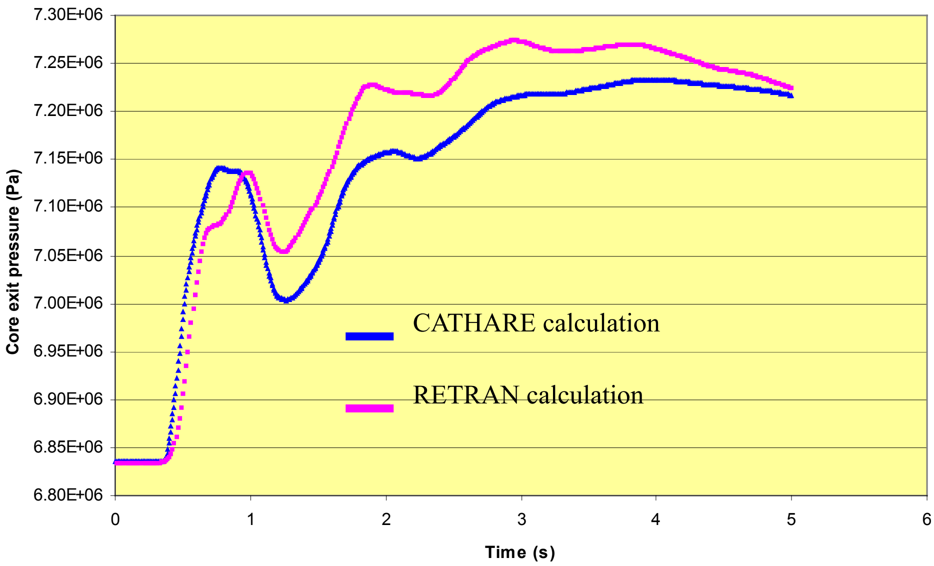

Figure 6. Core exit pressure evolution

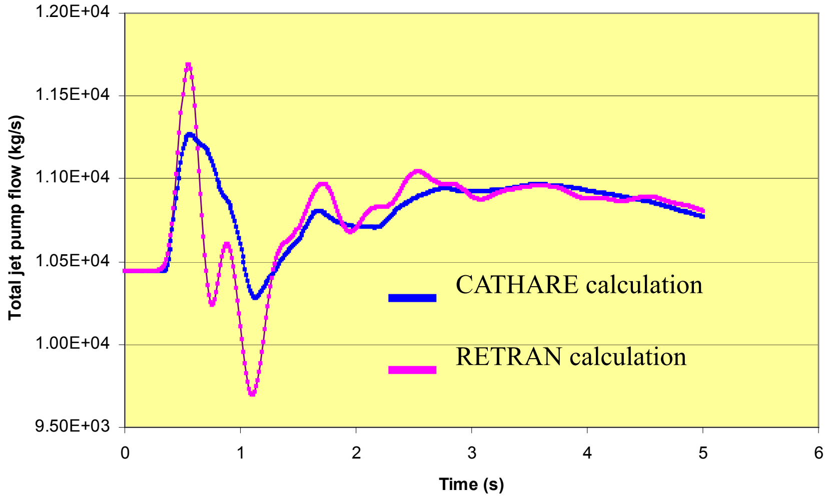

Figure 7. Total jet pump flow

The steam bypass line flow rate calculated by CATHARE is larger than the RETRAN value by about 20%. Here again the different nodalizations can explain these discrepancies: RETRAN has 6 elements for the steam lines whereas CATHARE uses 300 meshes.
A study of sensitivity to the singular pressure loss coefficient of the BPV(Ki coefficient, Figure 8) has been performed. Three different values have been tested. When the pressure loss coefficient is increased, the steam line flow decreases and the pressure in the reactor is increased. The evolution of the reactor pressure during the first second remains unchanged: the first peak is still obtained at about 1s and reaches 71.5 bars.

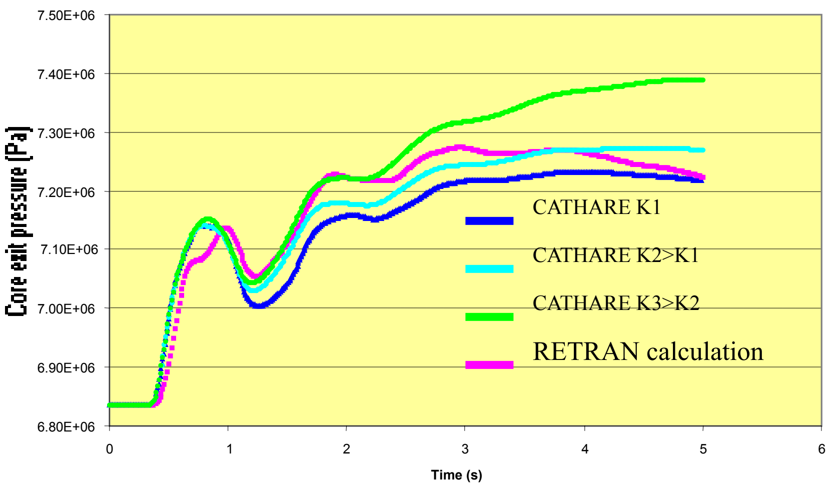

Figure 8. Core exit pressure. Sensitivity to the BPV coefficient

Calculations have been carried out to study the influence of the steam lines meshing: a calculation has been performed with 30 meshes instead of 300 and the results showed no major differences.

Sensitivity studies to the time step have shown that a maximum value of 10^{-4} s is required. The transient has been performed with this maximum time step value.

CONCLUSIONS

The PB2 TT2 transient defined as an OECD benchmark has been calculated with the CATHARE code. The aim of this calculation (first exercise of the benchmark) is to test the thermal hydraulic response of the reactor and to assess the modeling of the circuit before performing a coupled thermal hydraulic/kinetics calculation.

The initial steady state conditions calculated by CATHARE fully comply with the benchmark specifications. The results of the transient calculation are comparable to those of the RETRAN calculation. The evolutions of the reactor pressure and the core flow are in good agreement, although the flowrate in the steam bypass lines is slightly higher than the reference value. The results of the transient calculation are overall satisfactory.

The next objective is a coupled calculation with three codes (third exercise of the benchmark): the CATHARE code calculates the 1D plant thermal hydraulic, while FLICA and CRONOS codes calculate respectively the 3D thermal hydraulics/kinetics in the core.

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