CERCA UMo DEVELOPMENT
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Abstract

Considered as a suitable solution for non-proliferation and reprocessing purposes, UMo fuel has been chosen and studied by the RERTR program since 1996. Through the French working group whose aim is to qualify UMo before 2006, CERCA is in the process of qualifying the fabrication of U 7 % Mo with a density of up to 8 g Ucm^{-3}.

With a statistical process control (SPC) basis in the workshop and a wide experience of more than 20 years in the silicide and aluminide fuel element, CERCA has already shown its ability to manufacture UMo fuel. In 1999, for the first time in the world, seven full size plates of U-7Mo with a density of 8 g U cm^{-3} had been manufactured. Fabricated with machining powder, this first fabrication had allowed CERCA to define the adjustment needed to improve quality and delivery. Thanks to these first encouraging results, improvement axes have been set up for the second fabrication. Manufacture of U-7Mo full-scale plates is scheduled for 2002 using atomized powder.

This paper focuses first of all on the manufacturing results obtained on full scale plates manufactured in 2002 for the French UMo group. The plates are planned to be irradiated in OSIRIS and BR2 reactors. In a second section, we introduce the orientations and achievements which CERCA has already implemented so as to be able to produce in 2006 U-7Mo fuel through an industrial process which will lead to cost reduction, while retaining quality and on-time delivery.

1. Introduction

CERCA, a world-wide leader for civilian MTR fuel supplies, is continuously involved in the development of LEU fuel.

Within the frame of the international RERTR program, the French UMo Working group (CEA, CERCA, COGEMA, TECHNICATOME and NOVATOME) aims at qualifying U-7Mo fuel with a density of 8 gUt/cm^3 before the end of 2006.

In this way CERCA's goal is to succeed in the UMo fuel production on an industrial scale which covers quality, reliability and time delivery in order to satisfy the MTR community needs.

Based on our own experience of high density U_3Si_2 fabrication, our contributions are to set up as well as to get a better understanding of specific processes involved in the manufacturing of high density UMo fuel.

For this and in coherence with the French UMo working group strategy, R&D full size plates were manufactured. This policy which has been carried out since 1998 has allowed us to define specifics actions and investigations in order to improve the knowledge linked to the UMo behaviour through the CERCA advanced process.

After the first UMo full size plates production presented in 1999 and 2000 [1][2] the results obtained according to our latest R&D development program are described below.

These prototypes produced a few months ago will be irradiated in 2002/2003 according to the French UMo working group irradiation schedule.

The second part of this presentation introduces CERCA strategy and describes the main steps elaborated for the UMo workshop configuration set up.

2. R&D UMo fuel plates manufacturing and irradiation

After the first results obtained under irradiation in OSIRIS I (IRIS device) with surfacic power of 170 W/cm^2 and HFR (UMUS device) with 250 W/cm^2, two new irradiations with full size plates have been scheduled for 2002.

This second set of irradiations will allow us firstly to test a new type of UMo powder.

Secondly, limiting the cladding temperature while operating, a new set of data will be available in order to define the acceptable range for satisfactory UMo behaviour under irradiation.

For this, U-7%Mo atomized powder with Low Enriched Uranium (LEU) will be used and cladding temperature will be kept below 130 °C.

The irradiation conditions associated with the UMo plates described in this paper are mentioned below in Table 1.

Reactor	OSIRIS II	BR2
Max surfacic power (W/cm^2)	250	350
Max cladding temperature (°C)	< 130	< 130
Max BU (%)	50 or 70	50

Table 1: UMo French working group Irradiation conditions for U-7Mo full size plates

The French UMo working group plan development schedule is presented here after in Table 2.

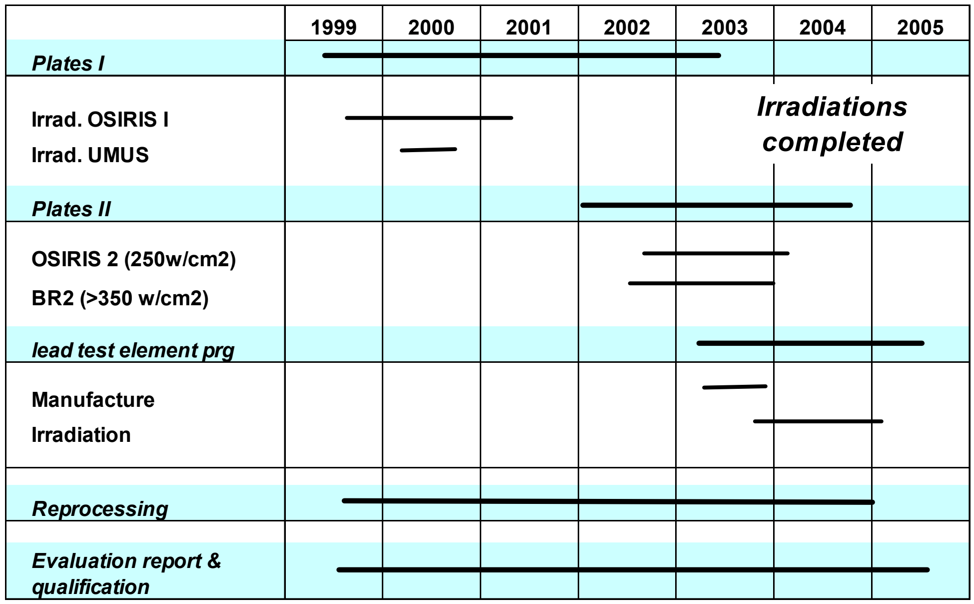

Table 2 : French UMo working group development time schedule

Concerning the project schedule, it can be pointed out that, the post irradiation examination (PIE) of OSIRIS and HFR presented during the 2002 RRFM [3] are still in progress.

Furthermore, honoring our global schedule commitments, CERCA will be ready for industrial UMo delivery by the end of 2006.

Concerning CERCA specifically, R&D UMo development program resources have been set up to optimize our advanced process through UMo fuel.

One is the numerical simulation of UMo plate rolling with a university partnership wherein significant improvement is expected for some plates characteristics.

Secondly, we are evaluating internally and externally the different production mode of UMo powder. Technical, industrial and safety aspects are considered for this evaluation.

Also encouraging results have been already obtained in the up-stream part of our advanced process and NDT studies have also been launched.

2.1. POWDER MANUFACTURING

UMo Powder production as a sensitive part of fuel manufacturing has to be evaluated.

Considering the powder production itself, machined UMo powder had been tested by CERCA three years ago. With a lot of difficulties due to UMo high ductility, this mode of powder manufacturing was questioned at the time with regard to production on an industrial scale.

Hydriding, milling and de-hydriding (HMD) is another way to produce UMo powder.

According to our own studies and the results obtained this production mode could be considered for the moment only for reduced quantities of powder. Further investigations are needed to reach industrial scale production.

Considering the mechanisms of hydriding and the sensitivity of each parameter, industrial scale production has to be demonstrated and R&D efforts have to be made to produce HMD UMo powder in a reproducible and safe manner.

Atomization of UMo is the third way to produce UMo powder.

Industrial production scale is demonstrated externally, but safety concerns have to be well managed and could reduce productivity. Investment and cost development have also to be considered.

Considering the intrinsic principle of atomization, the UMo fusion in a crucible, as a crucial step for quality aspect, needs to be carefully controlled to avoid any segregation of Mo while operating.

On the HMD or machined powder production a pre-heating (homogeneous heat treatment) step could be used in order to obtain good UMo homogeneity.

Industrially, CERCA has to investigate the UMo powder production process further while at the same time evaluating powder compatibility throughout the CERCA manufacturing process.

From our point of view, final product quality and reliability is a function of UMo powder characteristics.

Results from PIE examinations reflecting the behaviour of different types of UMo powder under irradiation will guide the final choice for an ad hoc UMo powder process production.

2.2. FUEL SIZE PLATE MANUFACTURING

The 6 plates produced for BR2 and OSIRIS II irradiations have been manufactured with spherical and gamma phase particles obtained by atomization.

Figure 1 presents UMo particles in the fissile core after the CERCA manufacturing stage.

The homogeneity of U and Mo obtained with an energy dispersive spectrometer (EDS) from one of the UMo particles center to the Al matrix of the meat is presented in Figure 2.

Interaction layer of UMo / Al in as-manufactured plates is not seen with CERCA's production parameters.

The main characteristics of full sized plates are given in the table 3 below.

Identification	1	2	3	4	5	6
Reactors	OSIRIS (II)				BR2	
% Mo in alloy	7.6				7.3	
Enrichment (%)	19.80				19.82	
^{235}U (g)	28.06	28.04	28.02	28.01	30.49	30.51
Meat density (gU cm^{-3})	8.3				8.5	
Porosity (%)	1.5	1.6	1.4	1.1	1.1	1.3
Cladding thickness (mm)	0.36				0.38	
Meat thickness (mm)	0.51					
Cladding material	AG3NE					

Table 3: U-7Mo plates characteristics produced by CERCA

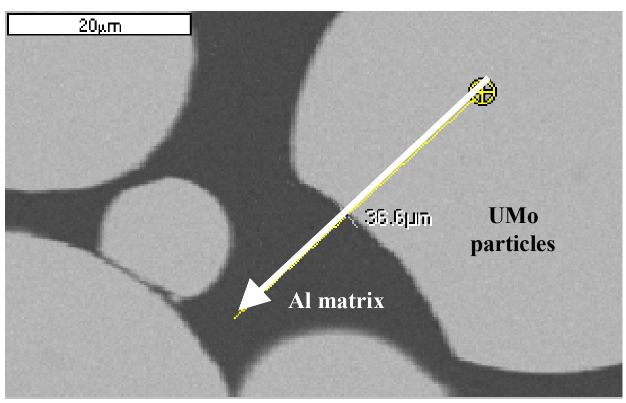

Figure 1: SEM picture of UMo particles in the fissile core after manufacturing

2.2.1. Homogeneity of U distribution

The homogeneity of Uranium distribution is quantitatively inspected by means of a radiographic system with X ray spot that scans the length of the plate. The uranium density is determined by measuring the absorption of the beam (Figure 4).

A significant improvement in homogeneity results is obtained. This improvement is linked mainly to our last advanced process development. In parallel, the atomized UMo powder enables local lopping of some irregular interface shapes between the fissile core and the cladding frame. The homogeneity average is then controlled by the CERCA process when the local response is optimized with atomized UMo powder.

As a function of the manufacturing process itself and the material used, homogeneity results will be optimized. Some studies are under way in order to improve the UMo / Al powder mixing step as well as the rolling procedure. Improvements connected with the reproducibility of homogeneity are expected for our future production.

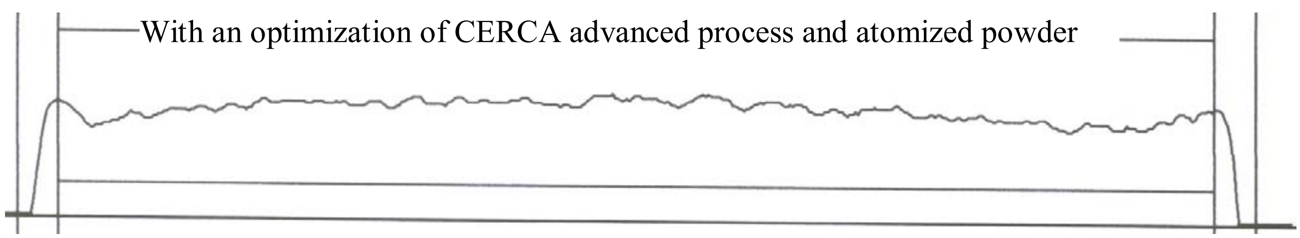

Figure 4 : Homogeneity of Uranium distribution in U-7Mo plates with 8 gU/cm^3

2.2.2. Stray fuel particles inspection

To avoid local temperature increase and fission products release in some particular plate areas during irradiation, the stray particle specification has to be well defined. This is very sensitive with high density fuels. Then, depending on customer specifications, plates are acceptable or rejected.

According to our long feed back experience, many manufacturing parameters impact the presence of free particles. From the compaction procedure to the rolling step, the stray fuel particles which can be seen by examination of properly exposed X radiographs, are, statistically speaking, very difficult to avoid.

Thanks to our considerable experience, CERCA has been able to produce plates that were acceptable to our customers without any problems.

2.3. CONCLUSION

After the first manufacturing experience in 1999 including Mo variability contents and different enrichment values, CERCA has manufactured 6 new full size UMo plates with an high density up to 8 gU/cm^3. Thanks to the new R&D procedures implemented in the workshop, improvements have been seen on the U-7Mo full size plates. Significant improvements in homogeneity are obtained and confirm the CERCA R&D developments previously defined.

The atomized UMo powder tested is compatible with CERCA's advanced rolling process.

Concerning UMo powder production, CERCA is willing to test all types of UMo powder in order to have a global view of these topics. Further investigations on a specific device for UMo powder production will be carried out in 2003 so as to update and complement the preliminary evaluation file.

3. Workshop part

In order to be able to produce and sell a new generation of high performance fuels not only is it of utmost importance to master production technology, but it is necessary to be able to provide, at any time, the highest level of quality and service that customers expect.

Due to our experience with U3Si2 fuels, we know that the road from development on a laboratory scale to industrial scale is long and difficult. Consequently, a lot of things need to be anticipated.

In the following items, as one of the leaders in the fuel development, but, above all, as an industrialist that sells fuels all over the world, CERCA reviews the different actions already in hand or on standby to be ready when UMo fuel is qualified.

3.1 THE PRODUCTION PROCESS :

Generally speaking, since the beginning of UMo development in 1997, CERCA has chosen to produce only **full size** plates for irradiation tests in order to be as close as possible to industrial conditions. That has been very useful for producing files for statistical analysis on production and inspection processes.

The operating points with their stability areas are now well known.

3.2 INFORMATION PROCESS :

As CERCA complies with all the Quality Standards, traceability and uranium accountancy is the main concern in a process with so many transformation steps.

To solve this difficult problem a computer system has been developed to monitor uranium throughout the process lines. At any time it is possible to know the exact amount of uranium contained in each ingot used in a plate. This new system has been parameterized to take into account UMo Alloys.

3.3. CRITICALITY :

If production is considered in a productive way, the question of economical batches quickly arises, but due to the specificity of our business, critical mass, with the different margin coefficients, provides the upper limit.

Preliminary neutron calculations are being carried out in FRAMATOME ANP and will go in depth in 2003 . These results are very useful for managing production fluxes through the process lines and preparing files for the safety authorities so as to get their approval of an industrial production.

3.4. SAFETY :

As the wish of our shareolder (FRAMATOME ANP, a joint AREVA and SIEMENS company) is the everlasting quality of MTR fuel supply, a lot of investments have been made to comply with the new safety rules. Therefore CERCA can be considered a reliable supplier due to more than 30 years experience and the constant development and renewal of production means within the framework of one of the most severe safety references.

3.5. SERVICES :

Because we think that the future of a manufacturing plant is the associated services around the manufacturing of fuel elements, CERCA has developped knowleges in the following items:

- **Experience in the transport of Uranium**: CERCA supplies Uranium for almost all its customers. CERCA has been the main logistic actor in the supply of Russian uranium for French and German reactors.

- **Experience in the delivery of fuel elements to reactors:** Since 2001, CERCA has developed a new "CERCA 01" cask licensed, in accordance with all the laws and regulations actually in force in many countries. This cask is already used for the shipment, all around the world, of U3Si2 and UAlx fuel elements. CERCA is rather confident in the issue for an extension of this agreement for UMo fuels.

- **Development of a recovering process of scraps** inherent to the fabrication process of elements. The Uranium which is in the scraps become usable.

4. CONCLUSION

To develop a new fuel requires a lot of technical resources, a clear vision of the development program and constant strength to reach the aim of qualification in 2006. That is the reason why, in the French UMo Group, CERCA has constantly steered a course towards the development program since the early schedule presented in 1999. All valuable technical options are being considered to be sure that the right choice is made regarding the industrial scale.

However, to be ready from the technical point of view is necessary, but not sufficient. The fuel business has a long time constant. We have to submit our projects to safety authorities, and so, a lot of things must be anticipated as far as industrial production is concerned. From that point of view, CERCA has launched, in parallel, an industrialization program taking into account the whole production processes up to fuel shipment. The aim is to offer in 2005 a stabilized, qualified, licensed and cost effective fuel production process.

In the meantime, CERCA is willing to help any reactor that needs, either fuel assemblies for tests or contacts or information from the French UMo Group.

References

[1] H. Vacelet, P. Sacristan, A. Languille, Y. Lavastre, M. Grasse "Irradiation of full size UMo plates", "22 nd International Topical Meeting on RERTR'99, Budapeste".

[2] JP. Sacristan, F. Plewinski, P. Couffin, C. Joly, A. Languille, H. Vacelet, Y. Lavastre, and M. Grasse, "A full programme for a world wide qualified UMo fuel," 4th International Topical Meeting on Research Reactor Fuel Management (RRFM 2000), Colmar, France, March 19-21, 2000, pp. 93-98.

[3] A. Languille, D. Plancq, F. Huet, B. Guigon , P. Lemoine, P. Sacristan, G. Hofman, J. Senelgrove, J. Rest, H. Vacelet, E. Leborgne, G. Dassel "Experimental irradiation of UMo fuel : PIE results and modeling of fuel behaviour " 6th International Topical meeting on Research Reactor Fuel Management (RRFM 2002), Ghent, Belgium march 17-21, 2002, pp : 26-31