COUPLING THE FRAPTRAN FUEL BEHAVIOR AND THE TRABCO HOT CHANNEL THERMAL HYDRAULIC CODES

István Panka, András Keresztúri, Attila Molnár
MTA KFKI Atomic Energy Research Institute
Reactor Analysis Department
H-1525 Budapest 114, P.O. Box 49, Hungary
kere@aeki.kfki.hu

ABSTRACT

The FRAPTRAN fuel behavior and the TRABCO single channel thermal hydraulic codes have been coupled and applied for the hot channel analysis of a fast Control Rod Ejection event. The paper surveys the arguments why the multi-physics treatment can be useful or even necessary for this type of the analyses. Specifically, the necessity of the parallel thermal-mechanical and thermal hydraulic calculations is emphasized and the method of the coupling is discussed. As a demonstration, the results of the analysis of a Control Rod Ejection event are presented and compared to those obtained by using the traditional methods.

1. INTRODUCTION

The evaluation of nuclear reactor safety usually requires simultaneous application of several disciplines like reactor physics, thermal hydraulics, thermal mechanics, material science. The usual approach is that the calculations applied for given different purposes are focusing on only one of these disciplines while the influence of the other ones are taken into account in an approximate manner which may result in a not satisfactory balance and representation of the different disciplines. The justification of this usual approach and its remedy, if necessary, can be based only on tightly coupled and detailed models of all disciplines. This is the main reason why the design and development of multi-physics systems have been started worldwide in the most recent times. The constituent models are depending on the specific problem to be solved. In our case, we investigate some multi-physics effects important for the hot channel calculation of the safety analysis of fast RIA events. The most important phenomena – to be modeled in parallel – are the thermal hydraulics of the coolant, the corresponding surface heat transfer processes and the heat conduction inside the fuel pin, especially in the gap.

2. WHY MULTIPHYSICS

The hot channel calculation is an important final stage of the safety analysis for checking the acceptance criteria fulfillment or/and for counting up the failed fuel rods, necessary for the activity release evaluation. Meanwhile, quantifying its uncertainties is an essential condition of the applicability for safety purposes. All of the uncertainty analysis methods require best estimate calculations, while the present traditional hot channel calculation methods are usually comprise essential assumptions, expected conservative, concerning the gap conductance and the coolant mixing. The gap conductance – influenced by the gap size and pressure - play essential role in case of fast reactivity transients because of the delayed and smoothened time dependence of the heat flux - in comparison to sharp nuclear power surge - which is a result of the heat conduction from the pellet up to the coolant. Both the initial and time dependent physical states of the pellet, the cladding and the gas gap, the latter one changing during the transient, are determining. On the other hand, the coolant mixing effects play also essential role, because the heat transfer regime, the heat transfer from the fuel pin to the coolant and consequently the cladding temperature depends to great extent on the coolant state. According to the mutual dependence of the above phenomena, the on-line coupling of the thermal mechanical and coolant thermal hydraulic calculations is unavoidable for the best estimate parallel handling of all the processes.

A further reason to use thermal mechanical codes for the hot channel analysis is the recent tendency to define acceptance criteria, which are closer to the real reasons of the fuel failure – namely for example ultimate strains or stresses - leading justly less conservative results than the traditional ones based on temperatures for example.

3. THE COUPLING METHOD OF THE TWO CODES

The main characteristics of the two coupled codes are as follows:

TRABCO: Thermal hydraulic hot channel code, single channel, 1D, 4-equation model. Without thermal mechanics, geometrical changes can be followed only in an implicit way: parameterized – conservative - gap heat conductance is to be applied.

FRAPTRAN: Transient fuel behavior code, supplemented with a simplified single channel thermal hydraulics, which frequently not used but instead the cladding outer surface temperature is prescribed and used as a boundary condition. Mixing from and to the adjacent channels cannot be taken into account.

The coupling method between the two codes, the transferred data are shown in Fig. 1.

The INTEL FORTRAN service function „USE DFWIN" was applied for sharing selected memory parts between separately parallel running processes, which gave the possibility to develop our own FORTRAN subroutines for assuring synchronization, too. These software tools made it possible to minimize the necessary modifications in the standalone codes because only few control points for the data transfer and synchronization had to be built in

- for using its own separated memory of each separate parallel task,
- and at the same time to define the shared part of the memory for the communication between them.

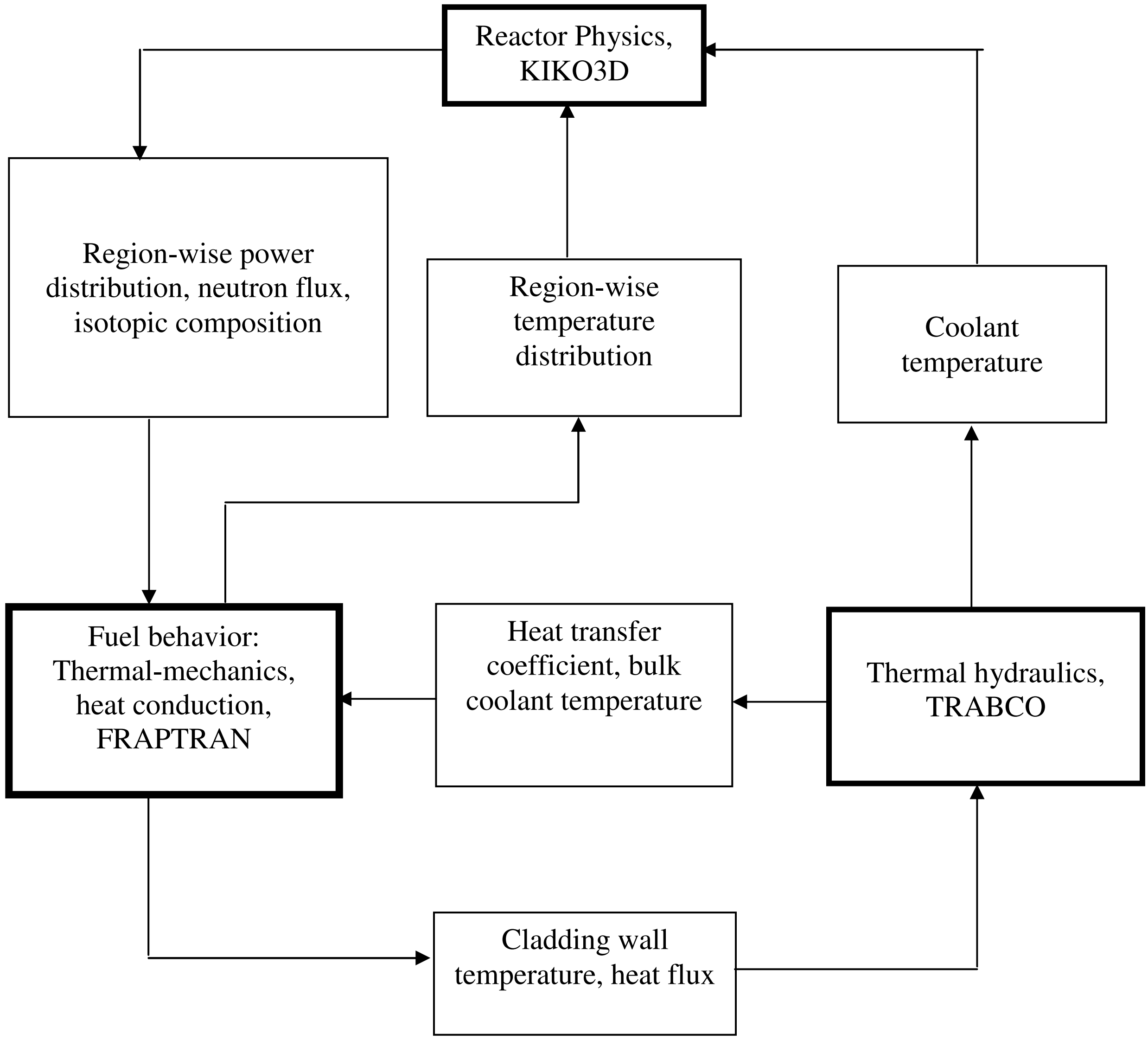

Fig. 1. The multiphysics connections between the codes representing the different disciplines

4. RESULTS

An asymmetric Control Rod Ejection from Hot Zero Power for a VVER-440 reactor was calculated by the KIKO3D code [1] in order to provide the hot cannel calculations with input data. The corresponding 30 ms half-with nuclear power surge is shown in Fig. 2. Three different ways concerning the connections between the TRABCO [2] and FRAPTRAN codes [3], used for the subsequent hot channel calculations, were investigated:

- "Mehod 1": Standalone TRABCO calculation with parameterized conservative „enveloping" gap heat conductance according to the preceding long term "stationary" fuel behavior calculations results (See Fig. 3.). Beside the pellet burnup, which is constant in these investigations, the average pellet temperature was selected for the parameterization. Two sub-cases: "Method 1.a" no DNB, "Method 1.b" for methodical reasons, DNB is supposed conservatively.

- "Method 2": Similarly to "Method 1", standalone TRABCO calculation with parameterized conservative „enveloping" gap heat conductance, but the gap conductance to be parameterized (See Fig. 3.) is taken from the FRAPTRAN results of the coupled calculation ("Method 3").

- "Method 3": On-line coupling of the TRABCO and FRAPTRAN codes. At the end of each time step, the parameters shown in Fig. 1 are exchanged.

The gap conductance of "Method 1" and "Method 2", cannot be the same due to the long term process of "creep" taking place in the "stationary calculations".

The further results are shown in Figs. 4-14.

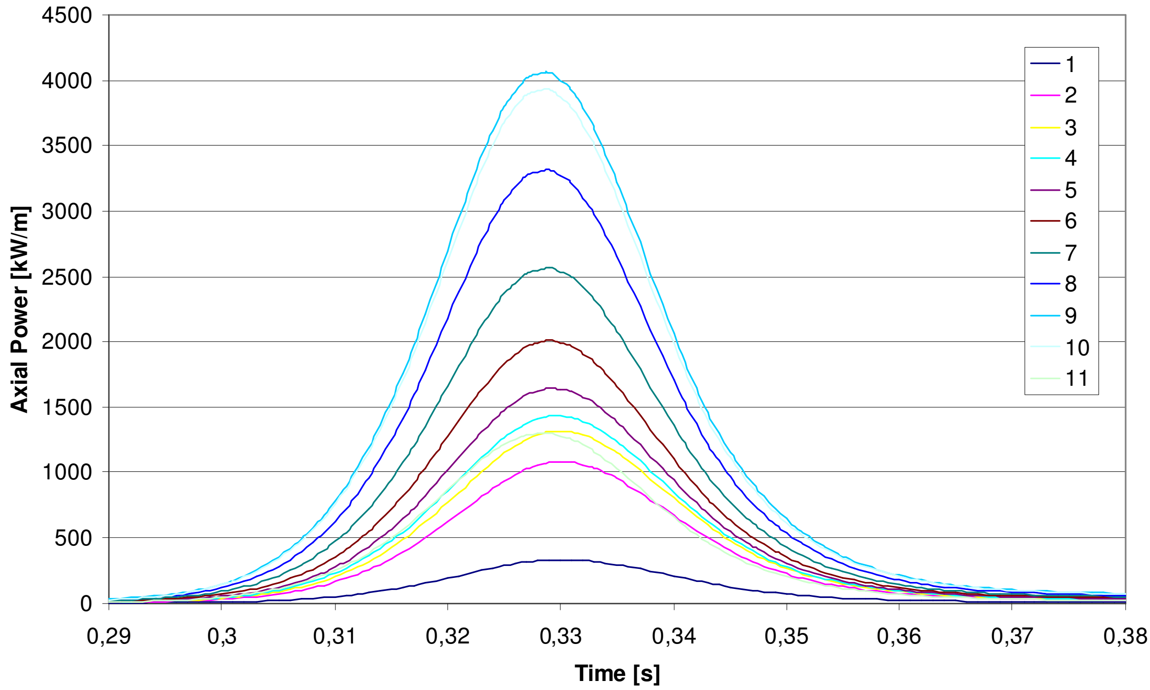

Fig. 2: Fission power for the CRE event starting from HZP state

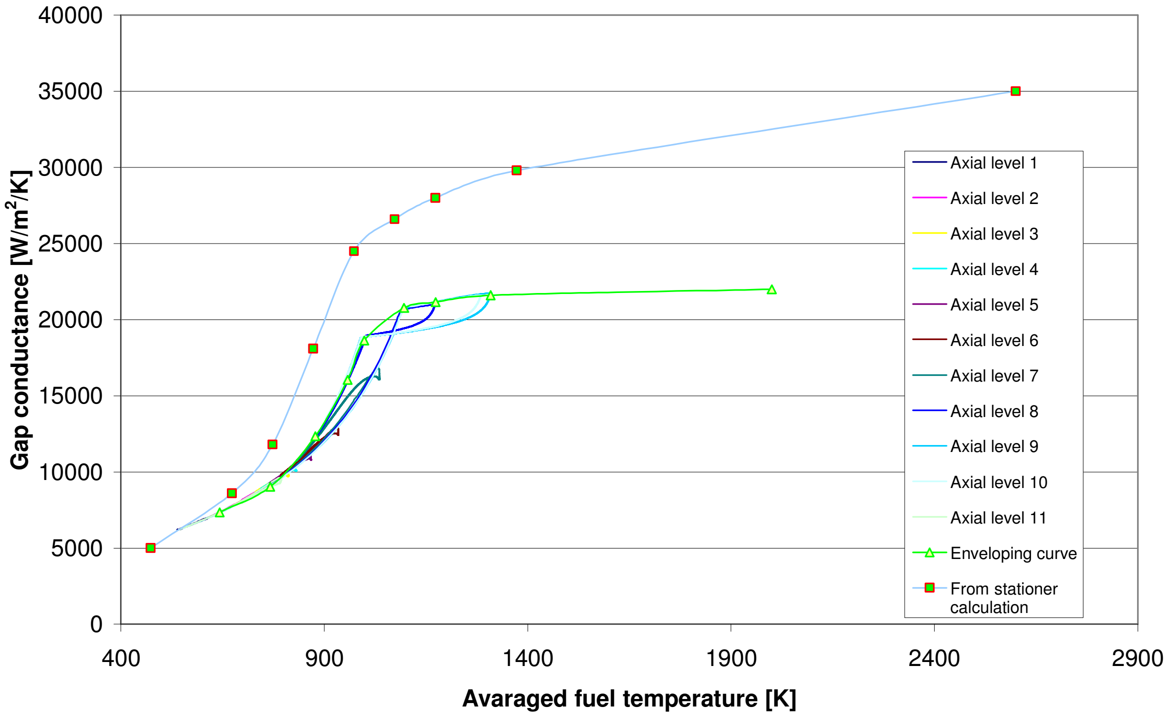

Fig. 3. Gap heat transfer coefficients from the preceding stat. calc. or from the FRAPTRAN

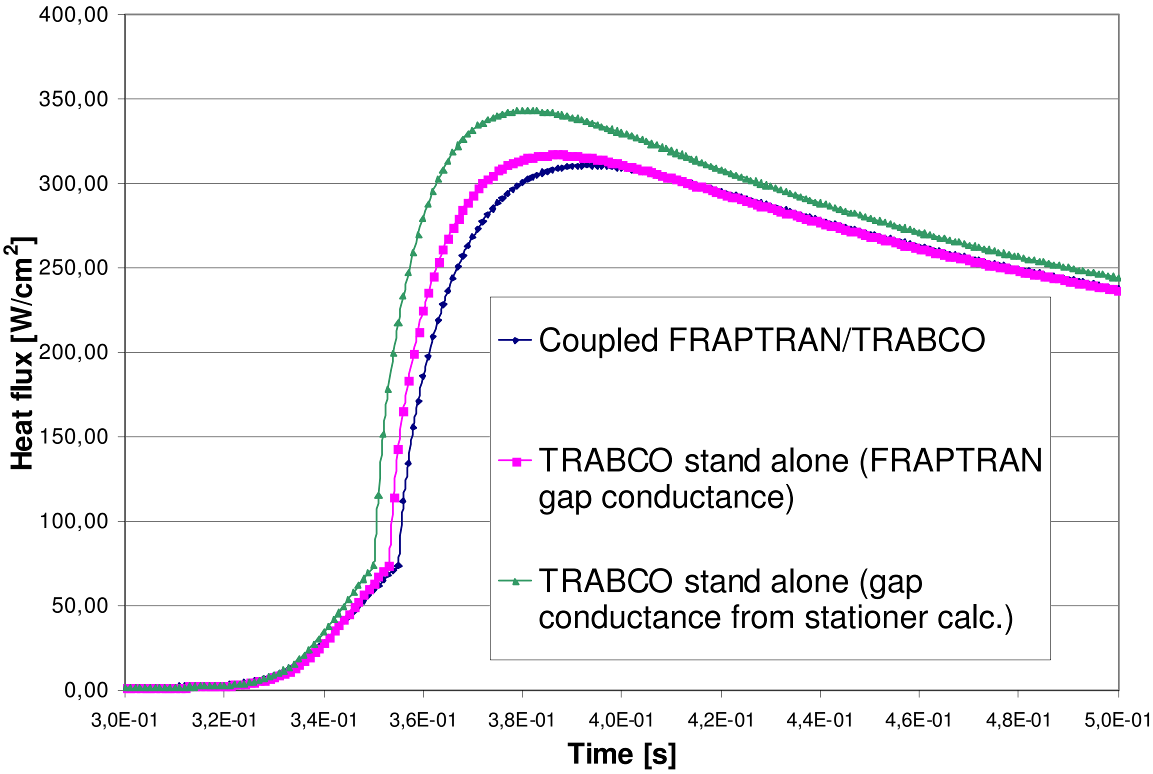

Fig. 4. Surface heat flux for the three cases, no DNB

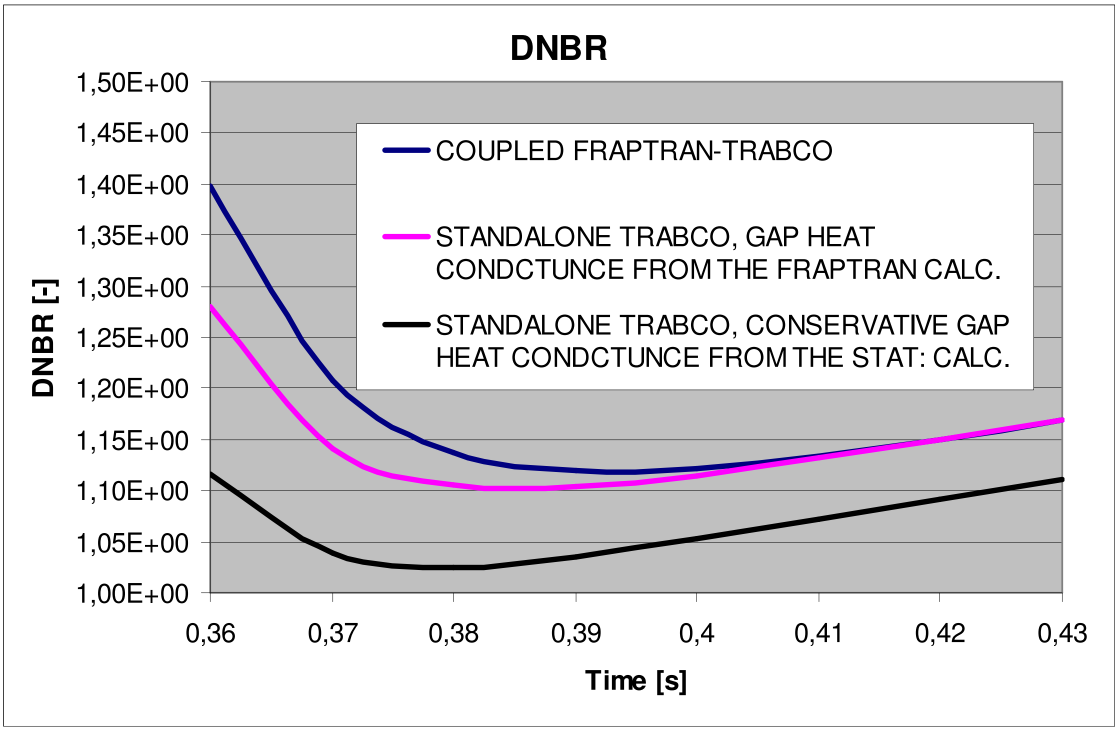

Fig. 5 DNBR for the three cases

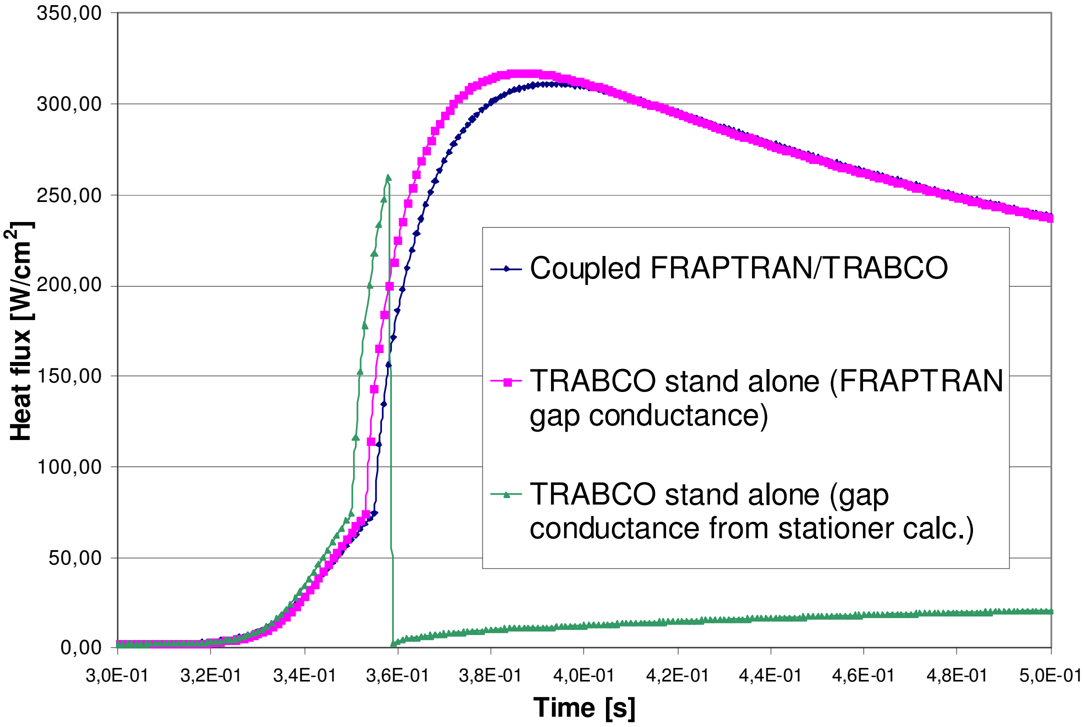

Fig. 6. Surface heat flux for the three cases, DNB in the worst case

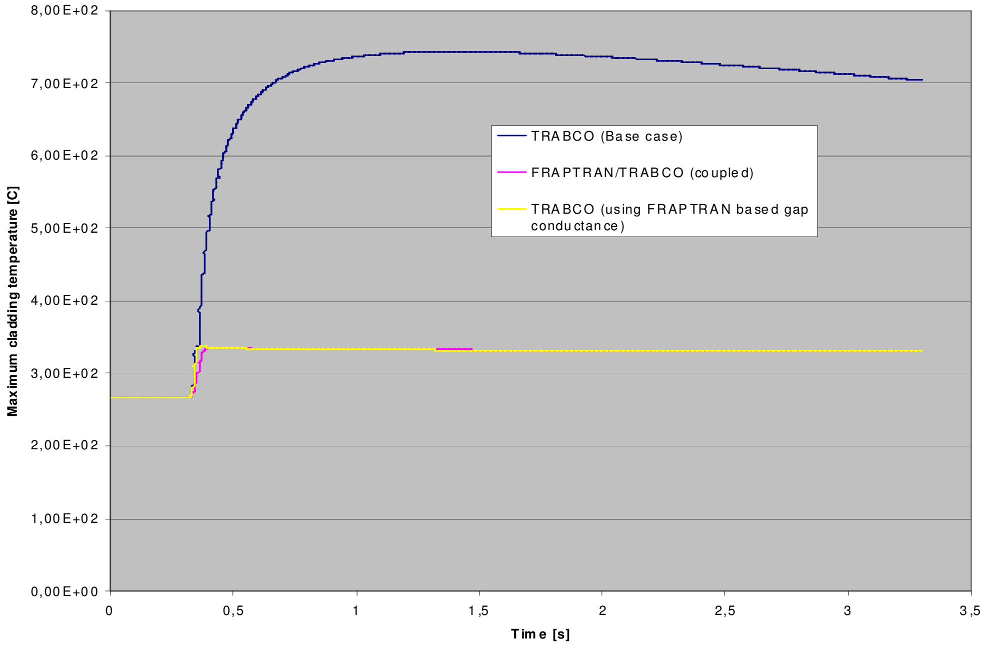

Fig. 7. Maximum cladding temperatures for the three cases, DNB in the worst case

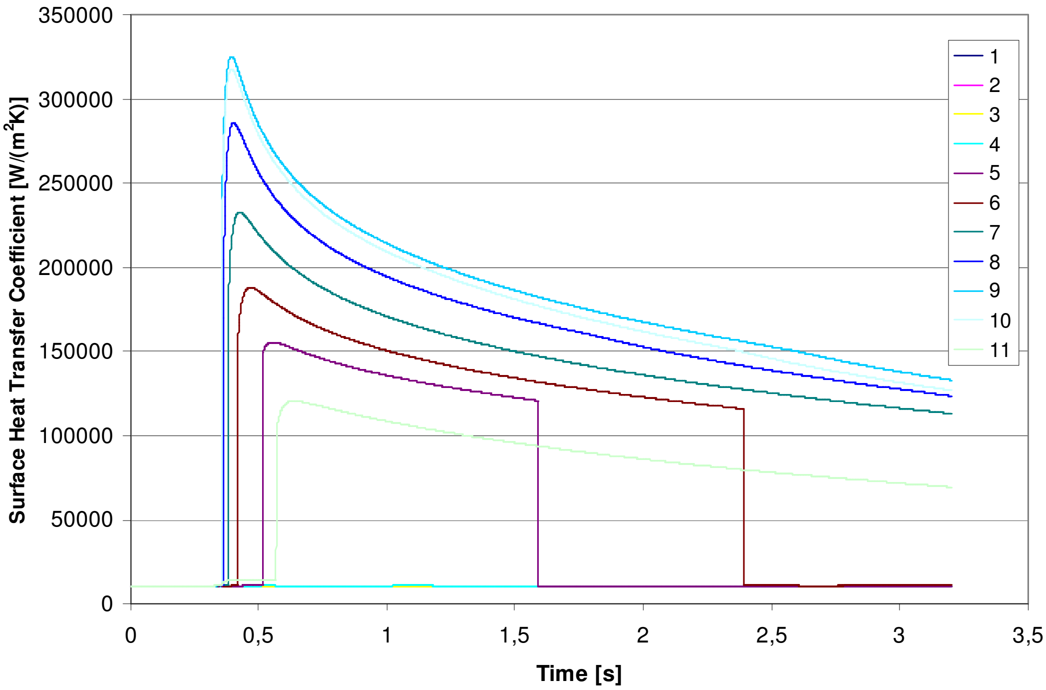

Fig. 8. Heat transfer coefficients to coolant without DNB

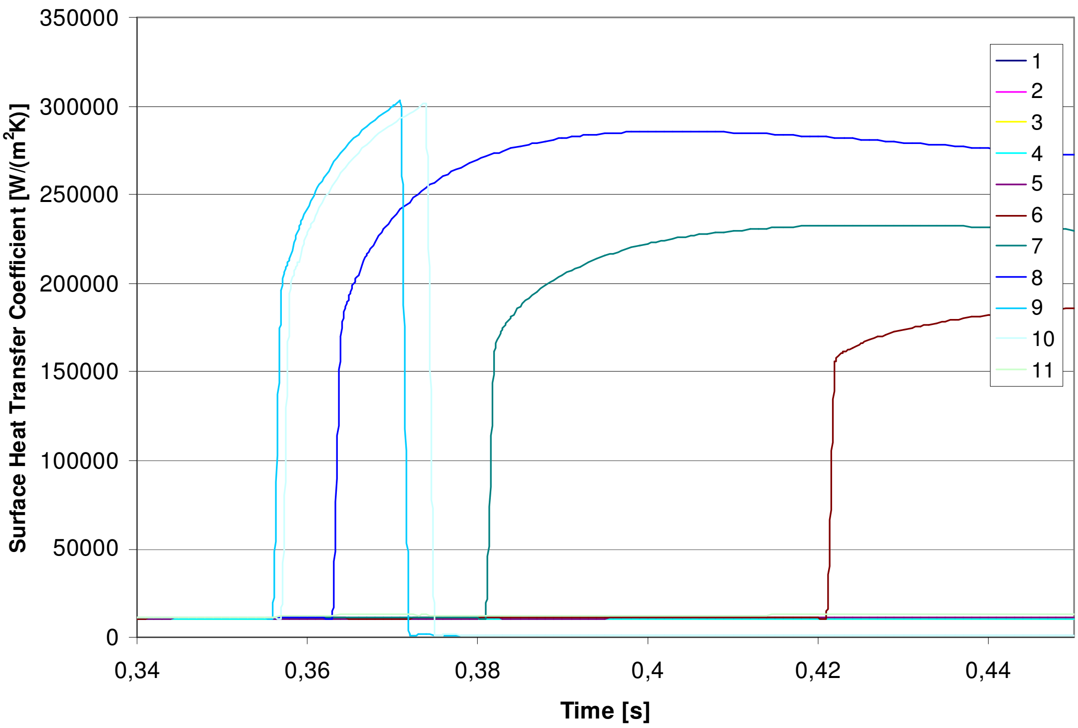

Fig. 9. Heat transfer coefficients to coolant in case of DNB

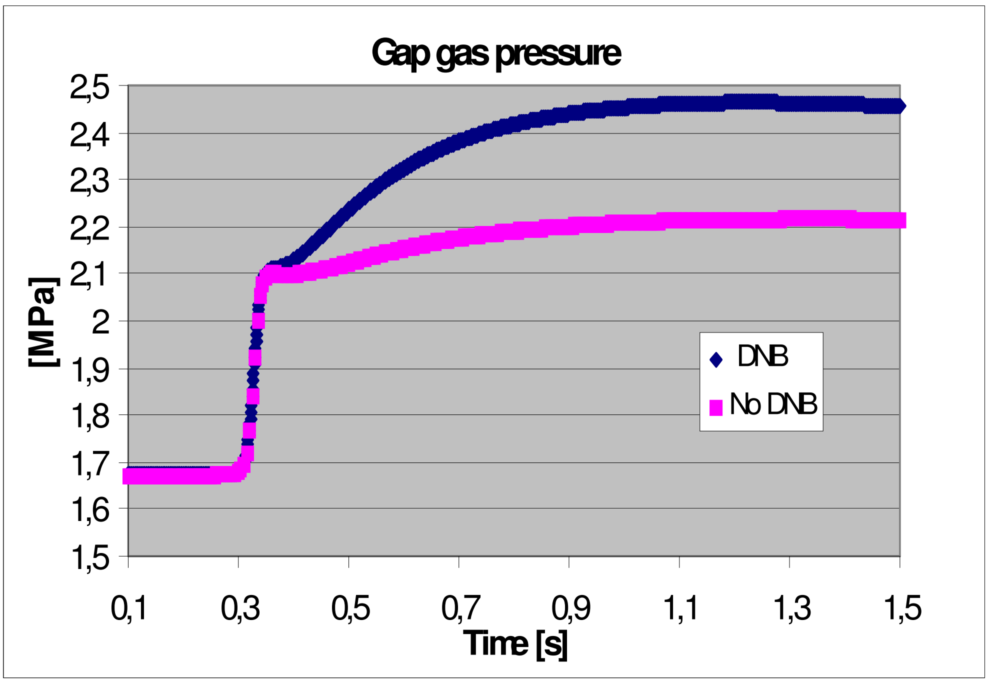

Fig. 10. Gas gap pressure

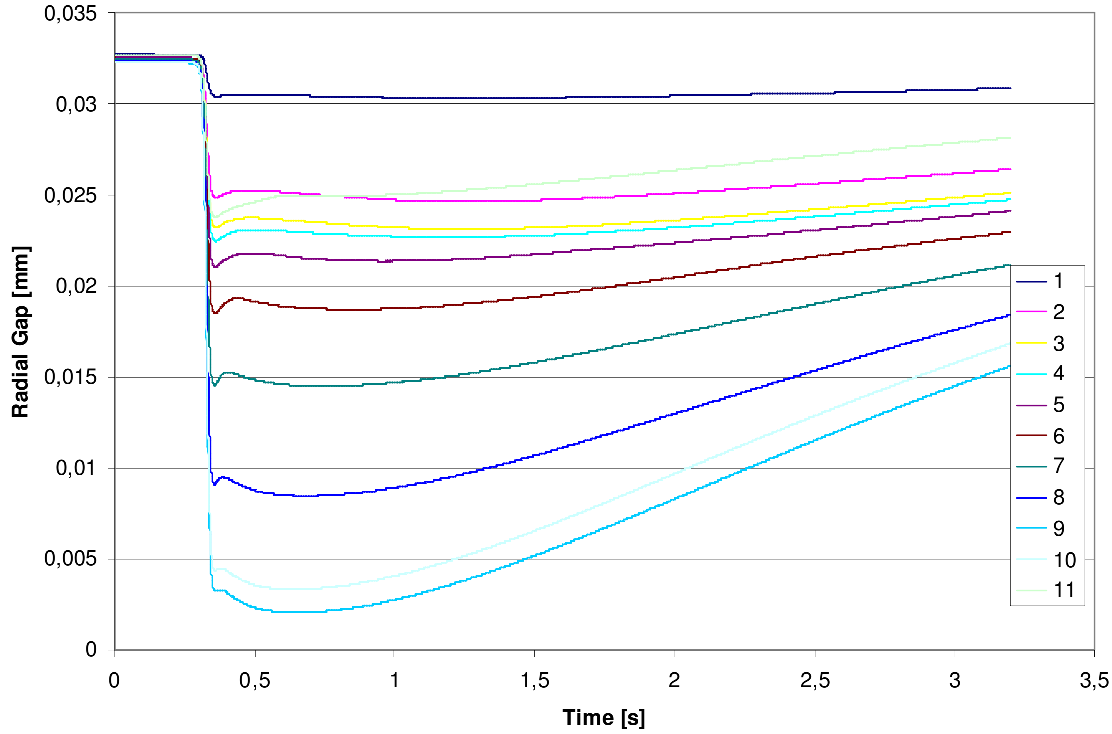

Fig. 11. Thermal mechanical processes, gap size in case of without DNB

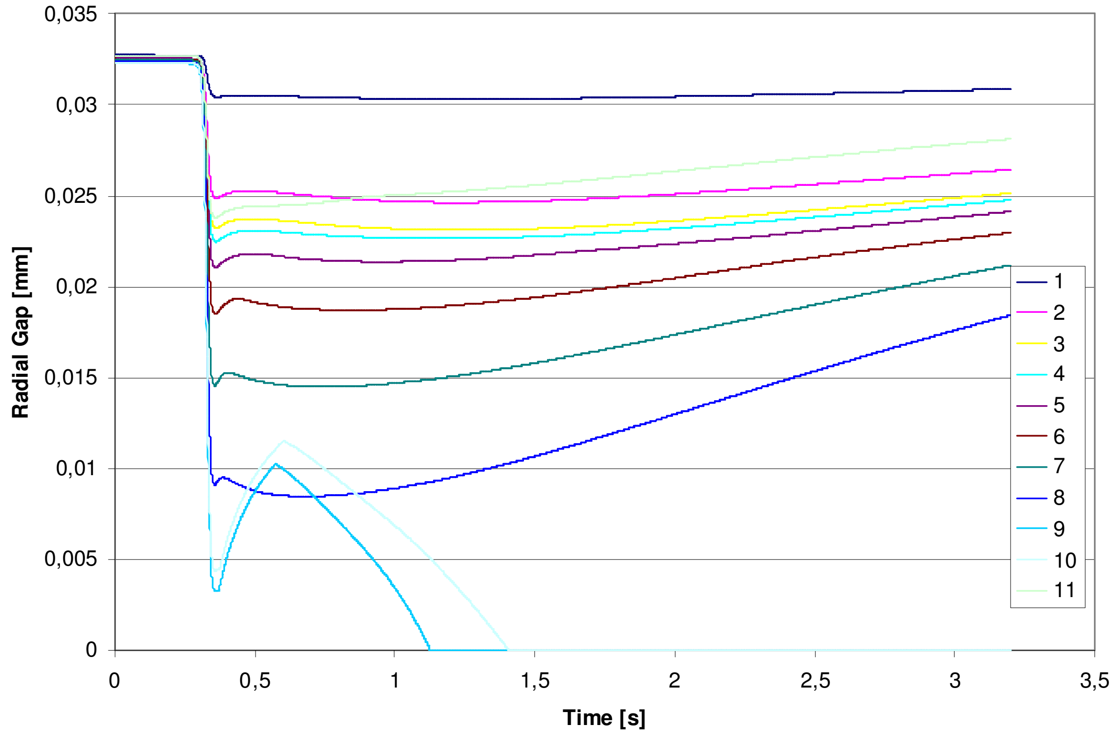

Fig. 12. Thermal mechanical processes, gap size, in case of DNB

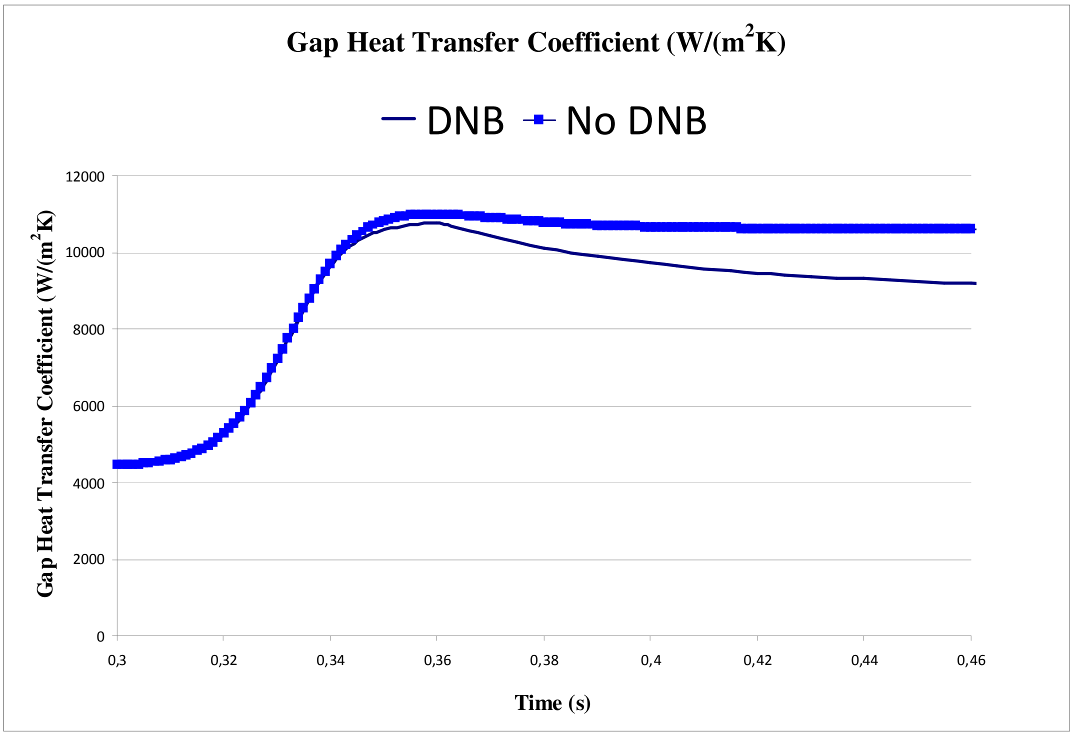

Fig. 13. Gap heat transfer coefficient

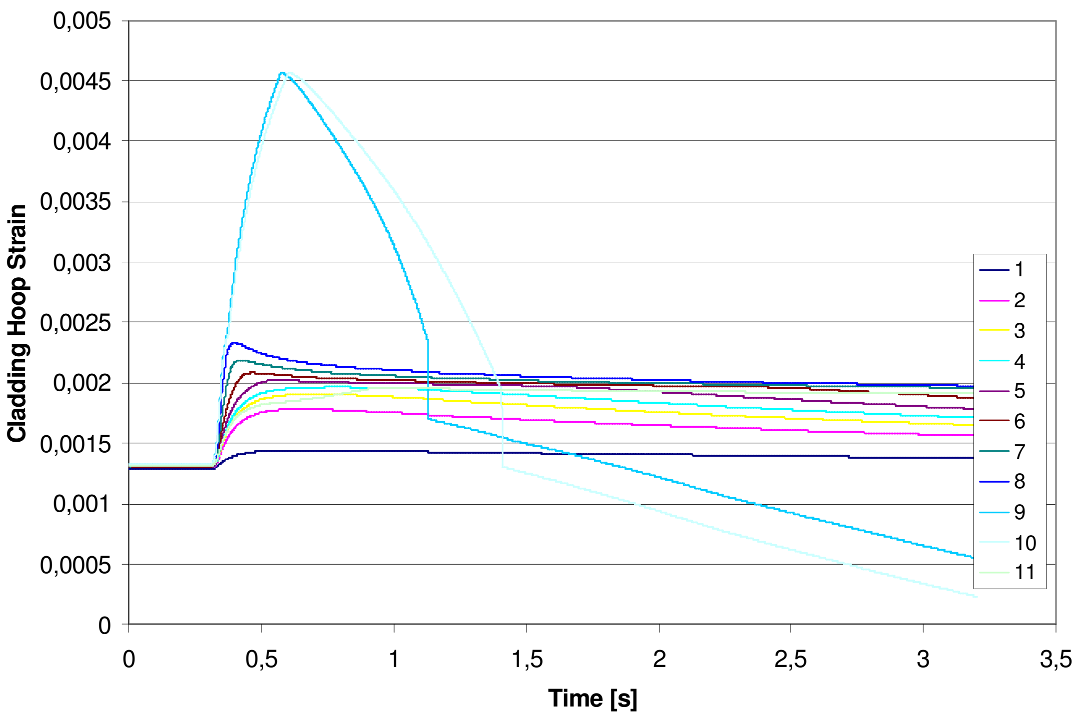

Fig. 14. Cladding hoop strain at different axial levels in case of DNB

5. SUMMARY

The gap conductance, gap size and pressure play essential role in case of fast reactivity initiated (RIA) transients. Both the initial and the time dependent values, the latter ones changing during the transient, are important. In case of fast RIA transients, a thermal mechanical code coupled on-line to the thermal hydraulics has to be applied for the best estimate calculation – the latter feature necessary for uncertainty analysis -, or even only for justifying a method, expected conservative. A not negligible reserve, concerning our earlier conservative method, could be explored by the on-line coupling TRABCO and FRAPTRAN codes.

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