

International
Nuclear
Fuel
Cycle
Evaluation

X18507078

INFCE

INFCE/DEP./WG.8/15

Uranium dioxide Caramel fuel - An alternative fuel cycle
for research and test reactors

URANIUM DIOXIDE CARAMEL FUEL

AN ALTERNATIVE FUEL CYCLE
FOR RESEARCH AND TEST REACTORS

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Communication presented at the International Conference on
Nuclear Non-Proliferation and Safeguards

Atomic Industrial Forum
October 22-25, 1978
NEW YORK

The work performed in France on Caramel fuels for research reactors reflects the reality of a program based on non proliferation criteria, as they have already appeared several years ago. This work actually includes the following different aspects :

- identification of the non proliferation criterion defining this action ;
- determination of the economical and technical goals to be reached ;
- realization of research and development studies finalized in a full scale demonstration ;
- transposition to an industrial and commercial level.

1 - Non proliferation criterion

The major part of the existing test and research reactors are fueled with highly enriched uranium, 90 % or 93 % U 235 ; this fuel is a highly sensitive material which can be obtained by an easy chemical process on unirradiated assemblies. Furthermore many reactors are located in places as accessible as universities, polytechnical research centers, medical centers ...

One might consider that such a fuel could be diverted as well by private people (as far as accessible locations are concerned), as by governments for guarded nuclear centers.

To exclude the possibility of an explosive use of the uranium obtained from an elementary chemical process, one needs to use a fuel less enriched than 20 weight percent in U 235.

This is the criterion we have taken into consideration when starting consideration of the use of Caramel fuels in research reactors.

2 - Technical and economical goals

The Caramel fuel's (uranium dioxide zircaloy clad) objective is the class of reactors using flat (or slightly curved) fuel plates in M.T.R. fuel assemblies. This class includes reactors with various programs and consequently

diversified characteristics : reactors for students' training, of very low power no more than 100 kW ; reactors with power limited to 5 MW capable of radioisotope fabrication, of a first stage of test and research, and of operators training ; research and test reactors of higher and higher performances in order to obtain high fluxes :

- for transplutonium production,
- for technological tests in severe environment (flux above 1 MeV up to $3.10^{14} \text{ n cm}^{-2} \text{ s}^{-1}$)
- or for fundamental physics experiments, of high scientific level and very specialized purposes (which might need thermal flux up to $10^{15} \text{ n cm}^{-2} \text{ s}^{-1}$).

At the same time, the fuel elements cover a power density range from zero up to about one MW/cm³. The design of the fuel assemblies based on metallic uranium-aluminium fuel aluminium clad technology has been adapted to these conditions. The fabrication of thin plates, 1.27 mm, in a lattice with narrow water channels (less than 2 mm) has made possible this performance level in very good reliability conditions.

The Caramel fuel goals have been defined by comparison with existing reactors : to keep the same performance level in the same safety and reliability conditions, without substantial increase in the fuel cycle cost. Taking into account the wide range of the reactors in operation, these goals will be reached, totally or partially, by assemblies with various geometries.

The Caramel fuels utilize slightly enriched uranium, because of the high density of the uranium dioxide 10.25 g/cm³. The reactivity control capacity of the core is consistent with the behaviour under irradiation so as to keep the operation cycle lengths with the same values as the present ones ; the average burn-up being limited to about 30 000 Mwd/t, the enrichment is maintained lower than 10 %. This value leads to a strong divergence between :

- 1 - an economic fuel cycle cost requiring a high lattice reactivity obtained with thick plates separated by wide water channels ;

2 - high performances reached only by a great division of the fuel lattice with thin plates and narrow water gaps. The proposed compromise will depend on each reactor characteristics. Nevertheless as the present fabrication limits do not allow the oxide thickness to decrease below 1.5 mm, very high performances cannot be reached.

Finally, it must be pointed out that the evaluation of such an operation of fuel replacement in an existing reactor has to be considered on a case by case basis, even when applied to very similar reactors.

3 - Research and development program

The research and development studies have been determined by the above considerations. They are the following :

- fabrication from 4 mm to 1.5 mm oxide thickness
- burn-up up to 50.000 MWd/t
- specific power up to 4000 W/cm³ oxide

But the Caramel program for research reactors is only one aspect of a larger Caramel fuel program, developed for low and medium power plants .

3.1 - General environment of the Caramel program

At the very beginning, the Caramel fuel has been developed for the need of low power reactors. Severe specifications have been assigned as far as power cycling, cycle length, and primary water radioactivity are concerned. The resulting fuel is shown in fig. 1.

The active part of the fuel is made of small pieces of sintered uranium dioxide whose density is 10.25 g/cm³ and approximate dimensions are 0.4 x 2 x 2 cm. These parallelipeds are surrounded by small zircaloy pieces, and put on a zircaloy plate ; the whole lot is then framed and covered with a second zircaloy plate. All this assembly is welded, producing a fuel plate in which the uranium oxide is compartmented.

Starting from this work, specific studies have been developed for the specific needs of research reactors.

3.2 - Fabrication development

The search for high specific power has led to developing thinner and thinner pellets, from 4 mm to 1.5 mm.

The implementation of zircaloy pieces adapted to such a small thickness has been realized. The assembly of the fuel plates in the fuel element has been realized so that good tolerances can be kept on the water gap in order to avoid a loss of the cooling characteristics.

3.3 - Irradiation behaviour qualification

A study of the Caramel behaviour under irradiation has been undertaken. It started with individual Caramel, and followed successfully with fuel assemblies, irradiated in the reactor Osiris within a significant environment :

- maximal specific power higher than 3000 W/cm²
- maximal burn up about 30 000 MWd/t

Finally safety experiments have led to creation of deliberate defects such as clad failure in order to test the irradiation behaviour to study its evolution. The results are positive, the kinetics being rather slow.

3.4 - Thermohydraulics studies

In order to measure the pressure drops, out of pile experiments had to be performed because of the local perturbations created by the grid of the zircaloy pieces on the fuel plate. Due to this specific point thermohydraulics tests have been performed with heated test elements, to estimate the pressure drops in double phase flow and then the maximal heat fluxes allowable in operation.

3.5 - Core operation

For each reactor, specific studies are required to determine :

- the exact geometry of the fuel assembly; particularly plate and water gap thickness
- the cycle length and the enrichment
- the core configuration and the associated reactivity control
- the physics and thermohydraulics performances ...

All these studies lead to a partial revision of the safety report.

The general success of these development works enables us to start a full scale demonstration, namely the complete loading of the reactor Osiris with Caramel assemblies. Our aim is to prove statistically the Caramel fuel capability of operating in the required conditions of specific power and burn-up (4000 W/cm², 50 000 Mwd/t), with a good reliability ; from this point of view the reference is that of the UAl fuel : no clad failure should occur.

In order to obtain these test conditions, it has been necessary to adjust some of the reactor characteristics :

- modification of the primary circuit with the replacement of the primary pumps to increase the coolant flow by 30 % from 4300 m³/h up to 5700 m³/h ;
- equipping of the cladding failure detection circuit with safety devices shutting down automatically the absorbing rods.

These changes led to new operating conditions which had to be evaluated, and kept consistent with the existing components of the reactor, then gathered in a safety report revision :

- the fuel enrichment has been fixed at 7 % U 235 to start with
- the core volume has been increased from 39 to 45 assemblies
- the power was kept constant at 70 MW
- the fast and thermal fluxes available have been decreased by about 20 %.

Fig. 2 shows the planning of the realization. The starting up of the reactor with the Caramel core should take place in the early Spring 1979.

4 - Transposition to industrial and commercial level

First of all, the reaching of the industrial and commercial stage implies the technical success of the Osiris demonstration. This success is partially achieved as far as the assembly fabrication is concerned ; the production capacities of the CEA and the outside manufacturers can be a basis for an industrial unit. The evaluation of the irradiation behaviour needs a six months operation period, which could be achieved by the Autumn of 1979.

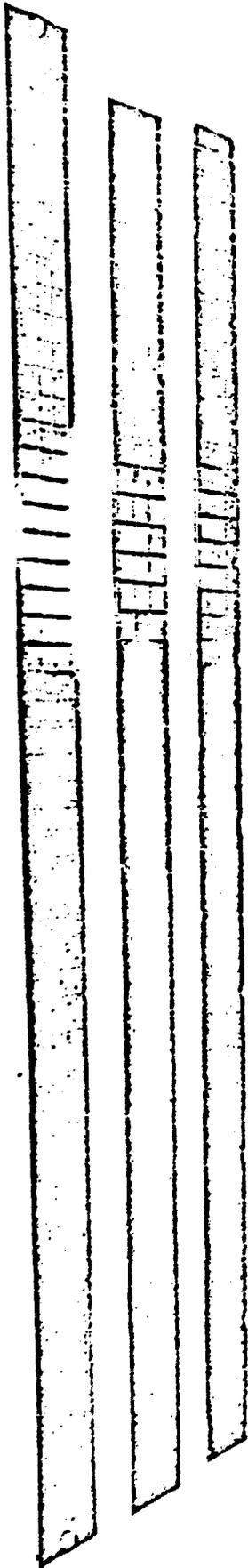
At this stage, it must be pointed out that we are testing the fuel in hard conditions, connected to the high performance reactors. In any case, for all reactors, the replacement of the existing fuel by the caramel fuel must be carefully considered on a case by case basis, after an accurate study. If there is no doubt that the Caramel fuel can be used in very low and low power reactors, the possibility of this substitution in more high-powered reactors, will depend on their flexibility and adaptability. Of course in case of new projects, the range of reactors capable of using Caramel fuel would be enlarged.

From an economical viewpoint, the fabrication cost evaluation is not easy, since the simple running of prototype operation is not sufficiently representative. It could only roughly show that the fabrication cost, as part of the total cycle cost, is higher than the fabrication cost of the present UAl fuel, 93 % enriched, without change in the order of magnitude.

Conclusion

The full change of a fuel cycle connected with non proliferation goals appears to be a very wide program with political, technical and industrial implications.

The development of the Caramel fuel for research reactors, set up by the CEA, is an illustration of these different aspects. Its final resolution is expected in about a year.



CARANIEL FUEL PLATES

FIGURE 1

| OSIRIS PLANNING | May 1978 | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Janv. 1979 | Feb. | March | April |
|---|--------------------------|------|-----------------------|------|--------------------------|---------|--------|--------------------------------------|------------|------|-------|-------|
| 1 - Fuel tests . irradiation . thermohydraulics tests | | | | | | | | | | | | |
| 2 - Mock-up ISIS - Neutronics | Assemblies Fabrication | | | | | loading | - Test | - Report | | | | |
| 3 - Works on OSIRIS reactor | | | shut- ting down | | Works on primary circuit | | | | | | | |
| 4 - Secondary works | | | | | | | | | | | | |
| 5 - Safety analysis | Analysis - Safety report | | | | | | | Examination by regulatory commission | | | | |
| 6 - Fuel element fabrication and delivery | | | | | | | | | | | | |
| 7 - OSIRIS tests without neutrons | | | | | | | | | | | | |
| 8 - Fuel loading - Starting up | | | | | | | | | | | | |

Figure 2