

# **CERCA's 25 YEARS EXPERIENCE IN U<sub>3</sub>Si<sub>2</sub> FUEL MANUFACTURING**

## **25<sup>th</sup> INTERNATIONAL MEETING ON RERTR**

**Chicago, United States of America**

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### **ABSTRACT**

This paper documents the experience gained at CERCA in manufacturing, testing, and inspecting U<sub>3</sub>Si<sub>2</sub> fuel elements for various Material Test Reactors (MTR) since the beginning of the RERTR Program in 1978, up to now. It emphasises how the company controls the product to insure compliance with the fuel-related safety parameters. Finally, those statements are considered in the UMo fuel production perspective.

#### **1. Manufacturing Experience**

By 2003 CERCA will have manufactured more than 2200 U<sub>3</sub>Si<sub>2</sub> fuel elements (see Attachment 1), with excellent in reactor reliability. The first two were delivered to the Oak Ridge Research Reactor (ORR) in 1983. They were used to qualify this fuel type in the RERTR Program.

NUKEM also introduced fuel elements in the ORR and participated to the U<sub>3</sub>Si<sub>2</sub> qualification program. Since then, this company transferred its MTR manufacturing capabilities to CERCA. Therefore we cumulate both experiences.

CERCA serves customers in various countries with demanding safety authorities and quality requirements: Belgium, Canada, France, Germany, Japan, Sweden... Obviously the manufacturing know how has considerably increased between the first fuel test assemblies and the last current productions. Some examples will be given here after when dealing with safety requirement.

## 2. In Reactor Tests

In addition to the manufacturing experience, there have been many in-reactor tests and examinations. The chart in Attachment 2 shows our Uranium – Silicium fuel irradiation test programs. It extends from 1982 to 1998 and covers  $U_3Si$ ,  $U_3Si_2$ , with Uranium density between 2 and 6 g/cm<sup>3</sup>.

This very large program of test and development goes even beyond the publication of the USNRC NUREG 1313 “Safety Evaluation Report related to the Evaluation of Low-Enriched Uranium Silicide-Aluminum Dispersion Fuel for Use in Non-Power Reactors” and covers various design parameters, for example meat chemical composition densities, and meat thickness. Several production parameters were varied, keeping the industrial conditions. By industrial conditions, as opposed to laboratory conditions, we mean manufacturing full size plates or elements, in the same workshop, with the same people, using the same work instructions, Quality system, etc, as our standard production.

It gave us the true confidence that our manufactured elements behave well under irradiation in various reactor operating conditions: OSIRIS, SILOE, HFR, ORR, R2, JRR3, JRR4, JMTR, etc. During these years we developed new techniques and processes. With our continuous contacts with the research reactor community around the world, we know very well what is important from a safety standpoint as far as fuel manufacturing is concerned.

## 3. Safety Requirements

The following table summarizes the main safety features that the fuel manufacturing can impact.

<b>Manufacturing requirement</b>	<b>Related safety parameter</b>
$U_3Si_2$ Powder composition and size, distribution of fine particles	Swelling, behaviour under irradiation
Uranium homogeneity in the meat	Power density, Hot spot and heat transfer
Cladding material	Corrosion, cladding integrity
Blister resistance	Meat to cladding heat transfer
Stray particles	Hot spot in non allowed areas
Regularity of water channel width	Coolant velocity and heat transfer

### 3.1. $U_3Si_2$ Powder Characteristics

In order to avoid  $U_3Si_2$  swelling, the NUREG-1313 insists that the  $U_3Si$  content in the  $U_3Si_2$  remains as small as possible. U,  $U_3Si$ ,  $USi$  are possible phases in the  $U_3Si_2$  ingot if special care is not taken. This is very sensitive to the casting procedure and the material used. In addition to a very precise weighing of U and Si, CERCA has qualified its melting process in order to keep a tight control of the Uranium silicide composition. When making the powder we keep control of the fine particles in order to guaranty the in reactor performance. Our fine particle distribution has been selected after our large irradiation experience (see Attachment 2).

Our investigations were so deep that we were able to identify a new phase in the (U – Si) phase diagram for the first time ( $U_5Si_4$ , 1996 RERTR publication).

### 3.2. Uranium Homogeneity and Power Control

The Uranium homogeneity in each fuel element and each individual fuel plate must be controlled. One percent of Uranium density increase above the nominal content at a given location of a fuel plate translates almost exactly in one percent of local power increase at that location. It is therefore critical to keep control of the Uranium density homogeneity in the meat. The higher that density, the harder it is to maintain homogeneity. For instance, a 1,2 g/cm<sup>3</sup>  $UAl_x$  or a 2 g/cm<sup>3</sup>  $U_3O_8$  fuel plate is easier to manufacture than a 4.8 g/cm<sup>3</sup>  $U_3Si_2$  one.

Furthermore, at each end of the meat area exists a transient zone called the dog bone area. It consists in a very local increase in meat thickness leading to a corresponding reduction of the cladding and also a lack of homogeneity. This dog bone must be kept under control.

A good homogeneity is obtained in several steps :

First, the U – Si ingot melting must be very homogeneous (see above)

Second, one must achieve a perfect homogeneity of the  $U_3Si_2$  – Al mixture when doing the ceramic-metal compound called CERMET.

Third, one must also maintain this homogeneity when selecting the rolling parameters. CERCA has developed advanced processes to produce  $U_3Si_2$  plates up to 6 g/cm<sup>3</sup> (RERTR 1992). This proves our manufacturing margin regarding the 4.8 g/cm<sup>3</sup> standard fuel and our ability to monitor the quality. Among other things, this improvement has been possible thanks to a methodical approach combining numerical calculation of the rolling and an accurate instrumentation of the rolling in order to guarantee a good reproducibility.

Lastly, one must do the appropriate control to demonstrate the plate homogeneity. It is of utmost concern to use inspection means in compliance with the homogeneity requirements. For that purpose, CERCA has developed a numerical X ray machine and software systems (RERTR 1992) . 100% of the fuel plates are inspected and we obtain a map of the Uranium density in the plates, letting us know the exact value at each square centimeter. The resolution of these maps can be further refined to fractions of square centimeter if needed. The particular requirements of the dog bone area are of course also controlled in the same way. These costly equipments are justified by the high volume of our production and our constant struggle for quality.

### 3.3. Fuel Cladding

Another key safety parameter is to maintain the integrity of the fuel cladding and to prevent any fuel release in the coolant circuit.

Originally a subsidiary of Pechiney, the French Aluminum company, CERCA has always maintained technical links with the Aluminum metallurgy experts that are producing our cladding materials.

AG3 NE and AlFeNi ( for high thermal flux reactors ) alloys have always been used since the beginning of the fuel production including the irradiation tests assemblies. Therefore, CERCA has gained a large background in using such materials and is able to optimise the products for better performances (  $U_3Si_2$  6gUt/cm<sup>3</sup>, UN 7g Ut/ cm<sup>3</sup> , UMo 8 gUt/cm<sup>3</sup> ....) .

### 3.4. Resistance to blister

In order to maintain a good heat transfer until the end of life of the fuel element, one must be sure that at the beginning (as fabricated) there are no weakness in the bonding of the meat and the cladding. Therefore a blister test is carried out by a worker in order to detect, after heat treatment of the plate, any blister on the external surface which means that gas is enclosed in the plate and the gas has swollen.

Furthermore, CERCA has developed special UT inspection equipment, as complementary inspections of the blister test. It can detect delaminating within the meat that cannot be detected with blister test.

### 3.5. Stray particles

For high loaded plates such as  $U_3Si_2$  fuel, the occurrence of stray particles is very sensitive because of the low level of Aluminium volume fraction within the meat, which tends less to retain fuel particles. A stray particle located in the edge of the plate can damage the plate during irradiation. Indeed, the stray particle in the swaging area won't be cooled properly.

CERCA controls the stray particles by microscope on X-ray films and has developed a partnership with film suppliers for a better quality.

### 3.6. Water channel width

The distance between two fuel plates, also known as the water channel width, must remain within tight tolerances. It affects the fuel element power peaking factor and its pressure drop coefficient

CERCA uses numerical assembling machines that allows a great reproducibility of the swaging parameters .

Following the old rule that “doing it right is good, proving it right is better”, electronic control machines are used to measure 100% of the channel width on 100% of our production. Furthermore there is no contact between the captors and the fuel plates while measuring the water gap preventing plates from surface defects.

#### 4. Quality

CERCA is certified ISO 9000 V 2000 by Lloyd register.

Quality system is completely independent from the manufacturing. Furthermore, for human inspections such as the blister test or surface defects on finished plates performed by the inspectors, statistical inspections are carried out by the Quality system in order to check the good quality of the inspections. From that point of view CERCA complies with the Japan quality reference, one of the most rigorous in the world.

It must be pointed out that the statistical inspections make sense only if the production batches are quantitatively and qualitatively representative and must be carried out on a stabilized process with industrial production tools.

Since 2001, CERCA is also ISO 14001 certified for environmental respect.

#### 5. Conclusion

Born in 1957, CERCA has a very long relation with the Research Reactor Community worldwide. The company has a vast knowledge of the safety requirements and how manufacturing can address them.

With more than 20 years in silicide fuel manufacturing and testing, CERCA has gained a very large experience and will have totalised almost 2200  $U_3Si_2$  elements by end of 2003.

A very long way has been walked since the first fuels test assemblies up to the last production standards. At each step of the development, CERCA has been driven by the reliability of the solution we proposed because, as an industrial, we deeply know that there is a gap between R&D tests on few plates and standard production. That explains why all the developments were carried out with industrial tools, on full size plates, with a large number of plates.

The challenge of the enrichment reduction has been solved by a combination of a pragmatic technical approaches and the use of scientific laboratories for a better understanding of metallurgical phenomenon involved in the fuel manufacturing. Of course that has not been done over night and 20 years after the beginning we still make improvements.

The promotion of  $U_3Si_2$  made us progress in all the production and inspection fields and helped us to develop so quickly the manufacturing of UMo fuel.

For this new fuel, CERCA will not change its approach and will still try to develop reliable manufacturing processes and take benefit of 20 years LEU fuel development.

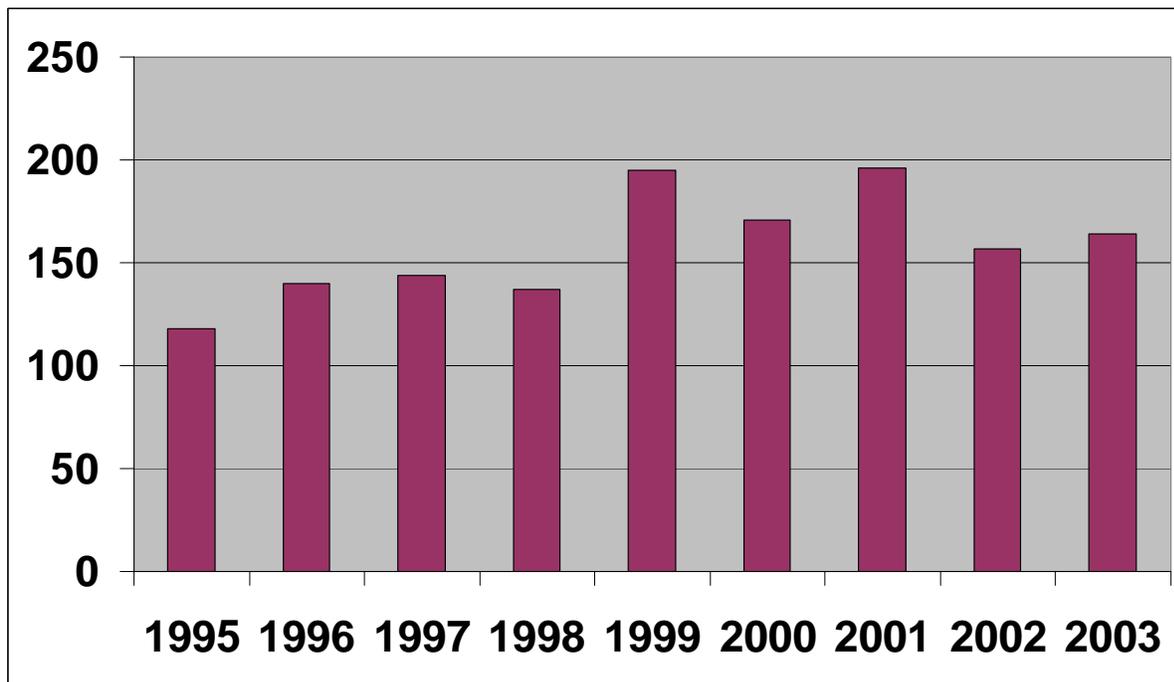
## Attachment 1

### Number of U<sub>3</sub>Si<sub>2</sub> Element Manufactured by CERCA

Before 1994, CERCA manufactured 787 elements.

Since 1995, CERCA delivered 1422 elements in France, Germany, Greece, Netherlands, Japan, Canada, USA, Sweden, Switzerland, Taiwan and Turkey.

The yearly breakdown is as follows:



**Flat Plates**



**Curved Plates**



**Ring-shaped Plates**



Attachment 2

CERCA's Silicide Fuel irradiation programs

Reactor	description	density	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
OSIRIS	2 elements	5.8 g Ut/cm <sup>3</sup>																						
	2 elements (thicker meat)	4.8 g Ut/cm <sup>3</sup>																						
SILOE	5 plates	6 g Ut/cm <sup>3</sup>																						
	5 plates	5.8 g Ut/cm <sup>3</sup>																						
	3 plates (thicker meat)	4.8 g Ut/cm <sup>3</sup>																						
feasibility of U <sub>3</sub> Si <sub>2</sub> plates up to 6 g Ut/cm <sup>3</sup>																								
feasibility of U <sub>3</sub> Si <sub>2</sub> plates with thicker meat																								
R2	1 element	4.8 g Ut/cm <sup>3</sup>																						
HFR	1 element	5.5 g Ut/cm <sup>3</sup>																						
	1 element	4.8 g Ut/cm <sup>3</sup>																						
ORR	20 elements	4.8 g Ut/cm <sup>3</sup>																						
	1 element	4.8 g Ut/cm <sup>3</sup>																						
	1 element	4.8 g Ut/cm <sup>3</sup>																						
OSIRIS	1 element	4.7 g Ut/cm <sup>3</sup>																						
SILOE	1 element	6 g Ut/cm <sup>3</sup>																						
	1 element	5.2 g Ut/cm <sup>3</sup>																						
	1 plate	5.4 g Ut/cm <sup>3</sup>																						
	1 plate	5.2 g Ut/cm <sup>3</sup>																						
	1 plate	3.7 g Ut/cm <sup>3</sup>																						
	1 plate	2 g Ut/cm <sup>3</sup>																						
	2 plates	6 g Ut/cm <sup>3</sup>																						
	2 plates	5.5 g Ut/cm <sup>3</sup>																						
feasibility of U <sub>3</sub> Si plates up to 7 g Ut/cm <sup>3</sup>																								
feasibility of U <sub>3</sub> Si <sub>2</sub> plates up to 5 g Ut/cm <sup>3</sup>																								
start RERTR Program																								



x% average BU reached

USNRC approves pure U<sub>3</sub>Si<sub>2</sub>, 4.8 g Ut/cm<sup>3</sup>