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Peach Bottom-2 Low-Flow Stability Test using TRAC-BF1/VALKIN and RELAP5/PARCS Codes

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1. Introduction

The possibility of instability in the core of a boiling water reactor induced by thermal-hydraulic and void reactivity feedback has been the subject of many analytical and experimental investigations. However, to improve the safety systems of these reactors, it is necessary to be able to detect in a reliable way these oscillations from the neutronic signals.

Four stability tests were developed in 1977 at end of cycle 2. These tests were conducted along the low-flow end of the rated power-flow line, and along the power-flow line corresponding to minimum recirculation pump speed. In this work, three dimensional time domain BWR stability analysis were performed on test point 3 (PT3) for the core wide oscillation mode.

We have carried out a number of perturbation analyses using two coupled codes: TRAC-BF1/VALKIN and RELAP5-MOD3.3/PARCS. A modal analysis of the 3D neutronic power evolution has also been calculated.

The purposes of these analyses are: to perform the real situation for comparing the results with real data and to compare the behaviour of the two coupled codes used.

For reducing the CPU time and looking for an unstable point, in most of the cases we have used a model with only one thermalhydraulic channel. The differences between the results obtained using 1 or 33 channels are important.

The calculated results show that point PT3 is a nearly stable point and it is at the end of cycle, while the obtained average axial power distribution shows a non bottom-peaked profile (stable). Nevertheless, the characteristics of the in-phase instability can be recognized in the different analyses.

To characterize the unstable behaviour of the Peach Bottom Unit 2 BWR, a number of perturbation analyses were performed: arrangements with Philadelphia Electric Company (PECo) were made for conducting different series of Low Flow-Stability Tests at Peach Bottom 2, during the first quarter of 1977.

The Low Flow Stability Tests are intended to measure the reactor core stability margins at the limiting conditions used in design and safety analysis, providing a one-to-one comparison to design calculations.

The selection of this reactor was based on its being a large BWR/4 which reaches the end of its Number 2 reload fuel cycle early in 1977, with an accumulated average core exposure of 12.7 GWd/t.

Stability tests were conducted along the low-flow end of the rated power-flow line, and along the power-flow line corresponding to minimum recirculation pump speed. The actual reactor operating conditions at which the low-flow core stability testing was conducted are listed in table I and showed in figure 1 [1].

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Table 1 Peach Bottom-2 End-of-Cycle 2. Low-Flow Stability Test Conditions

Test Number	Reactor Power		Core Flow Rate		Core Pressure[a]	Core Inlet Enthalpy
	(MWt)	(%Rated)	(kg/s)	(% Rated)	(MPa)	(kJ/kg)
PT1	1995	60.6	6753.6	51.3	6.89	1184.61
PT2	1702	51.7	5657.4	42.0	6.84	1187.78
PT3	1948	59.2	5216.4	38.0	6.93	1184.61
PT4	1434	43.5	5203.8	38.0	6.89	1183.83

(a)Based on process computer edit (P1), corrected for steam separator pressure drop

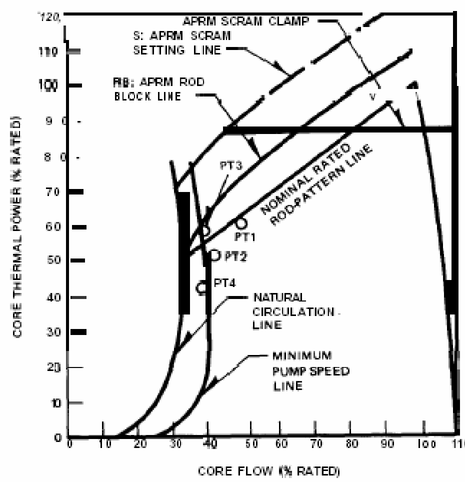

Fig.1 Peach Bottom 2 Low Flow Stability Tests Conditions.

For the analysis performed in this study, as actual steady state conditions, point 3 of these Low Flow Stability Tests has been chosen, in such a way that the reactor state is close to the stability boundary in the Power/Flow Map.

The core neutronic data used in all the calculations are specified in [2].

For all the calculations, it has been developed the same detailed thermal-hydraulic nodalisation reproducing each geometrical zone of the plant [3], [4].

For the core, 33 thermalhydraulic channels have been modelled to represent the active part of the core and one channel for all by-passes. For the rest of the plant a coarse nodalisation has been adopted for limiting the needed computer resources.

For the neutronic code, a nodalisation with a 3D core mesh composed with 764 axial nodes has been modeled. A large set of cross section data including 435 compositions has been adopted in neutronic input deck [2].

With the aim of better understanding the instability development process, it has been studied the stability response of this operational point to a steam line pressure disturbance of 8 Psi with the coupled codes TRAC-BF1/VALKIN and RELAP5Mod3.3/PARCS. With these codes it is possible to obtain detailed information regarding the state of the reactor for each time step.

Moreover, using nodal cross-sections obtained with RELAP5/PARCS, a modal decomposition with the VALKIN code [5], [6] has been performed, with the aim to compare the transient power evolution using a classic 3D neutronic- thermalhydraulic coupled code and a 3D modal code. To characterize the studied transient as in-phase or out-of-phase and also to study the importance of different modes during the transients, the amplitudes of the different power modes have been computed with VALKIN.

Finally, in order to observe the difference between the results obtained using different numbers of modes or different updating times, different transient calculations have been carried out.

2. Steady State Results

The main parameters obtained in steady state calculations and after zero transient calculations were compared to make it sure that the stable conditions exist before the reactor perturbation.

The list of compared parameters covers reactor power and mass flow, core exit pressure, core inlet temperature, core inlet enthalpy, power peaking factor and core average axial power distribution [1]. Table 2 presents the reactor main parameters prior to its disturbance for the two calculations performed and their comparison with available measured data. Figure 2 compares the core average axial power distribution calculated with the several codes, with the one measured.

Table 2 Reactor Main Parameters Prior to its Disturbance

Parameters, Units	Measured	RELAP5/PARCS (33 channels)	TRAC-BF1/VALKIN (33 channels)
Core Thermal Power, MWt	1948.0	1949.0	1949.0
Reactor Flow, kg/s	5216.40	5216.332	5212.6
Core Inlet Temperature, K	543.16	543.014	541
Core Inlet Enthalpy, J/kg	1.1846E6	1.1839E6	1.1741E6
Pressure at Core Outlet, Pa	7.0980E6	7.0979E6	7.035E6
Feedwater mass flow, kg/s	941.22	941.22	941.10

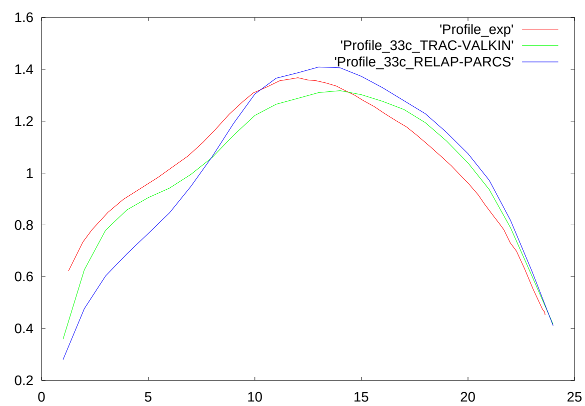

Fig.2 Comparison of RELAP5/PARCS and TRAC-BF1/VALKIN calculated core average axial power distributions with experimental test (process computer corrected).

3. Spatial modes

The first three spatial modes have been computed using the nuclear cross sections provided by a RELAP5/PARCS simulation as an input for the VALKIN code. Figure 3 represents the obtained modes shapes:

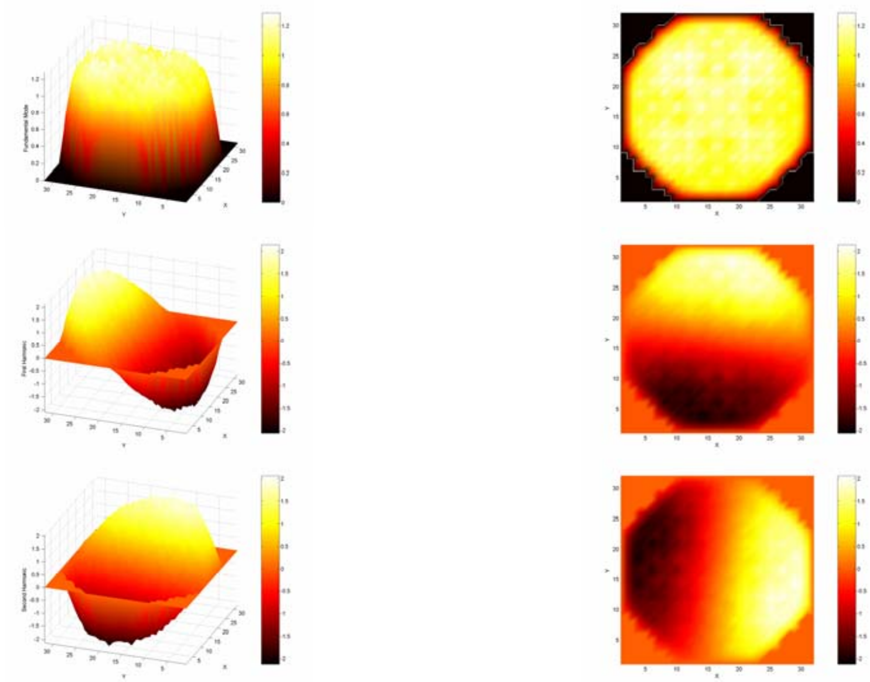

Fig.3 Power profile of the first three Lambda modes for Peach Bottom2 LFST PT3.

4. Transient results

Point PT3 has been simulated with RELAP5/PARCS and compared its results with the obtained using the stand alone neutronic code VALKIN.

With the coupled code TRAC-BF1/VALKIN have been performed two different calculations, the first, Case 1, without updating the mode, and the second one, Case2, updating the mode each 1 second.

Table 3 presents the Decay Ratio and the Natural Reactor Frequency that are usually used to characterize the instability phenomena.

Table 3 Time Series Analyses Results

	DR	Freq.
Reference	0.331	0.430
TRAC/VALKIN Case 1	0.4172	0.3032
TRAC/VALKIN Case 2	0.4883	0.3097
RELAP5/PARCS	0.299	0.316

We can see that the frequencies obtained are different from the reference, but they are similar to the obtained in other works [7].

4.1 RELAP/PARCS results

With the nuclear cross section provided by the transient calculation performed with RELAP5/PARCS, different analyses with the VALKIN code have been carried out.

The process of updating the modes increases considerably the accuracy of the obtained solution but is an expensive process from the computational point of view, thus it is necessary to find the equilibrium between the number of modes and its updating time to optimize the performance of the method. With VALKIN, we have executed two transient calculations, with 1 and 3 modes respectively, in order to analyze the influence of the number of modes in the results.

Figure 4 shows the power evolution calculated with 1 and 3 modes and the comparison with the one achieved with the RELAP5/PARCS calculation. It is possible to observe the good agreement among the results, so in order to reduce the CPU time but conserving the same accuracy we will continue the analysis using only one mode.

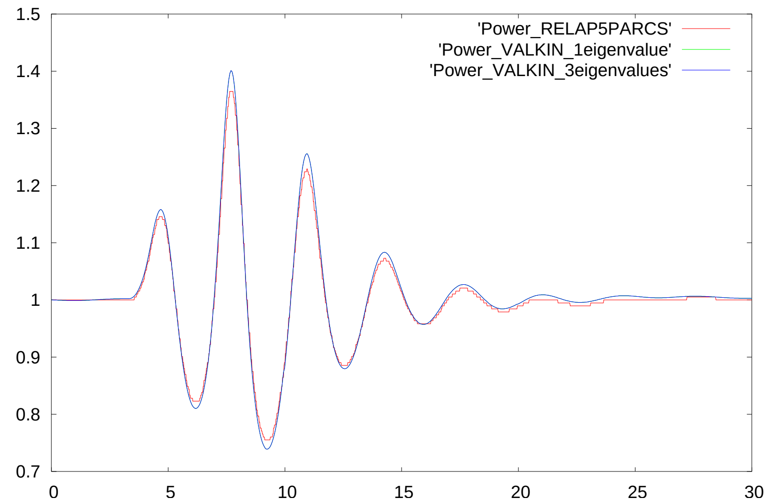

Fig.4 Comparison between the power evolution obtained with RELAP5/PARCS and the power evolution obtained using VALKIN code with different number of eigenvalues.

In Figure 5 we show a detail of the power evolution for the transient calculated using 1 mode. We compare the solution obtained without updating the modes and updating the modes each 0.956 seconds and each 0.0956 seconds with the solution obtained with RELAP5/PARCS taken as reference. We observe that the updating process increases the accuracy of the obtained solution.

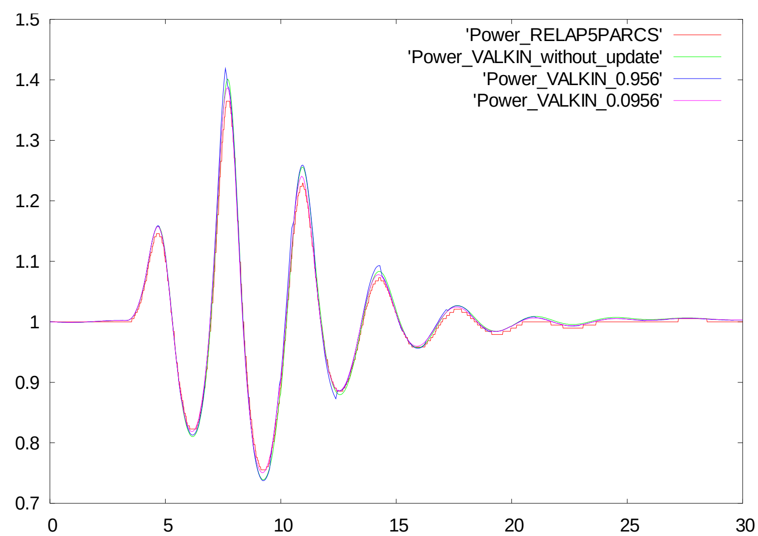

Fig.5 Comparison between the power evolution obtained with RELAP5/PARCS and the power evolution obtained using VALKIN code with 1 eigenvalue and different updating times.

The main difference in the transient appears in the maximum power peak achieved during the transient. As we have already mentioned, the relative error decreases as the updating time decreases.

To characterize the studied transients as in-phase or out-of-phase and also to study the importance of different modes during the transients, we have also calculated the time dependent amplitudes, of the fundamental mode and two harmonics, using an updating time of 0.956 seconds.

Figure 6 shows the evolution of $n_0(t)$, $n_1(t)$ and $n_2(t)$ obtained with an updating time of 0.956 seconds.

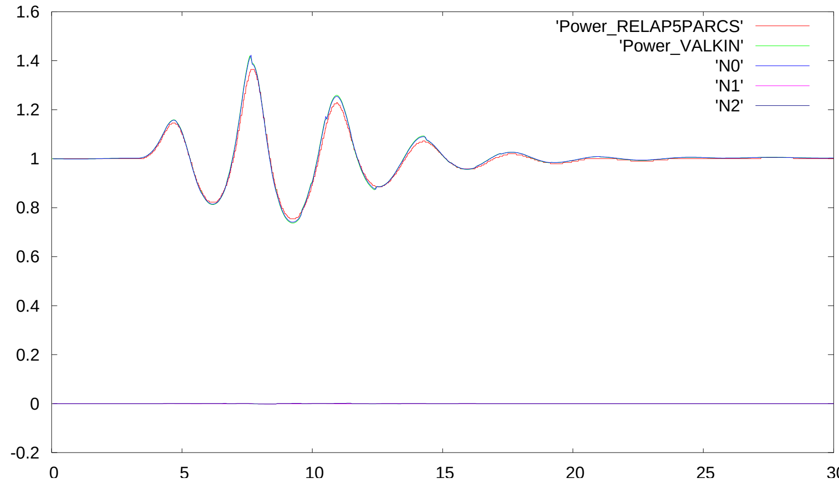

Fig.6 Power evolution with RELAP/PARCS and VALKIN, and amplitudes of the first three modes.

We observe that the amplitude $n_0(t)$ is clearly the dominant force during the oscillation, while $n_1(t)$ and $n_2(t)$ are practically negligible.

4.2 TRAC/VALKIN results.

Figure 7 shows the comparison between the obtained results for Case 1, with the 33 thermal-hydraulic channels model, and the 1 channel model. As we can see, in the 33 channels model, it remains a small oscillation along the transient, the 1 channel model presents a bigger numerical diffusion than the other model.

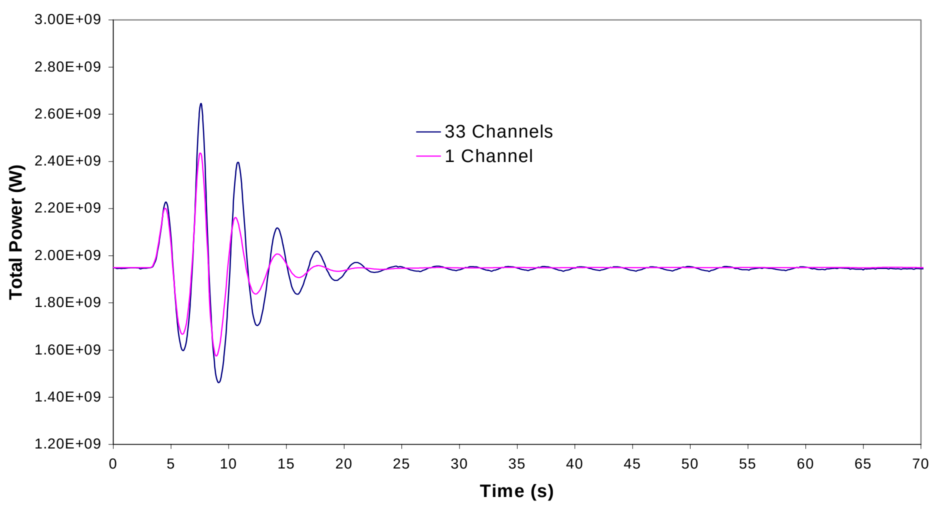

Fig.7 Power evolution for Case 1 with 33 and 1 channel model with TRAC/VALKIN.

Figure 8 presents the total power evolution along the transient obtained for the two cases for the 33 channel model.

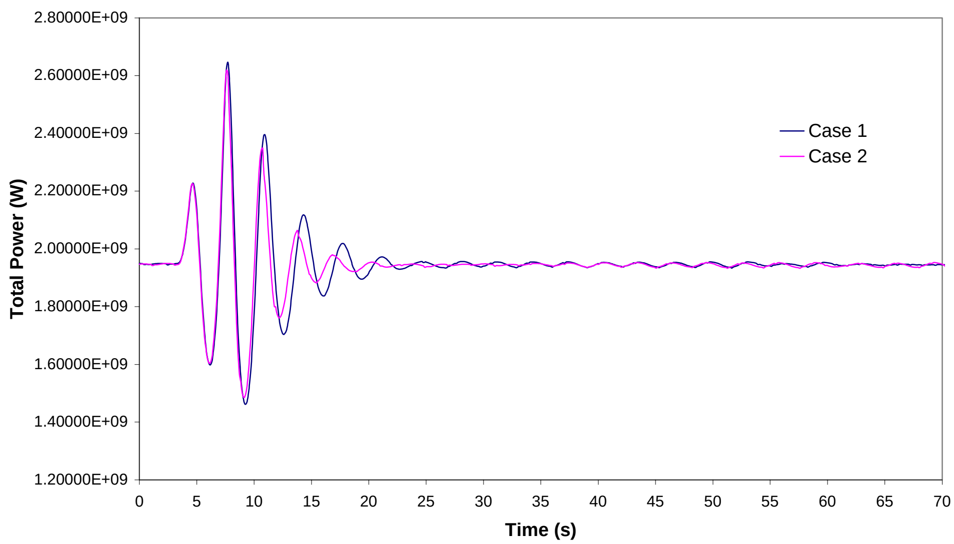

Fig.8 Power evolution for case 1 (no update) and case 2 (update 1 s) with TRAC/VALKIN.

Figure 9 presents a detail of the end of this transient, where we can see the evolution of the oscillations. For Case 1, without updating, the oscillations are decreasing, but in Case 2 the oscillation has a constant amplitude of about 20 MW.

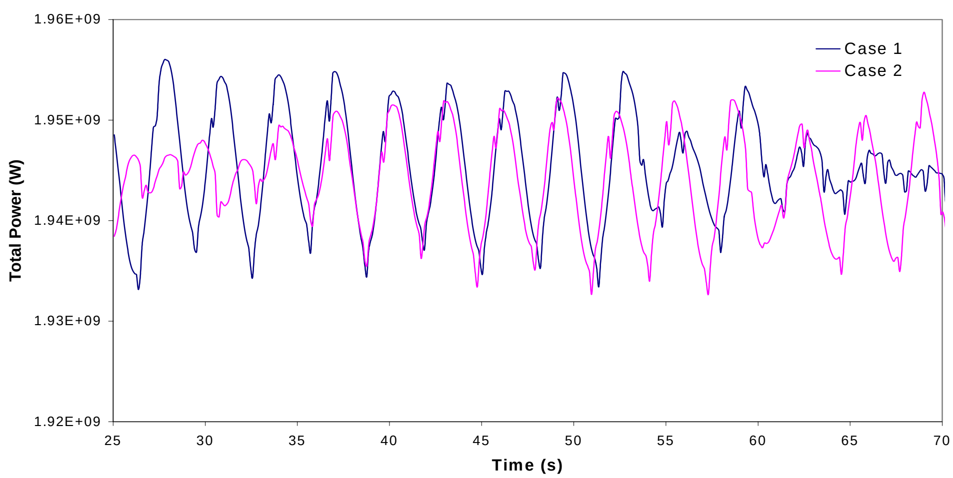

Fig.9 Detail of the residual oscillation at the end of the transient.

4.3 Comparison of results.

Finally, figure 10 compares the results obtained with RELAP5/PARCS and TRAC/VALKIN, using only one mode, without updating (case 1) and updating the mode each second (case 2). It shows a better agreement and 33 channels RELAP/PARCS and TRAC/VALKIN with the updating strategy.

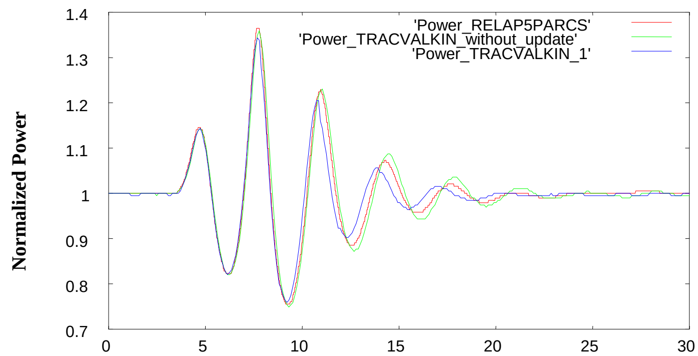

Fig.10 RELAP/PARCS and TRAC/VALKIN with no update and with updating time of 1 second.

We can remark that the results presented in this figure are practically similar, noting that the thermal-hydraulic codes (RELAP, TRAC-BF1) are very different, and also the neutronics codes (PARCS, VALKIN). It is very interesting to check that both coupled codes present the same quantitative and qualitative behavior for the total power for this transient corresponding to the PT3 operational point with a large steam line perturbation.

5. Conclusion

Point 3 of the Low Flow Stability Tests performed at Peach Bottom NPP is a nearly stable point at the end of the cycle 2, (this point is close to the stability boundary in the Power/ Flow map, and besides, its axial power profile is not bottom peaked).

Nevertheless, with the analyzed cases, the characteristics of the in-phase instability can be recognized; for example, frequencies in all the oscillations produced in the analyses were from 0.3 to 0.4 Hz, i.e., in the typical frequency range of this kind of instability events.

Characteristics of the in-phase instability can be recognized using the coupled codes TRAC-BF1/VALKIN and RELAP5/PARCS.

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