Assessment of the ^{3}He pressure inside the CABRI transient rods - Development of a surrogate model based on measurements and complementary CFD calculations

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Abstract—CABRI is an experimental pulse reactor, funded by the French Nuclear Safety and Radioprotection Institute (IRSN) and operated by CEA at the Cadarache research center. It is designed to study fuel behavior under RIA conditions. In order to produce the power transients, reactivity is injected by depressurization of a neutron absorber (^{3}He) situated in transient rods inside the reactor core. The shapes of power transients depend on the total amount of reactivity injected and on the injection speed. The injected reactivity can be calculated by conversion of the ^{3}He gas density into units of reactivity. So, it is of upmost importance to properly master gas density evolution in transient rods during a power transient. The ^{3}He depressurization was studied by CFD calculations and completed with measurements using pressure transducers. The CFD calculations show that the density evolution is slower than the pressure drop. Studies also show that it is harder to predict the depressurization during the power transients because of neutron/^{3}He capture reactions that induce a gas heating. Surrogate models were built based on CFD calculations and validated against preliminary tests in the CABRI transient system. Two methods were identified to evaluate the gas density evolution: CFD calculations and reverse point kinetics. The first one consists in adding a heat source in transient rods based on the experimental power conversion. The second one consists in using the measured power by boron ionization chambers to evaluate the net reactivity by a reverse point kinetics (PK) method and to subtract the reactivity feedbacks calculated with the DULCINEE multi-physics code.

Index Terms—CABRI, ^{3}He depressurization, CFD, DULCINEE, TOP effect.

I. INTRODUCTION

CABRI is an experimental pulse reactor operated by CEA (Commissariat à l'Énergie Atomique et aux Énergies Alternatives) at the Cadarache research center. Since 1978, the experimental programs have been aiming at studying the fuel behavior under Reactivity Initiated Accident (RIA) conditions. In order to study PWR high burn up fuel and new cladding materials behavior under such transients, the facility was modified to accept a pressurized water loop in its central

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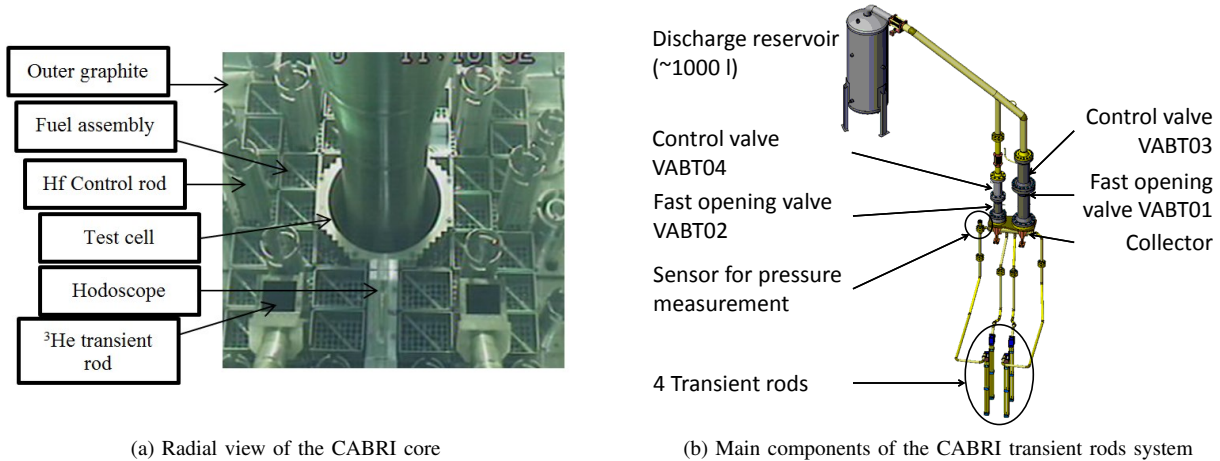
part able to reproduce thermal-hydraulics characteristics representative of PWR nominal operating conditions (155 bar, $300°C$). This project, which began in 2003 and supported first commissionning power tests from October 2015 to March 2017, was driven within a broader scope including both an overall facility refurbishment and a complete safety review. The global modifications were conducted by CEA. The experiments take place in the framework of the OECD/NEA CIP (CABRI International Program) Project led by IRSN (Institut de Radioprotection et de Sûreté Nucléaire), which financially supports the refurbishment as well as the operational costs of the facility. The CIP program will investigate several fresh and burnt UOx and MOX LWR fuel samples with new cladding materials under RIA conditions, with a foreseen completion by the end of 2023.

Power transients are generated by a dedicated so-called transient rods system [1] allowing the very fast depressurization of ^{3}He tubes positioned inside the CABRI core. This paper focuses on the study of the ^{3}He depressurization of CABRI transient rods. The main objective is to properly reproduce the ^{3}He density evolution in the transient rods situated in the CABRI core, from experimental data provided by pressure transducers situated in the valve and piping system far from the core. The paper presents two methods of prediction based on measurements and on complementary calculations. The first part of this paper consists of a brief description of the transient rods system, of the experimental sequence and of the power transients measurements and prediction. In a second part, the CFD (Computational Fluid Dynamics) approach is addressed. This approach allows the evaluation of state parameters in the entire system and not only at the pressure transducers locations. Afterwards, the elaboration of surrogate models based on CFD calculation is addressed. The last part of the paper deals with the explanation of the TOP effect that affects the depressurization during the transient over power.

II. CABRI REACTIVITY INJECTION SYSTEM

CABRI is a pool-type reactor, with a core made of 1487 stainless steel cladded 6 wo% enriched UO_2 fuel rods. The reactor is able to reach a 25 MW power level in steady state conditions. The reactivity is controlled via a system of 6 bundles made of 23 hafnium control and safety rods.

(a) Radial view of the CABRI core

(b) Main components of the CABRI transient rods system

Fig. 1. CABRI transient rods system

A. CABRI transient rods

The key feature of the CABRI reactor is its unique reactivity injection system [1]. This device allows the very fast depressurization of the ^3He (strong neutron absorber) into a discharge tank. The ^3He is previously introduced inside 96 tubes (so called "transient rods") located in 4 banks among the CABRI fuel rods (see Fig. 1a).

The CABRI transient rods system is made of the following main components (see Fig. 1b):

- 4 fuel assemblies (7x7 pins) equipped on their periphery with 24 tubes instead of 24 fuel rods. These tubes are connected together in the upper part of each assembly in order to join a collecting line leading to a main collector. The 4 transient assemblies are pressurized to the target pressure (15 bar maximum) by the use of a compressor which pumps the ^{3}He from its storage tank via a devoted circuit.
- From the top of this collector, two flow channels (low and high flow rates) lead to a 1000 l discharge tank set under vacuum before operation. Both channels are equipped with a fast-opening valve (respectively with small and large diameters) followed by a controlled valve. The volume of the circuit upstream the valves is around 50 l.
- A specific control device that triggers the different orders of the experimental sequence as for the opening time of the two fast-opening valves and the shutdown of the reactor control rods.
- Two different pressure transducers measuring the ^{3}He pressure at the inlet of the collector. For design reasons, the ^3He pressure cannot be measured directly in the transient rods.

B. Transient experimental sequences

The transient rods depressurization causes the absorber ejection that induces a reactivity injection reaching up to 3.9 $ in few milliseconds. The characteristics of the transient (maximum power, Full Width at Half Maximum (FWHM) and

energy deposit) depend on the experimental sequence applied to the fast valves and on the adjustment of the associated controlled valves. The transients are stopped by the Doppler effect and other delayed reactivity feedbacks, and then by the scram of the control rods. Short FWHM power transients, so called "natural transients", will be generated by the fast opening of the unique high flow rate channel. In this case, the maximum power is then very high (until $\sim$ 20 GW) and the FWHM is short ($\sim$ 10 ms). The energy deposit in the central experimental pressurized loop then depends on the initial pressure in the transient rods, the control valve aperture and the control rods drop time after transient

In order to be representative of other LWR accidental conditions, an increase of the transient pulse FWHM is necessary. This can be done by successively opening the fast opening valves of the low-flow and then the high-flow rate channels. The adjustment of the time difference between the apertures of the fast opening valves allows to generating so called "structured transients" characterized by FWHM varying from 20 to 80 ms. A good precision on this time difference is very important to fulfill the experimental goal. For those last transients, the final energy deposit in the tested fuel rod depends on the initial ^{3}He pressure but can also be adjusted by the control rods drop trigger time.

Two main parameters are influencing the depressurization speed and thus the speed of injection of reactivity : the control valves apertures and the initial pressure. However, the quality of ^{3}He and the initial temperature make also differences between the reactivity injections speed and amount. Indeed, the pollution of the gas (O_2, N_2) makes the gas heavier and hence slows the depressurization kinematics. In the previous life time of the facility, the pollution ratio in ^{3}He may have reached more than 10 %. Today, the rate of air inside ^{3}He is around 1 %.

C. Pressure measurement

Two transducers (Kulite HKM-375 and HBM P3MB types) measure pressure transients. They are located near the collector

(see Fig. 1). Two types of gauges can be used in those transducers depending of the pressure range :

- For pressure between 0 and 35 bar, foil strain gauges are employed. Those lead to 0.2 % sensitivity plus 0.1 % sensitivity for 10 K temperature difference.
- For 0 to 5 bar, semiconductor strain gauges, so called piezoresistors. They have usually a larger gauge factor than a foil gauge, it results in better precision (0.1 %), but also a bigger sensitivity to temperature changes (0.2 %).

Those transducers work using piezoelectric properties of materials, in other words their abilities to have their electrical conductivity changed with mechanical stress. In order to cover the entire range of the transient rods depressurization, the technology activated is the strain gauges.

D. Transient measurement

Specific boron ionization chambers are used for measuring high powers levels during steady states and during transients. In the case of power transients, several chambers, located at increasing distances from the core, are used to be able to measure the whole range power (i.e. from 100 kW to ∼ 20 GW). More details can be found in references [2]–[4].

E. Transient prediction

In order to reach the experimental objectives, transients are predicted using the DULCINEE [5] code. DULCINEE is a multi-physics code including point kinetics equations resolution, thermal transfers calculation and two-phase thermal-hydraulics models. A dedicated algorithm included in DULCINEE allows to calculating the power transients using the ^{3}He depressurization curve.

The measured pressure is converted into the injected reactivity by a spline function based on static experimental measurements of the ^{3}He reactivity worth vs. pressure. However, the ^{3}He pressure is only measured at approximately 3 meters from the rods, and might not be an adequate parameter to numerate the real number of atoms inside the transient core (i.e. inside the core). That's why studies were made using the STAR-CCM+ CFD code [6] in order firstly to validate measurements at the transducers, and secondly to extrapolate the results in therms of density as well as pressure drop in the transient rod (as far as satisfactory results are found at transducers location).

III. CFD SIMULATION OF ^{3}HE DEPRESSURIZATION IN TRANSIENT RODS

The CFD modeling, unlike an analytical approach, can precisely handle complex geometries. The ^{3}He pressure evolution during the depressurization will then be calculated in the entire transient rods system, and not only at the pressure transducers location.

A. Simulation parameters

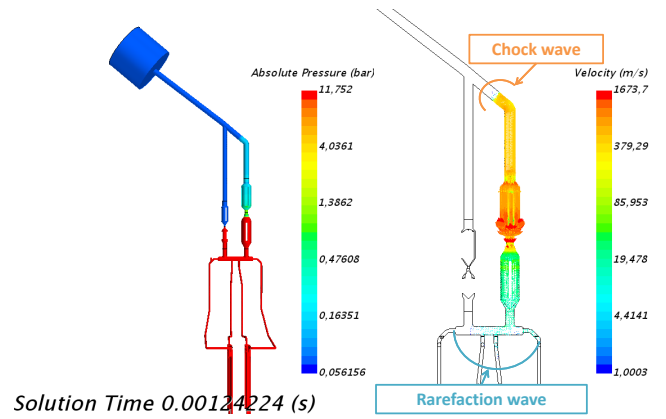The main features and chosen physical models for the CFD simulation are :

Fig. 2. Visualization of ^{3}He transient rods depressurization with STAR-CCM+ - pressure (left) - velocity (right)

- 3D modeling,
- RANS (Reynolds Averaged Navier-Stokes) approach to solve the Navier-Stokes equations,
- Use of a turbulence model. The usual k-ϵ model consists in representing the effects of turbulence and of eddy diffusivity by a turbulent viscosity. This eddy viscosity is calculated according to the turbulent energy "k" per mass unit, and energy dissipation "ϵ" per mass unit. Each of these two terms is the solution of a transport equation,
- Wall laws "All y + wall treatment" for approximating boundary layers,
- Unsteady calculation with the implicit solver,
- ^{3}He considered as an ideal gas,
- Laws of evolution of gas thermal conductivity and viscosity.

The complete validation of the CFD Simulation is described in [7]. Fig. 2 reproduces ^{3}He pressure and velocity in the circuit shortly after the beginning of depressurization. Both pressure and velocity are calculated on a very refined meshing (∼ 460000). This is an interesting moment because the shock and the rarefaction waves are visible on the velocity profile.

B. Assessment of the pressure and of the temperature evolutions inside the transient rods

The ^{3}He gas depressurization induces a temperature drop in transient rods (see Fig. 3). Assuming an ideal gas, the gas quantity "n" is defined as in (1).

$$n = \frac{PV}{RT} \qquad (1)$$

A good state parameter that can be linked to the injection of reactivity is the ^{3}He density, that is proportional to the number of atoms (2).

$$d_{^3He} = \frac{nM}{V} = \frac{PM}{RT} \qquad (2)$$

The density evolution inside the transient rods is slower than the pressure "P" evolution (see Fig. 4), as temperature "T" varies in about the same proportions. That induces a slower calculated evolution of the reactivity injection.
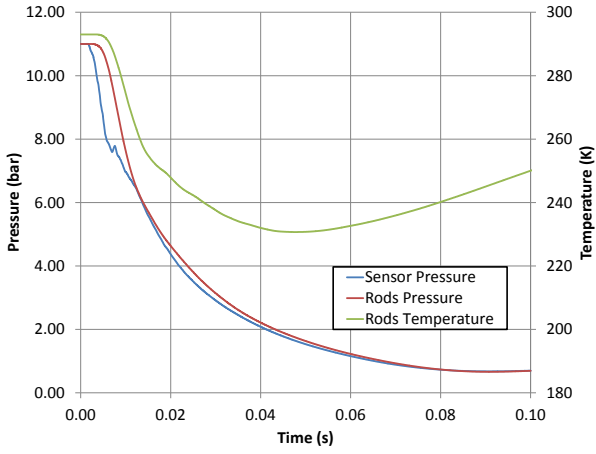
Fig. 3. Helium pressure and temperature evolution during a depressurization according to CFD calculation
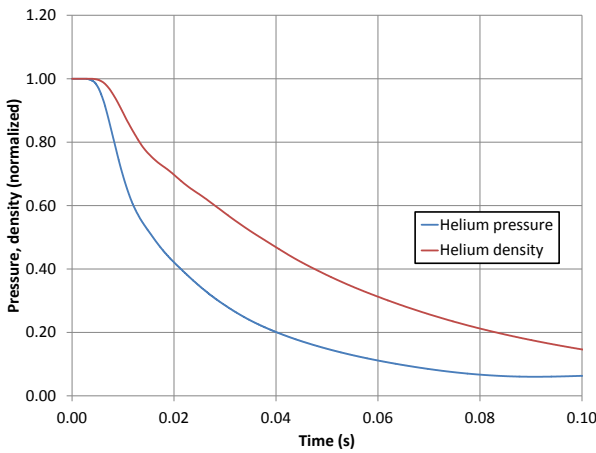

Fig. 5. Multilayer perceptron representation (URANIE manual)

Fig. 4. Helium pressure and density evolution during a depressurization according to CFD calculation

Fig. 6. Comparison between surrogate model pressure (red) and experimental depressurization (blue) results

IV. Surrogate models based on CFD calculations

Several types of surrogate models were built based on validated CFD simulations. Some of them are used to evaluate pressure at the transducer in order to validate the CFD calculation results. The others are built to evaluate the ^{3}He density variation in the transient rods during CABRI transients.

A. Making surrogate models

The CEA's URANIE uncertainty platform [8] was used for the surrogate models construction. The creation of surrogate models consists of 4 main steps:

- Make of a design of experiments using deterministic or stochastic methods for simulating the target parameter. In our case, we mostly used Sobol sequences which better cover the parameter space than a pseudo-random distribution,
- Launching of the code with the different entry parameters,
- Treatment of the results,
- Configuration of the surrogate models. We chose to use multilayer perceptron (artificial neuron network - ANN,
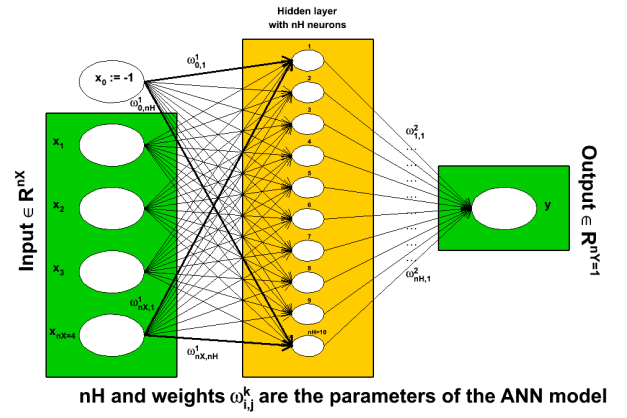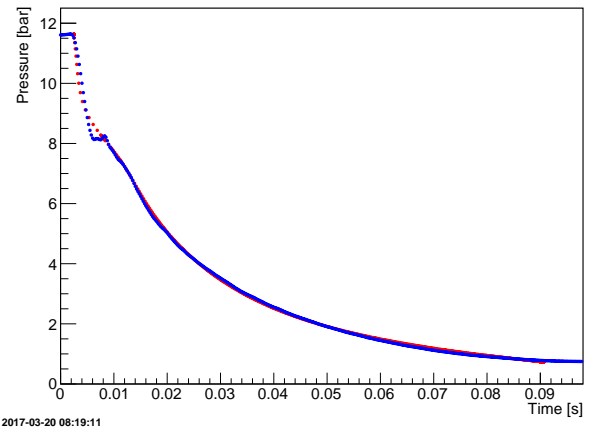
see Fig. 5), with an hyperbolic tangent as an activation function. This method gave better approximations of the simulation results than other models such as polynomial multi-parameter regression. Good precision was reached with 6 hidden layers.

B. Surrogate model Validation

The surrogate models are validated by experimental comparison to measured depressurization. One example of validation is reproduced Fig. 6. For the density evaluation, the only results come from best-estimate calculations from CFD, by extrapolating the transducer response to transient rods location. We can logically assume that if the method works for the pressure, it also works for the density.

C. Limits of those surrogate models

In fact, transient rods depressurization is a little different when core power evolves. This little difference can have big effects on power transients. This effect appears when the gas pressure and the core power are both relatively high. It is named "TOP effect" as "Transient Over Power effect". We can observe it on the pressure curves measured during power transients (Fig. 7).
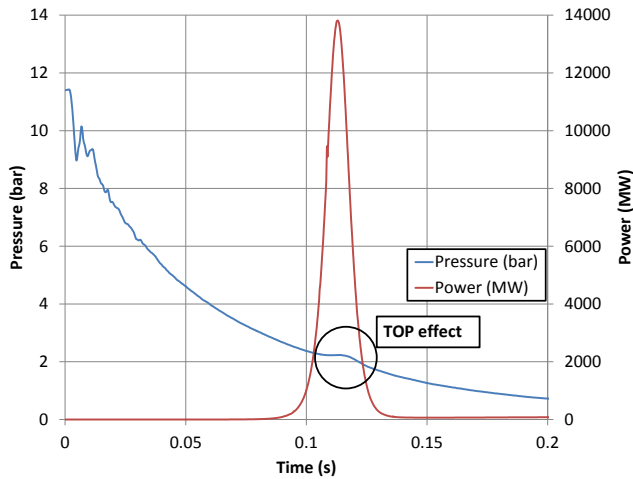
Fig. 7. TOP effect visualization on a recent CABRI power transient (2017)

Fig. 8. CFD calculation of simple depressurization by high flow rate channel (VABT03 aperture $\sim$ 40 %) including TOP effect

V. THE TOP EFFECT

A. Phenomenon description

The TOP effect comes from ^{3}He heating during power transients. As power increases, the thermal neutron flux also increases. So, the neutron absorption by ^{3}He intensifies. This reaction produces two charged particles : proton and tritium. One part of their energies is deposited in the ^{3}He gas by ionization before reaching the metallic wall of the transient rods. Denser is the gas, higher the probability of ionization is and more important the deposited energy is. The direct effect of this energy deposit is that the gas temperature increases. A temperature increase is equivalent to a pressure increase. The differential pressure between rods and flow channels implies a faster depressurization of helium from the transient rods. That is why we observe a rise of pressure at the transducers location during the pulse, that corresponds to a decrease of the gas density in the transient rods. This finally implies a rise of the reactivity injection speed. TOP effect increases the maximum power and the energy deposit. For relatively slow transients (at least 20 ms FWHM), it can represent more than the half of the maximum power and at least 30 % of the energy deposit. Thus the TOP effect has to be taken into account in order to have an accurate predictive tool for transient of power. In this paper, two methods are presented. The first one consists in calculating the density evolution using best-estimate CFD calculations.

B. ^{3}He density evaluation using CFD

To take into account the TOP effect, a factor linking core power and energy deposit in ^{3}He has to be calculated. The research of this factor was the object of a study realized in 2010-2011 [9]. This study consisted of two steps:

- The first step was made of neutronics calculations of the CABRI core using the French stochastic TRIPOLI4 [10] code. One function was designed giving the ratio between the energy created by (n, p) absorption reaction rates inside ^{3}He and the energy deposited in the CABRI core, depending on the ^{3}He density.
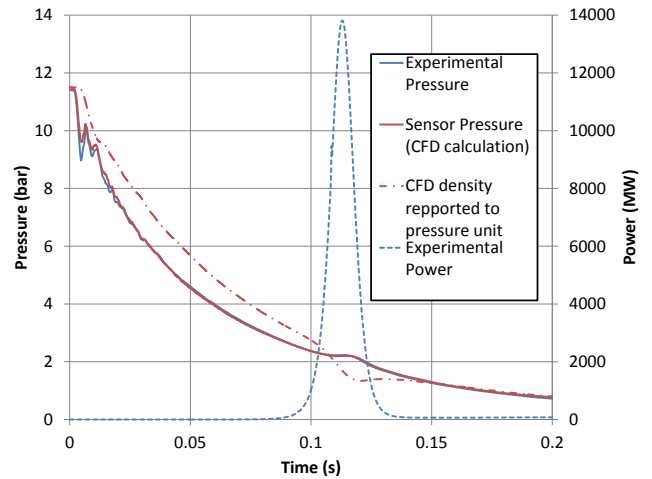
- The second step was devoted to the study of the ionization after neutron/^{3}He interaction. The code SRIM [11] was used to establish a function giving the average energy deposited in the Helium volume by proton and tritium particles, depending on the gas density.

Then, a heat source was added to the CFD simulation using those last functions and experimental powers. The ^{3}He heating was tested on the cases of a simple depressurization by low flow rate channel and a simple depressurization by high flow rate channel.

Fig. 8 shows the results of CFD calculation for the case of the simple depressurization by high flow rate channel using the experimental recordings during a power transient. We can observe the density and pressure evolution during the transient. On one hand, it shows the good consistency between calculated pressure at the transducers location with TOP effect and measured pressure. On the other hand, we observe that density evolves slower than pressure until the power rise. During the pulse, the ^{3}He density is dropping very fast. At the same time, the gas temperature is increasing very high (see Fig. 9).

In the case of a depressurization by the low flow rate channel, the TOP effect has a bigger influence on transient shape. That can be explained by the fact that the ^{3}He pressure is still high at the pulse moment (see Fig 10). This higher pressure implies a higher heating ratio of ^{3}He and thus faster rod depressurization.

The final project is to elaborate a surrogate model including TOP effect, based on approximately 60 experimental transients and complementary calculations. In the future, this density surrogate model could replace the pressure model as an input data of DULCINEE, in order to improve the code predictability. Today results of this evaluation of the ^{3}He density by CFD calculation work well. Nevertheless, one calculation needs around one to two weeks. So, a complete surrogate model of TOP effect would require more than a year to be built. Another method, much faster, is presented here after. It consists in using a reverse point kinetics method from the power transients to
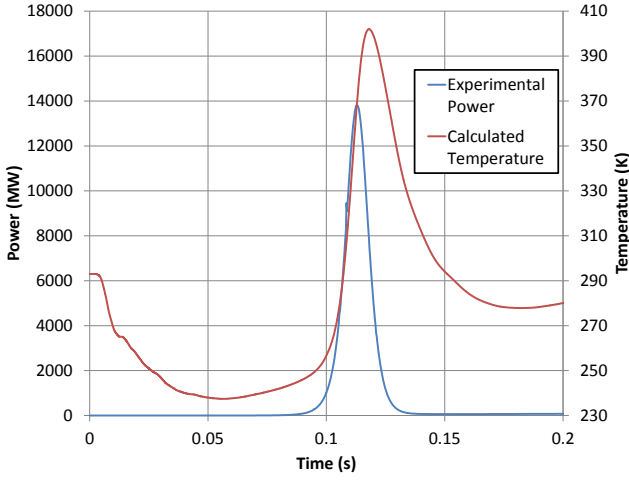
Fig. 9. Evolution of ^{3}He temperature in transient rods according to CFD calculation
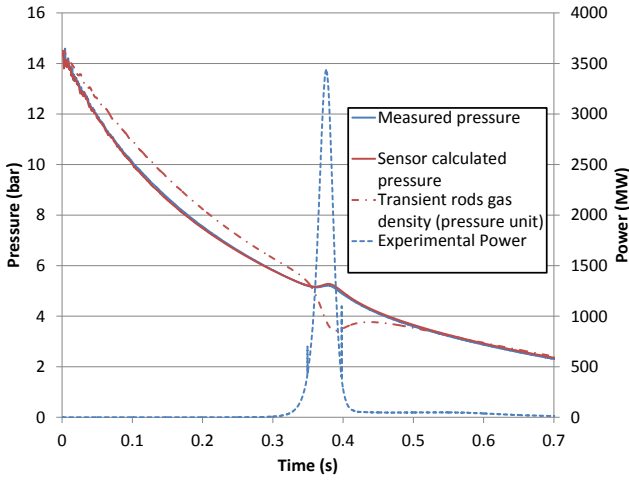

Fig. 10. CFD calculation of simple depressurization by low flow rate channel (VABT04 aperture $\sim$ 30 %) including TOP effect

recreate the density curve inside the transient rods. Based on those calculations a surrogate model can be made.

C. ^{3}He density evaluation using a point kinetics method

The algorithm for density calculation is described as follows:

- Using power transient shapes to evaluate net reactivity evolution using point kinetic equations (3),

$$\frac{dP_{fis}}{dt} = \frac{\rho(t) - \beta}{\Lambda}.P_{fis} + \sum(\lambda_i.C_i)$$
$$\frac{dC_i}{dt} = \frac{\beta_i}{\Lambda}.P_{fis} - \lambda_i.C_i \qquad (3)$$

- Evaluating the reactivity feedbacks using the DULCINEE code in an imposed power mode,
- Injected reactivity is then computed (4) by subtracting feedbacks reactivities to the net reactivity as follows,

$$\rho_{ext} = \rho - \rho_{fb} \qquad (4)$$

- Injected reactivity comes from 2 phenomena : ^{3}He depressurization and control rods drop. Control rods drop reactivity is subtracted to isolate ^{3}He reactivity.
- Correlation between ^{3}He density and reactivity is finally used to evaluate the density at each moment. Here, a surrogate model coming from TRIPOLI4 calculations of the CABRI core in different configurations of control rods insertion and ^{3}He density is used.

However, unlike the first method, this procedure sums a large amount of uncertain parameters. Uncertainties reduction is, in that case, the biggest issue. Those uncertainties come from feedback calculations, kinetics parameters of the core (effective delayed neutron fraction and prompt neutrons generation lifetime), control rods drop reactivity and correlation between density and reactivity. However, it is also possible that a gap exists between real density and CFD calculation. A comparison was done between the 2 methods and is illustrated on Fig. 11.

The power transients calculations were done with SPARTE. SPARTE is based on DULCINEE code and includes several new functions based on Best-Estimates simulations (see [12] for more informations). Dotted lines represent ^{3}He density evolutions, whereas full lines represent transient power shapes. In red is presented transient prediction without TOP effect. We can observe that the reactivity injection is a little too fast by comparison of calculated power to the measured power. Because of the lack of TOP effect, the power transient is only reaching 1 GW, compared to 3.4 GW in reality. Simulation of TOP effect by CFD simulation (green) shows a really better consistency with experimental transient. The calculated power pulse is reaching approximately 2 GW. So, calculated TOP effect doubles maximum power in that case. Moreover, we can observe a better consistency in power rise, power stabilization, and power drop after control rods drop. We can see on blue dotted line the ^{3}He density evolution that would have been needed to recreate the transient by point kinetic algorithm. It is not far from green dotted line, but we can see that the ^{3}He density drop is faster on the reverse kinetic curve. We can assume that it is a 3D effect : 96 tubes are composing the transient rods, and every tube is heated more or less according to his location in the core. So, the TOP effect should be more intense in most heated tubes where neutron streams are the highest. The effect on reactivity injection is then more important as we can observe on Fig. 11.

VI. Conclusions

The present study points out differences between measured pressure and ^{3}He density in transient rods. It shows that the gas density evolution is slower than pressure evolution because of temperature changes in the rods. Surrogate models were developed in order to replace old models based on analytical solution of the problem (with simplification of the geometry). The study demonstrates that the ^{3}He density evolution is different if core power is boosted due to gas heating by neutron/^{3}He interactions. This effect, named TOP effect, affects density evolution by increasing depressurization speed during the transients. It explains some difficulties in the
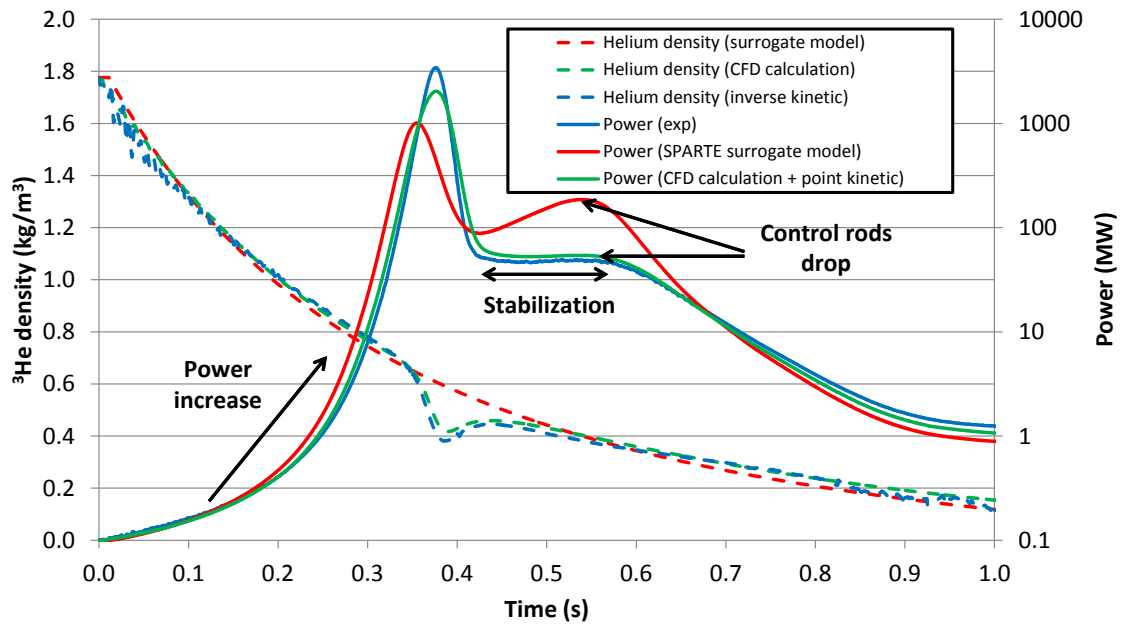
Fig. 11. Comparison of measured CABRI power transient and power transients calculated with density surrogate model and CFD calculation including TOP effect - Case of low flow rate channel depressurization

CABRI power transients prediction. Surrogate models are in development in order to be used in future power transients calculations.

APPENDIX A
NOMENCLATURE

Name	Definition
n	Amount of substance of the gas (in moles)
P	Pressure
V	Volume
R	Gas constant ($8.314\ J.K^{-1}.mol^{-1}$)
T	Absolute temperature
d_{3He}	Mass density of the gas
M	Molar mass of the gas
P_{fis}	Power produced by fission reaction
$\rho(t)$	Core reactivity (pcm)
β	Delayed neutron fraction
Λ	Neutrons life time
λ_i	Decay constants of delayed neutrons precursors
C_i	Concentration of precursors of the group i
β_i	Proportion of delayed neutrons of the group i
ρ_{ext}	Exterior/injected reactivity
ρ_{fb}	Feedbacks reactivity

REFERENCES

[1] B. Duc, B. Biard, P. Debias, L. Pantera, J.-P. Hudelot, and F. Rodiac, "Renovation, improvement and experimental validation of the Helium-3 transient rods system for the reactivity injection in the CABRI reactor," in *International Group On Research Reactors*, 2014, Bariloche, Argentina, November 17 - 21.

[2] J. Lecerf, Y. Garnier, J.-M. Girard, C. Domergue, L. Gaubert, and C. Manenc, "Study of the linearity of CABRI experimental chambers during RIA transients," in *Proc. Int. Conf. ANIMMA2017*, Liege, Jun. 2017.

[3] J.-P. Hudelot, E. Fontanay, C. Molin, A. Moreau, L. Pantera, J. Lecerf, Y. Garnier, and B. Duc, "CABRI facility: upgrade, refurbishment, recommissioning and experimental capacities," in *Proc. Int. Conf. PHYSOR2016*, Sun Valley, USA, 2016.

[4] J. P. Hudelot, J. Lecerf, Y. Garnier, G. Ritter, O. Gueton, A. C. Colombier, F. Rodiac, and C. Domergue, "A complete dosimetry experimental program in support of the core characterization and of the power calibration of the CABRI reactor," in *Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2015 4th International Conference on*. IEEE, 2015, pp. 1–8. [Online]. Available: http://ieeexplore.ieee.org/abstract/document/7465504/

[5] G. Ritter, R. Berre, and L. Pantera, "DULCINEE. Beyond neutron kinetics, a powerful analysis software," in *RRFM IGORR*, 2012, prague, Czech Republic, March 18 - 22.

[6] CD-Adapco User Guide, *STAR-CCM+ Version (10.02)*. CD-adapco, 2015.

[7] O. Clamens, J. Lecerf, B. Duc, J.-P. Hudelot, T. Cadiou, and B. Biard, "Assesment of the CABRI transients power shape by using CFD and point kinetic codes." in *Proc. Int. Conf. PHYSOR2016*, Sun Valley, USA, 2016, pp. 1747–1758.

[8] F. Gaudier, "URANIE: The CEA/DEN Uncertainty and Sensitivity platform," *Procedia - Social and Behavioral Sciences*, vol. 2, no. 6, pp. 7660–7661, Jan. 2010. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1877042810013078

[9] A. Rondeaux, "Caracterisation de la puissance deposee dans les barres transitoires du systeme d'injection de reactivite CABRI," INPG/CEA, Cadarache, DIPLOME DE RECHERCHE TECHNOLOGIQUE, May 2011.

[10] E. Brun, E. Dumonteil, F. Hugot, N. Huot, C. Jouanne, Y. Lee, F. Malvagi, A. Mazzolo, O. Petit, J. Trama, and others, "Overview of TRIPOLI-4 version 7, Continuous-energy Monte Carlo Transport Code," 2011.

[11] J. F. Ziegler, M. D. Ziegler, and J. P. Biersack, "SRIM The stopping and range of ions in matter (2010)," *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, vol. 268, no. 1112, pp. 1818–1823, Jun. 2010. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0168583X10001862

[12] O. Clamens, J. Couybes, J. Lecerf, J.-P. Hudelot, B. Duc, L. Pantera, P. Blaise, and B. Biard, "Analysis of the CABRI power transients - Prediction improvements using a combination of measurements and calculation." in *Proc. Int. Conf. ANIMMA2017*, Liege, Jun. 2017.