MANUFACTURING AND LICENSING OF A LEAD TEST ASSEMBLY FOR THE R2 REACTOR

JP. DURAND, F. OBADIA, Ch JAROUSSE,
Y. LAVASTRE, M.GRASSE

CERCA

ZI les Bérauds, 26104 Romans, France

J.L. FALGOUX

CERCA

Tour FRAMATOME, 92084 Paris La Defense, France

U. LINDELÖW

Studsvik Nuclear AB, SE-611 82 Nyköping, Sweden

ABSTRACT

In Sweden there is a law stating that a reactor operator must have a final solution for the back-end of the fuel cycle. The R2 reactor, operated by Studsvik Nuclear outside Nyköping in Sweden, has such a solution at hand until May 2006, through the US policy regarding Foreign Research Reactor Spent Nuclear Fuel, FRRSNF. For the period after that date the RERTR program has been working on a new fuel type the UMo fuel. However, this program is lagging behind and the full qualification program will not be finalised in time for the R2 needs. Based on this Studsvik Nuclear decided to go along on its own with an LTA-program aiming for the full qualification of an UMo fuel design in 2005. In 2002, CERCA proposed to develop, manufacture and deliver to the R2 reactor, a new design of fuel element based on the alloy (UMo 7% alloy) as an alternative to the common Low Enriched Uranium silicide element. The development challenge was to keep the fuel element performances as high as possible without going beyond the actual inspection criteria. The specification agreed between STUDSVIK and CERCA showed the possibility to manufacture this high-density fuel element in CERCA's facility in Romans-sur-Isère (France).

We propose to present how the fabrication was conducted and what were the main obtained results and how the licensing of and the introduction into the R2 reactor are planned.

1. Introduction

For a long time, CERCA, as a fuel manufacturer, and Studsvik Nuclear, as a reactor operator with two MTR reactors, R2 and R2-0, have maintained a close relationship regarding LEU fuel development. In fact, after the ORR test with a full core loaded with Silicide fuel, R2 became in 1984 one of the first reactors in the world to activate, and in 1987, to start irradiation and reactor testing several U_3Si_2 fuel assemblies. One of these first U_3Si_2 assemblies was manufactured by CERCA. These first assemblies were manufactured to demonstrate the acceptable range of U densities that was feasible, both from a manufacturing as well as from an operating point of view. The assembly manufactured by CERCA had a U-density of 4.8 gU/cm^3, corresponding to the maximum density licensed by the US NRC in 1988 [1].

Since then, almost one thousand U3Si2 fuel assemblies have been manufactured by CERCA whereof about 500 assemblies have been delivered to the R2 reactor without any reactor operating problems. The R2 fuel assemblies have all had a lower fuel meat density of 3.9 gU/cm^3.

Recently, the U_3Si_2 fuel design for R2 has been slightly changed. In order to increase the cycle length and consequently decrease the cycle cost (and in the same time the amount of spent fuel to manage), the meat density has been changed from 3.9 gU/cm^3 back to the test assembly density of 4.8 gU/cm^3. Due to the Swedish legislation no reactors are allowed to operate if there is no final solution of the back-end of the fuel cycle. In order to have a solution ready before the present solution is running out at the end of the US FRRSNF Acceptance Program in May 2006 Studsvik Nuclear has decided to try to speed up the process. A further reason for this is that the R2 operating license is running out in 2004 and Studsvik Nuclear has to demonstrate in the renewed license application what it has done to handle the backend situation for the next license period, i. e. 10 years.
In parallel, Studsvik Nuclear is still careful to plan reactor activity on a long-term basis and to anticipate technical changes. In 2001, they contacted the French UMo group to offer the R2 facility as a test facility for a prototype UMo fuel assembly. The aim of the R2 team concerning the UMo fuel is to convert the reactor to a fuel type suitable for conditioning/passivisation, (that is, reprocessable). Due to thermohydraulic, neutronic, operating, manufacturing as well as economic and fuel reliability considerations, the R2 management wouldn't accept a fuel loaded to 8 gU/cm^3 which is still the qualification aim of the French UMo Group. As the French group did not want to disperse its development effort, it was decided that the R2 management had to deal directly with CERCA for the manufacture of a 7 gU/cm^3 fuel (which was the preferred option by the reactor operator). Of course it was also stated that the R2 team and the French UMo Group could pool their resources in order to be more effective regarding the analysis.
This paper is divided into two parts. On one hand, CERCA will deal with the UMo R2 fuel manufacturing while on the other hand; Studsvik Nuclear will discuss on how the introduction of the lead test assembly is planned.

2. The R2 UMo fuel manufacturing 2.1

The main characteristics

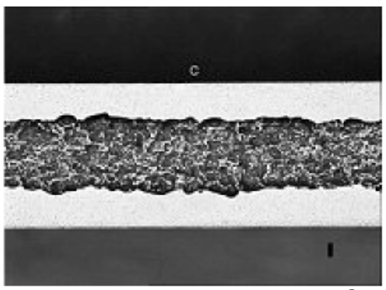
The main characteristics are summarised as follows. A comparison is made between standard U_3Si_2 fuel of the first and second generation and the UMo fuel. As explained previously, R2 has ordered U_3Si_2 standard fuel loaded to 4.8 gU/cm^3 instead of 3.9 gU/cm^3.

Table 1. Characteristics of CERCA fuel manufactured for R2

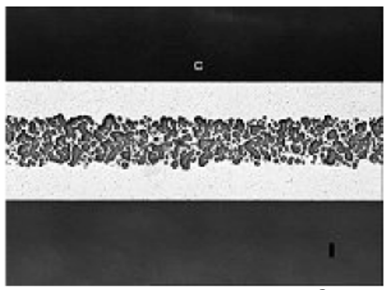
Main characteristics	**U_3Si_2 Fuel first generation**	**U_3Si_2 Fuel second generation**	**UMo Fuel**
Density g Ut / cm^3	3,9	4,8	7,00
Type of Powder	Comminuted	Comminuted	Atomised
U alloy	U_3Si_2	U_3Si_2	U- 7 wt% Mo
Meat length (cm)	59.7	59.7	59,7
Meat width (cm)	6.38	6.38	6.38
Meat thickness (cm)	0.76	0.76	0.51
Cladding thickness	0.38	0.38	0.38
Number of plates	18	18	19
^{235}U / Fuel assembly	410	489	510

It must be pointed out that there is a limited increase in the U 235 content due to the use of dense U Mo compound because in the same time the meat volume has decreased. The design of the fuel element (number of plates, geometry of the meat, geometry of the element, water gap) has been chosen to minimise the thermohydraulic changes, and the geometry of the fuel has been kept as close as possible to the current fuel element. Nevertheless, the geometry configuration of the plate is the same as for the other irradiation planned within the framework of the UMo fuel qualification program. For the same conventional cladding thickness of 0.38 mm, the meat thickness was 0,51 mm. Here below is shown, for comparison purposes, micrographs of U_3Si_2 (4.8 gU/cm^3) and of UMo (7 gU/cm^3) R2 plates and a micrograph of a UMo plate from the French UMo group (8 g U/cm^3)

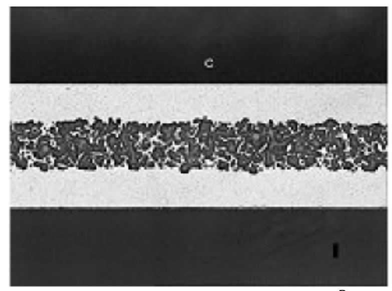
Those pictures emphasise the change in meat thickness, the impact of the density and the powder geometry.



R2 U_3Si_2 4.75g Ut/cm^3



R2 U-7Mo 7g Ut /cm^3



French group U-7Mo 8g/cm^{3}Ut

2.2 The R2 UMo Fuel manufacturing at CERCA

From the plate manufacturing point of view, the main recent developments were applied especially concerning the mixing procedure, the core preparation and the rolling parameters. Then, one can state that the homogeneity was quite good (under the limits of +/- 10 %) and stood easily within the specification limits of +/- 20 %.

Consequently, the mechanical deformation of the materials, during rolling, was smoother leading to a more regular cladding thickness. The minimum cladding thickness measured by destructive test was 0.29 mm (specification 0.25 mm) for the internal plates and 0.48 mm (specification 0.44 mm) for the external ones.

Furthermore, a special care was taken in order to prevent stray particles of UMo that is very sensitive with such high-density fuel.

For more details, see the paper "CERCA UMo Development - Status as of March 2003" by Ch. JAROUSSE from CERCA in Session 2 of this conference.

The manufactured plates were inspected and approved before assembling by Studsvik Nuclear at the fuel factory in Romans in the beginning of December 2002

CERCA strongly recommends its specification approach. As UMo fuel manufacture is completely different from the one for U_3Si_2 and UAlx, the specifications have been focused on the parameters that are sensitive for reactor safety. Those are, the homogeneity of the fuel meat, the bonding of the plate and the cladding thickness. Other parameters were carefully measured. The aim of this approach is to avoid adopting U_3Si_2 specification parameters that were based on UAlx specifications that are, is some cases, out of scope.

Afterwards, the irradiation results will also be used to validate a new UMo specification based on the fabricated plates used in the irradiation test, rather than being reusing old UAlx specifications. From the assembly point of view, as the geometry was very close to the actual U_3Si_2 fuel, no manufacturing problems were noted. Nevertheless, some criticality adaptations were needed due to the fact that UMo assemblies were not described in the factory safety reports. Thanks to the engineering department of CERCA's shareholder, FRAMATOME, the safety case has been very quickly demonstrated, allowing CERCA to manufacture the fuel assembly before the end of 2002 as promised to R2. Owing to CERCA’s background in the fuel manufacturing business, and especially in the UMo fuel development, its industrial approach combined with the support of FRAMATOME, CERCA has been able to manufacture **the first UMo fuel assembly in the world** within a short time period. It must be emphasised that this was possible also thanks to the French UMo group that constantly maintains the same aim and the same schedule since the beginning of the UMo fuel development.

3. Introduction of the UMo Test Assembly into the R2 reactor in Sweden

In order to be allowed to introduce a new fuel type into the reactor, several conditions have to be fulfilled before the safety authorities will give their consent. However, some constraints may be relaxed due to the very nature of a Lead Test Assembly, LTA, program. Some aspects of the new fuel type behaviour are already very well examined by test irradiation of mini fuel plates, full-scale plates and all other development efforts that have been the subject of many RERTR and RRFM conferences. However, the final proof of principle before the full scale introduction of reloads is the irradiation of an LTA assembly into the reactor to demonstrate the behaviour at site, such as the response to the operating and chemical conditions of the reactor.

To minimise the licensing efforts and to facilitate the LTA introduction, Studsvik Nuclear has chosen to try to apply as many features as possible from the earlier fuel experience, while at the same time adhering to the specific requirements of the new fuel type.

The fuel types that mainly have been in use in the R2 reactor are described in Table 2 together with the new UMo LTA assembly.

Table 2. Comparison of the main fuel types in the R2 reactor and the LTA UMo fuel assembly

Assembly type		**LEU 400**	**LEU 490**	**HEU 250**	**UMo 510**
U alloy		U_3Si_2	U_3Si_2	UALx	UMo
No. of fuel plates		18	18	19	19
Plate thickness*	mm	1.90/1.52	1.90/1.52	1.65/1.27	1.65/1.27
Cladding thickness*	mm	0.57/0.38	0.57/0.38	0.57/0.38	0.57/0.38
Fuel meat thickness	mm	0.76	0.76	0.51	0.51
Uranium density	gU/cm^3	3.90	4.80	0.73	7.00
Total Uranium weight	g	2025	2481	269	2580
Total U-235	g	399	490	250	510
Typical enrichment	wt.%	19.75	19.75	93.00	19.75

* Outer and inner plates, respectively

As can be seen from Table 2, there are in reality only two fuel types from a geometric point of view. The two U_3Si_2 LEU assembly types differs only in Uranium density, which means that

their thermohydraulic properties are the same, while they differ from the HEU fuel type.
When Studsvik Nuclear started the conversion from HEU to LEU in the late 1980'ies the LEU design was at the time chosen based on the manufacturing capabilities for the new U_3Si_2 fuel and the need for as small changes as possible of the fuel geometry. The outer fuel dimensions where kept the same and so was the water channel dimensions. Due to the need to increase the U-235 content of the meat and thus the total Uranium content even more, notwithstanding the five-folded increase in the Uranium density, the number of fuel plates was reduced to 18. This resulted in a 5 % reduction of the assembly flow area and a resulting decrease in total coolant flow but an increase in flow velocity. The safety implications of these changes were a decreased margin to flow instability, an increase in power peaking factors. The safety consequences were an increased scram level for minimum core flow. The same considerations were at hand when contemplating an UMo LTA introduction. Even more so as the experience of UMo fuel is smaller compared to the situation when introducing U_3Si_2. Thanks to the large efforts already made in the RERTR program, by the French UMo group and by all other stake holders Studsvik Nuclear considers the UMo fuel development program being mature enough to motivate a full LTA insertion. However, the UMUS failure demonstrates that problems can occur and that a cautious approach is preferable, thus the somewhat lower fuel density. The benefit of this decision was that the UMo LTA could be designed with exactly the same geometrical dimensions as the old HEU 19-plate fuel, as is shown in Table 2. This means a lower surface heat flux and a better cooling capacity than for the LEU 490 assembly. Thus, the T/H safety case for UMo is already demonstrated.

The UMo assembly has a slightly higher U content than the LEU 490 assembly. This is due to the fact that Mo has a somewhat high neutron absorption cross section, higher than the one for Si. With this increase in U content we match very well the unirradiated k-inf of the two fuel types, see Figure 2. There is an almost perfect match between the UMo and the LEU 490 assemblies with the UMo fuel slightly lower. The fuel types are undermoderated, but the LEU-490 assembly has a 5% lower flow area and has thus a higher potential for a reactivity increase if the assembly geometry is changed. This means that also the criticality analysis is contained by the design.

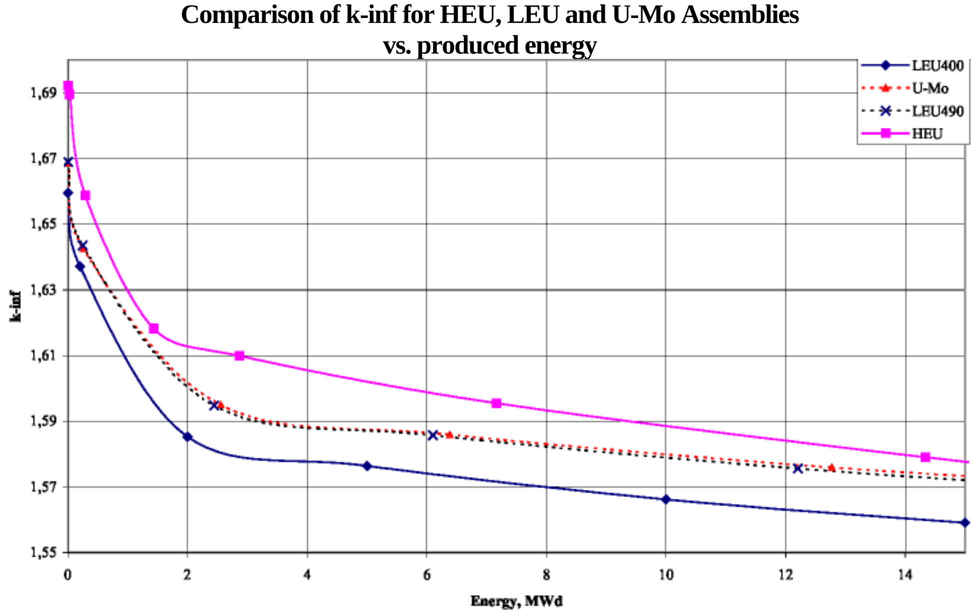


Figure 2. K-inf at low burnup for the R2 fuel types

By maintaining the same fuel cladding as for the U_3Si_2 fuel, there is no reason to expect any different corrosion behaviour with the UMo LTA assembly compared to the well-known and proven LEU experience.

In summary, all aspects of the LTA assembly are already proven and demonstrated in the R2 reactor except for the meat type. The UMo LTA is thus compatible with the other fuel of the core, it is contained by the existing safety analysis and the existing experience of UMo from irradiation experiments demonstrates that the introduction of an LTA UMo assembly into the R2 reactor can be safely done. The LTA assembly will although be cautious introduced into the reactor in low power positions in the first cycles and then slowly be moved to higher demanding positions. It is expected that the assembly will have reached its final burnup of up to 80 % after about 17 operating 3-week periods, that is one and a half-year after the introduction into the reactor which is planned to take place during the spring.

If everything goes as planned, the UMo fuel would then be qualified for reload insertions in the beginning of 2005.

4. References

[1] NUREG 1313 Safety Evaluation Report related to the Evaluation of Low-Enriched Uranium Silicide-Aluminium Dispersion fuel for Use in Non-Power Reactors

[2] Ch. Jarousse, JP.Durand, Y. Lavastre, M. Grasse, "CERCA UMo development -status as of March 2003-", 7th International topical meeting Research Reactor Fuel Management RRFM, Aix en provence, France, This proceeding