FRENCH APPROACH IN FUEL PIN MODELLING FOR FAST REACTORS

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The purpose of this short introductory paper is to present the general philosophy on the problem of fuel modelling now prevailing in France after a twelve years period of tremendously increasing knowledge on fuel behavior.

At the beginning, when the RAPSODIE fuel pin was designed in 1962 , little was known about the behavior of a mixed oxide fuel pin under fast flux ; but a large body of knowledge on UO_2 behavior in thermal reactor was available together with some sparse irradiation results on $(U\ Pu)O_2$ in french experimental reactors. The performances assigned to the pin were then rather modest in rating (≃ 400 w/cm) and in burn-up (30 000 MWd/t).

The AISI 316 steel in solution annealed state was chosen as cladding material. The clad itself was supposed to deform by thermal creep due to fission gas pressure (100 % release), and was affected consequently by a strain limit criteria. The importance of clad temperature (≃650 °) was considered only in connection with thermal creep, the possibility of a chemical reaction between mixed oxide and clad being at that time hardly suspected.

RAPSODIE had only been at full power for a few months when appeared the evidence of stainless steel swelling under a fast neutrons flux. This swelling was observed on RAPSODIE pins as soon as they experienced sufficient neutrons dose, roughly one year later. This entirely new problem came immediately in the front stage (and is still of major importance to-day), and was at the origin of the change from the RAPSODIE to the

FORTISSIMO core in order to accelerate materials testing versus voidage swelling by multiplying the flux by a factor two.

Even with unforeseen swelling, the design of the RAPSODIE and later on FORTISSIMO pin, allowed not only to reach the goal burn-up, but to increase it steadily to roughly 100.000 MWd/t. Since then, the french approach in fuel pin design has still retained something of its original simplicity, and technological efficiency, attitude which is justified by the following considerations :

The many problems concerning fuel pin behaviour which have been encountered when developing LMFBR , have been mostly solved by a judidious extrapolation of the previously obtained experimental results.

In order to perform this type of extrapolation, we need :

- First of all and mainly a correct analysis of the technological key-phenomena (e.g. clad deformation) as a function of the known irradiation parameters.

- Then the inventory of the other phenomena which maybe implied in the above analysis in order to unknot the inter-linkage and cross effects.

When no such effect can be found it is then of no use for the desired extrapolation a heavy, general and complex behaviour code containing what we may call " the unitary theory of the fuel " for a simple calculation dealing with the few implied parameters is quite sufficient.

A typical example may be given with clad swelling

It is known that clad swelling induces thermal changes in the fuel and changes in the loading of the clad by the fuel and the fission gases. When it is experimentally established (as it is) that the mechanical interaction between fuel and clad remains weak during steady state operation, the whole description of the fuel and clad in interaction becomes of no use for the modelisation of clad swelling.

On the other hand the general code would be bandy-legged if a proper model for such an important phenomenon as clad swelling were lacking (as it is).

The following list gives the inventory of the different phenomena or properties dealt with independently, and the mechanisms and main parameters involved. When these elementary mechanisms are obviously interdependant, we have to do with a code " stricto sensu " (ROSACE) ; when they are simply additive, the "code" resume in fact to a computer tool (VULKIN).

Another point, subject of some dispute in fuel modelling, is the extent and the soundness of the physical bases needed to construct useful codes, that is, to make reference to the very subject of this meeting, to decide up to which degree, modelling ought to be theoretical. The answer obviously depends on the domain to which modelling must apply. For steady-state anormal transients operation , the designer certainly would prefer exact empirical laws to physically based but approximate ones. This is the case for clad swelling, for which satisfying theoretical prediction (still lacking) would not preclude the use of laws laboriously elaborated from experiments. The general philosophy of french fuels modelling as a tool to evaluate the fuel pin performance is then to rest mainly on a large body of experimental results. Theory is the indispensable support which makes us confident in the significance of these results, their reproducibility , and permits a reasonable degree of extrapolation.

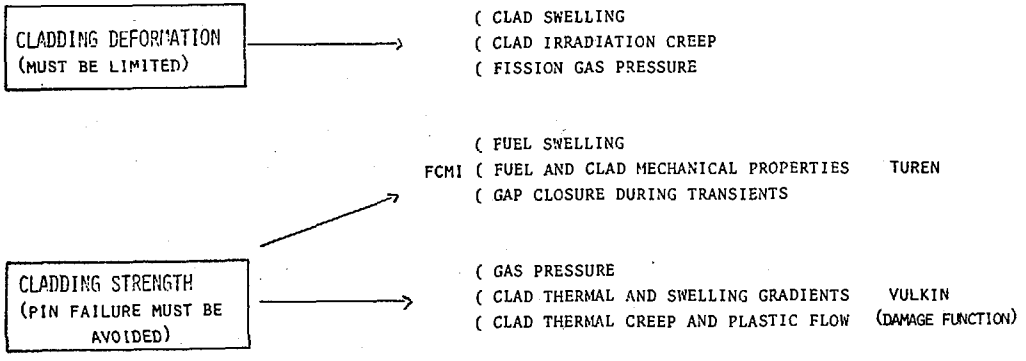
Things are very different when we enter upon safety studies, where experimentation is much more difficult if not impossible and exclude any kind of statistical approach. Then we need absolutely the purely "intellectual" construction represented by theoretical fuel modelling in order to master completely the phenomena in these entirely new conditions. Furthermore, when we pass to safety, the order of preseance of vital questions may be modified. A classical example is given by fission gas release for which the designer is satisfied with a conservative value of 100 %. On the other hand, because fission gases are supposed to play a crucial role in whole-core accidents, an exact value of retained fission gases and a theoretical mechanism for their release during transients are obviously needed.

Since a few years, we observe in every country, a substantial effort to extend fuel modelling, up to now mainly restricted to the evaluation of fuel performance, to the safety domain. No doubt that this will be very beneficial for design codes, whose "theoretical" level will certainly improve through the safety incentive.

I - THERMAL BEHAVIOUR

CRITERIA		MECHANISMS AND PARAMETERS INVOLVED	CODE
FUEL MELTING	INSTANTANEOUS TEMPERATURE AT BEGINNING OF LIFE	(THERMAL CONDUCTIVITY (O/M, Pu/M) (GAP CONDUCTANCE (FRAGMENTATION (OXYGEN REDISTRIBUTION	ROSACE
	TRANSIENT STATE	(RESTRUCTURATION KINETICS (GAP CLOSURE KINETICS (UNRESTRAINED SWELLING (GAS RELEASE (HEAT TRANSFER COEFFICIENT	
	STEADY - STATE TEMPERATURE	(THERMAL CONDUCTIVITY (O/M, FISSION PRODUCTS) (O/M VERSUS TIME (HEAT TRANSFER COEFFICIENT	

II - CLADDING MECHANICAL BEHAVIOUR



EXPERIMENTAL AND THEORETICAL REQUIREMENTS FOR FUEL MODELLING

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From a scientific point of view it may be considered that any event in the life of a fuel pin under irradiation should be perfectly well understood and foreseen ; from that deterministic point of view, the whole behaviour of the pin may be analysed and dismantled with a specific function for every component part and each component part related to one basic phenomenon which can be independently studied on pure physical grounds. When extracted fron the code structure the subroutine is studied for itself by specialists who try to keep as close as possible to the physics involved in the phenomenon ; that often leads to an impressive luxury in details and a subsequent need for many unavailable intput data.

It might seem more secure to follow that approach since it tries to be firmly based on theoretical grounds. We should think so if the phenomenological situation in the pin were less complex than it is. Just as for Hi-fi the value of a code is that of it's less valuable key-component ; so, whatever the scientific concern in developing highly sophisticated physical models, and as long as some of the pieces will be missing in the puzzle, we consider of no help the incorporation into the general codes of models whose level of elaboration and precision is well above the overall uncertainty ; we rather think that such models may induce an over-estimation of the whole code capability even when they do not conceal behind fittable parameters their own inaptitude to cope with the complexity of the described phenomena.

That clear-cut assessment was necessary to define the more technological and seemingly rather rough approach we adopt with regard to fuel modelling : our codes are not designed for an ambitious and, in our opinion, out-of-scope exact reproduction of the detailed features happening during an irradiation. They are designed to help as a tool in a fuel design procedure which is mainly based on experimental testing. We should not be too confident in the absolute values pedicted by the codes, but we actually take care of the relative trends