Advanced Plutonium Assembly (APA) : Evolution of the Concept, Neutron, Thermal-mechanic and Thermal-hydraulic Constraints

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Within the framework of the plutonium cycle control, and associated minor actinides and following the policy of irradiated fuel reprocessing which is the rule in France for nuclear industry, some works were initiated since 1994 in order to define an innovating fuel which can at the same time tend towards high burn up rates and an optimised use of plutonium.

In order to bring suggestions to solve these two aspects, the composite fuels CERCER and CERMET were selected insofar as the use of uranium free plutonium (without uranium) authorises a good assessment of plutonium consumption owing to the fact that the source by ^{238}U conversion is removed.

However, the use of plutonium in a water reactor results in hardening the neutron spectrum and by there, strongly degrades the parameters which depend on the spectrum: soluble boron worth, moderator temperature coefficient, effective beta, Doppler coefficient, without forgetting that plutonium contributes to the voiding coefficient a positive share which can be significant.

A first solution using a large annular pin (external diameter: 26 mm), low thickness (1.8 mm) with internal and external cladding, whose pellets (ceramics) consist of mixed oxide of plutonium and cerium ($(Ce,Pu)O_2$) define the APA reference concept. This concept " **A**dvanced **P**lutonium **A**ssembly" considers 36 large annular pins in a standard 17X17 array and 126 UO_2 pins. The performances with regard to the management of plutonium are excellent, moreover, the versions including Minor Actinides and Long Lived Fission Products (LLFP) show that it is possible to lead to a very significant reduction in the waste amount.
If the neutron performances of this concept are excellent, some hard points appear rather quickly:

* the manufacture of a ceramics ring 26 mm in diameter for a thickness from 1.6 to 1.8 mm is not easy and if significant works were carried out at the laboratory level, the industrial production will pose problems due to the brittleness of these rings,
* internal/external cladding of the rings as well as the welding of the upper plug is not a simple thing,
* the thermal-hydraulics of such a system is complex and the first studies let foresee problems of hot points on external cladding and an over-cooling of the internal channel, which lead to still complicating the pin (pressure reducing intern).

The simpler techniques of manufacture and the plasticity of CERMET, as well as good behaviour under irradiation shown by TANOX experiments make CERMET an excellent choice to be used as fuel. The good thermal conductivity of CERMET then exempts need for

having a mean thickness on the one hand and internal cooling on the other hand. This additional degree of freedom concerning the "pin" opens new prospects to define an alternative concept. By considering two strong constraints which are the respect of the plutonium mass in the assembly and the respect of the zircaloy assessment in the assembly (to limit the hydrogen risk) in the event of severe accident, an original neutron study results in defining an alternative geometry more easily realisable. This new drawing of assembly authorises plutonium balance very similar to those obtained with original APA concept, while preserving neutron control at a good level.

The mixture in the same assembly of a cylindrical geometry (UO_2) and "alternative" one (CERMET) as well as the ceramics cohabitation (UO_2) and this CERMET presenting of great differences in thermal conductivity can pose problems which it is necessary to evaluate in terms of thermal-hydraulic hot point and mechanical constraints even if heterogeneities are not as significant as in the original concept. The neutron studies indicate that the hot point will be in a CERMET plutonium pin, however, the design of this pin authorises a profit of 44% on the cross section, 21% on the heating perimeter, and 20% on the hydraulic diameter. It is reasonable to think that these values associated with a good thermal conductivity will defer the "thermal" hot point towards UO_2 standard fuel pins. These studies make it possible on the one hand to direct the priority R&D with the comprehension of physics and on the other hand to quickly extract the directing coefficients to direct the design of the assembly, of the grids and the stand assembly which can bring relevant answers in terms of mechanical resistance, thermal-mechanical, and tribological behaviour for the definition of this new assembly.

One will also present in conclusion the preliminary computation results which define the R&D program aiming at fixing the great characteristics of this assembly by the end of 2001