LEU FUEL DEVELOPMENT AT CERCA
Status as of October 1998

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ABSTRACT

The aim of this paper is to detail the recent progress on both U_3Si_2 high loaded fuels and new γ phase fuels. Concerning high density silicide plates up to 6 g Ut/cm^3, the CEA irradiation programme is completed. Data are still under analysis but one can state that the behaviour was globaly similar to conventional fuels known in SILOE and OSIRIS reactors.

From the new Uγ fuel point of view, after demonstration feasibility in 1997 of UMo thermally stable plates loaded up to 8.3 g Ut/cm3, CERCA has analysed the technical ability of quality inspection means assuming that it is of an utmost interest for the insurance of a proper use of high performances fuel in reactors. There are mainly two differences between UMo fuels (and more generally γ fuels) and conventional ones. Firstly, X ray diffraction analysis on the fuel powder are needed because the chemical analysis is not sufficient to characterise the γ structure requested. Secondly, the physical limits of the Ultrasonic inspection have been reached due to transitory effect between the meat and the edges. Therefore this technic can't be applied in the transitory areas. From that knowledge, the manufacture specifications for a plate dedicated to an irradiation plan can be discussed with a clearer view of the main differences with the U_3Si_2 fuel reference.

1- INTRODUCTION

Since the beginning of the RERTR, CERCA has been actively involved in the LEU Fuel development. After the qualification period of the U_3Si_2 fuel between 1978 and 1988 followed by an industrial deployment phase, CERCA demonstrated in 1992 the feasibility of high loaded U_3Si_2 plates up to 6 g Ut/cm^3 [1]. As a result of this significant progress, plates and fuel assemblies were manufactured, for the CEA, destined to irradiation tests in the SILOE and OSIRIS reactors.

On a different matter, the Argonne National Laboratory, on behalf of the RERTR programme, presented in 1996 an R&D plan for new fuels which theoretically allow densities far higher than in the existing fuels [2]. The Uranium fuel was supposed to be a γ stabilised phase of an Uranium alloy. Mainly Uranium Molybdenum and Uranium Niobium Zirconium alloys were considered because of their higher density as compared to U_3Si_2. As soon as 1997, CERCA demonstrated, on a laboratory scale, the manufacture feasibility of plates loaded up to 9 g Ut/cm3 with UMo fuel [3].

The aim of this paper is to detail the recent progress on both U_3Si_2 high loaded fuels and new γ phase fuels. More particularly irradiation results concerning 6 g Ut/cm3 U_3Si_2 fuel will be summarised and on the other hand UMo fuel inspection will be analysed after a brief review of the past results on γ fuel development.

2- STATUS OF HIGH DENSITY SILICIDE FUELS

Following on the manufacture feasibility demonstration by CERCA of high loaded plates up to 6 g Ut/cm3 with U_3Si_2 fuel, the French CEA set up an irradiation programme divided in two steps in order to test this new fuel. Firstly, fuel plates were irradiated in IRIS facility of the SILOE reactor. Secondly, two fuel assemblies were irradiated in the OSIRIS reactor.

2.1. Irradiation of 6 and 5.8 g Ut/cm^3 plates in IRIS facility

IRIS facility located in SILOE reactor is an irradiation device designed as a fuel assembly but allows the removal of R&D plates between irradiation cycles for thickness measurements. Macroscopic swelling behaviour can then be analysed when comparing to a reference plate loaded to 4.8 g Ut/cm^3 and irradiated in the same conditions. For that purpose, 6 g and 5.8 g Ut/cm^3 plates were manufactured in 1994 and irradiated between 1995 and 1997 reaching an average Burn Up of 55%.

The results of irradiation tests will soon be published by the CEA. Nevertheless, in anticipation one can state that no cladding failures have been detected and the swelling measurements were fairly similar to the reference plate loaded to 4.8 g Ut/cm^3.

2.2. Irradiation of 5.8 g Ut/cm^3 fuel assemblies in OSIRIS reactor

Taking into account IRIS irradiation back ground, two fuel assemblies loaded to 5.8 g Ut/cm3 were manufactured in 1996 for the OSIRIS reactor and irradiated between 1997 and July 1998 reaching an average burn up of 74 %. For the time being, one can state that no cladding failure have been detected and the behaviour was similar to the typical OSIRIS fuels loaded to 4.8 g Ut/cm^3.

As a matter of fact, the technical design staff in charge of the new CEA reactor (JULES HOROWITZ reactor) is now considering 5.8 g Ut/cm^3 fuel concept as an alternative to the reference fuel loaded to 4.8 g Ut/cm^3.

3- STATUS OF HIGH DENSITY gFUELS

Straight away at the beginning of 1997, CERCA started R&D work on new γ fuel alloys in order to evaluate the technical ability from the manufacturing point of view. More particularly Uranium Molybdenum and Uranium Niobium Zirconium with high and low alloy content have been examined from the casting metallurgy, rolling process and thermal stability point of view. The main results are summarised as follow :

3.1. Review of the past work

	Low alloy content		**High alloy content**	
	U-5%Mo	U-4%Zr-2%Nb	U-9%Mo	U-3%Zr-9%Nb
Metallurgy : pure γ phase	Yes	Impossible	Yes	Yes
Thermal stability : 3 days at 400 °C	Diffusion with Al	Diffusion with Al	**Stable**	Diffusion with Al
Fuel plate manufacture	Demonstrated 9g Ut /cm^3	Not tested	Demonstrated 8.3g Ut /cm^3	Not tested

Finally, it can be concluded that the most valuable tested candidate is an high alloy content fuel such as U-9%Mo because of the great stablility with the surrounding aluminium of the matrix.

Nevertheless, according to ANL publications, thermal stability of U-5%Mo alloy can be increased when adding metal traces of Platinum or Ruthenium. On the other hand, the percentage of Molybdenum could be optimised (between 5 and 9%) in order to get both high density and a good thermal stability. Within the framework of these preliminary tests such solutions have not been tested yet

After the demonstration feasibility of high loaded plates with a stable U-9%Mo alloy, CERCA has focused one's attention on the inspection means applied to this new type of fuel. Indeed, new γ fuels are supposed to offer high neutronic performances in order to replace HEU fuel or to improve existing LEU fuel. Consequently, quality inspection will be of utmost concern for a proper use in the reactor .

3-2. Technical evaluation of fuel plate inspection means in the case of UMo Fuels

The aim of the study is to emphasize the main differences between new γ fuels and the « conventional » one , from the quality inspection point of view. Aspect inspection and micrographs for cladding measurement are not reported because the inspection procedures are quite similar to the other fuels.

3-2-1. Chime and Metallurgy of fuel particles

Although U-Si phase diagram is relatively complex, the U_3Si_2 compound in itself has a very simple metallurgy. The Crystal structure is stable from the melting point up to the ambient temperature. Consequently, whatever cooling is carried out to the melted alloy with the right U-Si chemical composition, will lead to the U_3Si_2 compound with the right Crystal structure. Therefore chemical analysis is sufficient to demonstrate that the sample is composed of U_3Si_2.

On the contrary of U_3Si_2, UMo And UNbZr alloys can have several Crystal structures between the melting and the ambient temperature depending on cooling speed and Uranium homogeneity. For a proper use in reactor γ cubic structure is requested because the irradiation behaviour is supposed to be satisfactory. γ phase can only be obtained when quenching the alloy from almost 900°C.

On the other hand, when the melted alloy is solidifying, segregations occur near the grain boundary resulting in an Uranium rich zone that will not be able to maintain the γ phase when quenching.

Obviously, except if the process itself can guarantee the elaboration of pure γ phase, chemical analysis is not sufficient for UMo an UNbZr alloys. Therefore, X ray diffraction analysis will be necessary at least during the development phase.

3-2-2. Bonding of the plate after rolling

The thermal conductivity continuity between the several components of the plate (cover, meat and frame) is of major interest to test in order to make sure there won't be a hot spot that could lead to a failure of the cladding. For this reason, the bonding quality is inspected by means of a blister test and completed with Ultrasonic test.

Blister test

The blister test is carried out on finished plates and after a heat treatment of at least one hour at 400° to 500°C. Plates are visually inspected under an incident light to detect blisters. Indeed, if there is a lack of bonding, when heated plates, enclosed air in the non bonded area will inflate and create a blister at the surface of the plate.

This procedure can be applied as existing for γ fuels.

Ultra sonic inspection

Complementary to blister test, UT inspection is carried out in order to detect lack of bonding that didn't lead to a blister and also eventual delamination of the meat.

UT inspection is performed when comparing Ultra sonic signal crossing the inspected plate and a reference plate with a standard defect in the meat area where the Ultra sonic signal is strongly toned down leading to an easy inspection analysis. Nevertheless, with the increase of density the transitory effect between the Aluminium edges of the meat and the meat itself produce a decrease of the Ultrasonic signal. This transitory effect is almost insignificant for UAlx fuels loaded up to 1.2 g Ut/cm^3 and can clearly be differentiated from the standard delamination signal. For U_3Si_2 fuel loaded up to 6 g Ut/cm^3, the transitory effect needs a finer analysis rather than for γ fuels loaded up to 9 g Ut/cm3 it is impossible to make a difference between transitory effect and standard defect (see figure 1). It must be pointed out that the problem is almost independent of the Ultrasonic technology as Ultrasonic flux diffusion phenomenons are involved at the interface of material with such a big difference of density.

3-2-3. Meat dimension and homogeneity

X Ray film

X Ray films are used for meat dimensions and homogeneity analysis. From that point of view high loaded plates with γ fuel don't create problems except that two films are needed in order to optimise the contrast for either meat or edge inspection by means of exposure parameters.

Automatic X Ray homogeneity inspection

Complementary to X ray film inspection, the homogeneity of Uranium distribution is quantitatively analysed with a real time X ray imaging machine based on the following principle. A focused beam of X ray goes through the thickness of the plate. The Uranium density variations are determined by measuring the absorption of the beam across the plate when scanning all the meat surface.

This inspection procedure has no physical and technical limits concerning the density of the plate to be inspected. X ray gun and counter are designed to analyse equivalent density of at least 12 g Ut/cm3 with a meat thickness of 0.51 mm .

Figure 2 shows X ray scanning measurements on both 8.3 and 9 g Ut / cm^3 plates manufactured by CERCA as a feasibility test with UMo fuel.

For the 8.3 and 9 g Ut / cm^3 plates the homogeneity diagram stands easily between the allowed limits all along the plates length . That means that both plates are in conformity with the specification commonly used for Silicide fuels.

4 - CONCLUSION

The high density fuel R&D at CERCA is still going on for both U_3Si_2 and $U\gamma$ fuels.

Concerning high density silicide plates up to 6 g Ut/cm3, the CEA irradiation programme is completed. Data are still under analysis but one can state that the behaviour was globaly similar to conventional fuels known in SILOE and OSIRIS reactors.

From the new $U\gamma$ fuel point of view, after demonstration feasibility in 1997 of UMo thermally stable plates loaded up to 8.3 g Ut/cm3, CERCA has focussed the development effort to analyse the technical ability of quality inspection means assuming that it is of an utmost interest for the insurance of a proper use of high performances fuel in reactors. There are mainly two differences between UMo fuels (and more generally γ fuels) and conventional ones.

Firstly, X ray diffraction analysis on the fuel powder that doesn’t exist routinely with UAlx and U_3Si_2 fuels are needed because the chemical analysis is not sufficient to characterise the γ structure requested.

Secondly, the physical limits of the Ultrasonic inspection have been reached due to transitory effect between the meat and the edges. Therefore this technic can’t be applied in the transitory areas.

From that knowledge, the manufacture specifications for a plate dedicated to an irradiation plan can be discussed with a clearer view of the main differences with the U_3Si_2 fuel reference.

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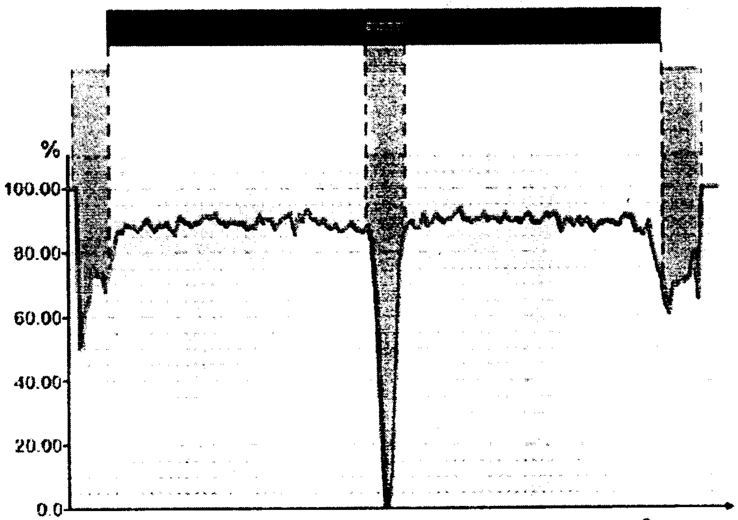
PRELIMINARY DEVELOPMENTS OF MTR PLATES WITH UMo FUEL
presented at the RERTR 1997 meeting in Jackson Hole (USA), October 1997
By JP Durand , Y. Lavastre , M. Grasse (CERCA)

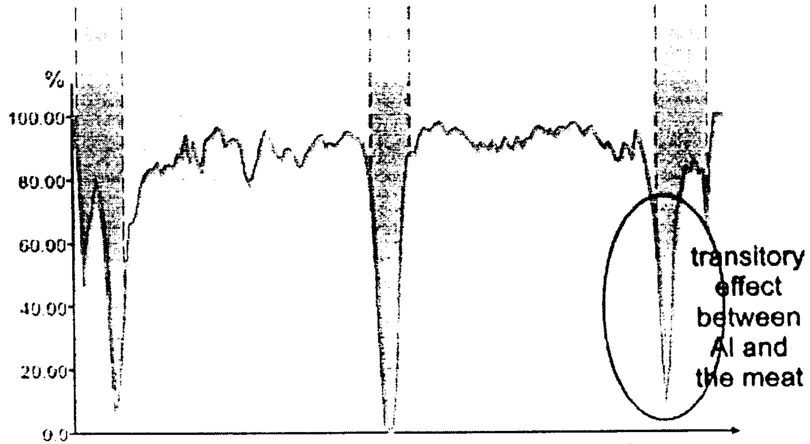
FIGURE 1

TECHNICAL EVALUATION OF UMo FUEL PLATE INSPECTION (Ultrasonic Test)

Fuel plate cross section



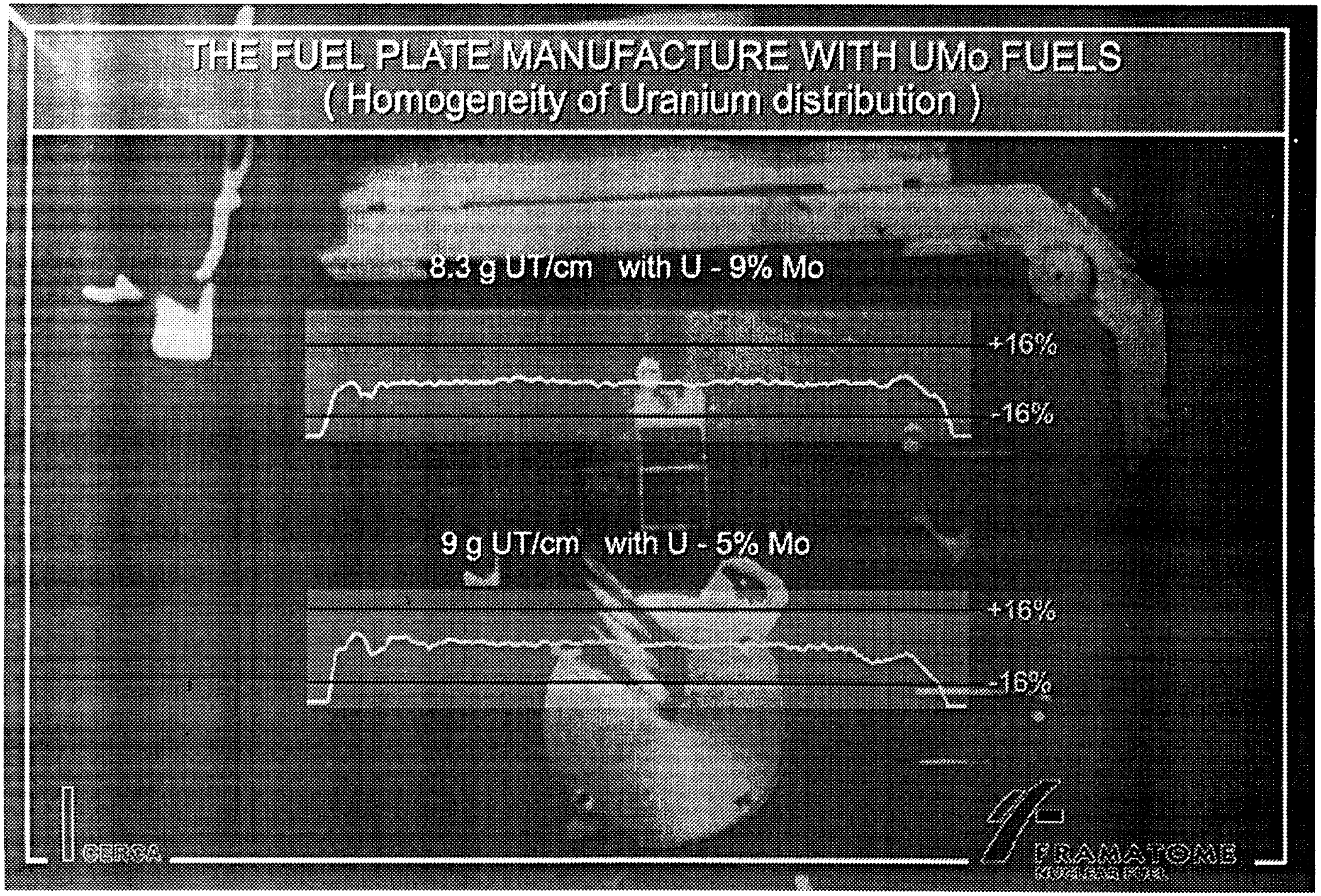
UAlx plate (1,2 g Ut / cm^3)



UMo plate (9 g Ut / cm^3)

CERCA

FRAMATOME
NUCLEAR FUEL



THE FUEL PLATE MANUFACTURE WITH UMo FUELS
(Homogeneity of Uranium distribution)

8.3 g UT/cm with U - 9% Mo

9 g UT/cm with U - 5% Mo

FIGURE 2