Safety assessments relating to the use of new fuels in research reactors: application to the case of FRM II reactor fuel

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Abstract: After giving a brief reminder of the procedure applied in France for the licensing of the use of a new fuel type or design in a research reactor, we outline the main safety aspects associated with such a modification. Finally, by way of an example, we focus on the safety assessment relating to the IRIS irradiation device used in SILOE reactor, in particular for the qualification of the fuel dedicated to FRM II reactor of the Technical University of Munich. This qualification was carried out on a U_3Si_2 fuel plate enriched to about 90 % in weight of ^{235}U and containing 1.5 g of uranium per cm^3. The evaluation performed by the IPSN for GRS did not call into question the choice of U_3Si_2 fuel plates for the FRM-II reactor.

1. INTRODUCTION

In France, the technical requirements sent by the safety authority (Nuclear Installation Safety Directorate - DSIN) to the operators of research reactors stipulate that the installations have to comply with their safety reports and they describe the licensing procedures applicable to the modifications of the installations and to the experiments. Generally speaking, the content of the safety report has to be modified whenever a new type or design of fuel is to be used in the reactor core and because of this, the operator applies to the DSIN for a licence on the basis of a detailed safety analysis.

The use of a new fuel type or design in research reactors implies the realisation of a qualification experimental programme in order to study the behaviour of the fuel under irradiation. Such a qualification programme was carried out for the FRM II reactor fuel in the IRIS device which was irradiated in the SILOE reactor. The IPSN has assessed the experimental conditions of the qualification irradiations for the benefit of the French safety authority and has also assessed their results for GRS. The conclusions of these safety assesments are presented below in paragraphs 3 and 4.

2. LICENSING PROCESS

2.1. French practice

Each modification with consequences for safety, such as the use of a new fuel, has to be approved by the safety authority. In the case of major modifications, the DSIN considers whether a new licensing procedure and a new decree should be asked for or not. Prior to this, the operator has to send the DSIN a licence application along with the corresponding documents describing the planned modifications, the qualification programme, the commissioning test programme and the safety analysis. These documents are then examined by the IPSN, for the benefit of the safety authority. The assessment work involves extensive discussions with the applicant particularly as regards the safety arrangements. It terminates with an IPSN document equivalent to an expert opinion, followed by the DSIN decision.

This procedure was applied when the OSIRIS and ISIS cores were being converted from high enriched uranium to low enriched Caramel fuel (in 1980 and 1979) and from this fuel to silicide fuel (in 1995 - 1996 and 1998).

When a large number of modifications have to be made to an installation or when new safety problems arise, the DSIN usually asks that the corresponding reports be examined by the “permanent group” of experts in charge of nuclear reactors. In this case, the IPSN makes the analyses and drafts a report containing proposed recommendations which are presented and discussed at the permanent group meeting, attended by the applicant. After this meeting, the president sends the group’s conclusions and recommendations to the DSIN, which then takes its decision.

For fuel design and manufacturing related to safety, general requirements were specified by the safety autority in a document issued in 1978. These requirements are primarily devoted toward ensuring that fuel design limits and safety criteria are not exceeded. They deal with thermal, mechanical, neutronics and thermal-hydraulic behaviour of the fuel assembly in the different anticipated conditions.

2.2. Main safety issues relating to the use of new fuel

Prior to the use of a new fuel type (i.e. silicide fuel, oxide, metal alloy fuel, ...) or the use of a new fuel design, either in a new reactor or for the conversion of an existing reactor, the behaviour of the fuel has to be verified by means of qualification tests covering its operating conditions. The use of a new fuel in a research reactor should be dealt with in detailed safety studies.

The safety reports submitted by the applicant should contain mainly:

– the characteristics of the new fuel and specifications for its manufacture, the quality assurance system and details of fuel qualification,

– the neutronic and thermal-hydraulic calculations relating to the core in normal and transient conditions,

– in the case of the conversion of an existing reactor, detailed analysis of the effect of the proposed modifications, in particular on neutronic and thermal-hydraulic parameters of the core as well as the radiological consequences of the accidents identified in the safety analysis report,

– the test programme, including pre-operational tests and initial criticality, low-power and power build-up tests which are needed to check the neutronic and thermal-hydraulic calculations and to assure that adequate safety margins are maintained. The use of fuel elements instrumented with thermocouples allows an experimental validation of these calculations.

With regard to this, the safety studies and the test programme should demonstrate that the use of the new fuel is in compliance with the specified neutronic and thermal-hydraulic safety criteria. They should also show that the radiological consequences of the design basis accidents do not call into question the conclusions of the analyses presented in the safety report.

3. SAFETY ASSESSMENTS OF IRIS IRRADIATION TESTS PERFORMED IN SILOE FOR THE QUALIFICATION OF FRM II REACTOR FUEL

3.1. Presentation of the IRIS device

The IRIS device is intended to qualify various types of fuel plates for research reactors. It includes an in pile part consisting of a fuel plate irradiation box made of aluminium alloy and a part consisting of a plate thickness measurement bench and associated control and acquisition rack. The figure 1 represents the irradiation box.

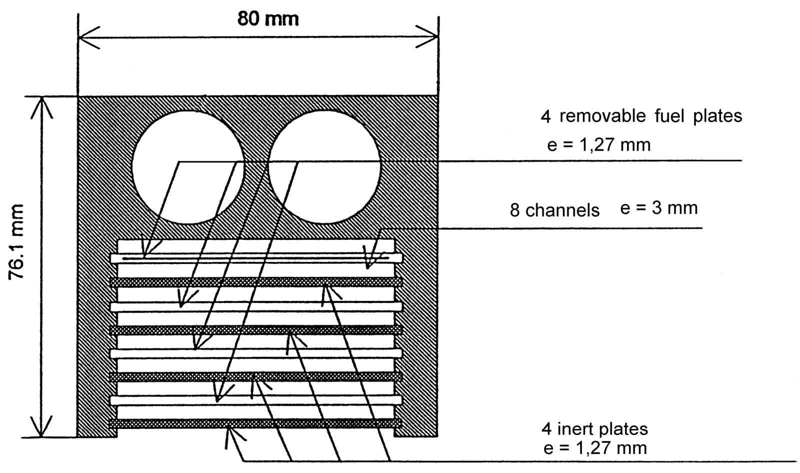

Figure 1 - IRIS irradiation box

This device was used in the SILOE reactor since 1982 to qualify various types of silicide fuels and fuels based on uranium and aluminium alloy. The maximum surface power density authorized for the experimental fuel plates in SILOE was initially 150 W/cm^2, and has been increased to 175 W/cm^2.

After the definitive shutdown of the SILOE reactor (35 MW) at the end of 1997, a new device was built for the OSIRIS reactor (70 MW). It enables qualification tests to be carried out on the fuel at a higher power level. It was used for further qualification tests to those carried out at SILOE for the FRM-II reactor silicide fuel, and is currently used for the qualification of UMo fuel planned for the future RJH reactor.

The IRIS device is cooled by the water of the reactor core cooling system. The width of the cooling channel between the plates is 3 mm. The device occupied, on the perimeter of the core, a location equivalent to that of a standard fuel element. The fuel plates to be tested were removable and the inert plates were crimped in the device. The mid-height plane of the plates corresponded to the mid-height plane of the core.

There was no alarm or automatic shutdown of the reactor directly associated with the IRIS irradiation device. During the irradiations, the experimental fuel plates placed in the irradiation device received the same surveillance as the fuel elements of the reactor core, in particular for cladding failure detection. Any failure of the cladding of an experimental fuel plate during the irradiation would be detected by the core fuel integrity surveillance system, based on the detection of delayed neutrons, and would lead to an automatic reactor shutdown if the maximum counting threshold were exceeded.

After each irradiation cycle, dimensionnal measurements (thickness, cooling width, blister, ...) and visual inspection were performed on the tested fuel plate according to the defined surveillance programme.

3.2. Safety reports submitted by the operator of the SILOE reactor

The safety reports sent to the DSIN by the operator of the SILOE reactor presented, in particular:

- thermohydraulic studies intended to determine the maximum power allowable for the experimental plates,
- programme of surveillance and tests planned before the first qualification irradiation of fuels,
- studies of the radiological risks associated with the use of the IRIS device.

The operator applied to the experimental fuel the same safety requirements as to the core fuel. In particular, it was required that the experimental plates irradiated in the IRIS device comply with the thermohydraulic safety criteria applied to the core. These criteria are the following:

- no nucleate boiling under nominal power and flow conditions, with the worst-case uncertainties cumulated at the hot point,
- no flow redistribution and critical heat flux not reached in operation at the limits of the power and flow safety thresholds, with the worst-case uncertainties cumulated at the hot point.

The computer code SILCOR was used by the operator to determine the thermohydraulic conditions in the reactor core. Results of calculations have shown that:

- the heat flux at the hot point leading to nucleate boiling under the nominal reactor operating conditions is 190 W/cm^2,

- a flow redistribution could occur for a heat flux at the hot point of 212 W/cm^2.

It should be noted that the use of SPND (Self Powered Neutron Detectors) in the IRIS device allowed an important reduction of the uncertainties associated with the calculations.

In the case of the qualification irradiation of the fuel plate for the FRM-II reactor, the maximum surface thermal power density at the hot point was limited to 175 W/cm^2, leaving a margin of approximately 8% with respect to nucleate boiling.

The assessments carried out by the IPSN have shown that the experimental conditions of IRIS irradiations in SILOE reactor were acceptable from the safety point of view.

QUALIFICATION EVALUATION BY THE IPSN FOR THE FRM-II REACTOR FUEL

4.1. Background information

The new research reactor for the Technical University of Munich (FRM-II reactor, P=20 MW) will use a silicide fuel enriched to about 90% in weight of ^{235}U (densities of 1.5 g/cm^3 and 3 g/cm^3). In 1997, 10 irradiation test cycles have been carried out in the SILOE reactor with a U_3Si_2 fuel plate enriched to 90% with a density of 1.5 g/cm^3. The main goal of this irradiation was to qualify the thermal-mechanical behaviour of this type of fuel. The burn-up level attained was 1.2×10^{22} fissions/cm^3 (corresponding to the consumption of 55.8% of the initial mass of ^{235}U).

The IPSN has assessed for the benefit of the German safety organization GRS (in the framework of a contract signed in 1997) the results of the above-mentioned irradiation. This assessment was based on the report submitted by the future operator of the reactor giving the results obtained after the irradiation test cycles of the U_3Si_2 fuel plate and the post-irradiation examinations carried out, as well as a brief analysis of them.
The assessment carried out by the IPSN was focused on the only one fuel plate with a density of 1.5 g/cm^3, which is representative regarding the uranium density of part of the fuel to be loaded into the FRM-II reactor. The fuel assembly of FRM-II reactor will also contain U_3Si_2 fuel with a density of 3 g/cm^3, on which irradiation tests were performed in the OSIRIS reactor.

4.2. Results of the assessments performed by the IPSN

These assessments performed by the IPSN only related to the thermal-mechanical behaviour of the fuel with no allowance for the cooling conditions which will be encountered when it is used in the reactor. The fact that these conditions are very important for correct behaviour of the fuel means that particular attention should be paid to the validity of the neutronic and thermal-hydraulic calculations relating to the core in normal and transient conditions and to the representativeness of the tests carried out in this area. The use, when it is possible, of a fuel element instrumented with thermocouples allows experimental validation of these calculations (this practice was applied in France for some pool-type research reactors). The final aim is to demonstrate that the neutronic and thermal-hydraulic safety criteria corresponding to the new fuel are fulfilled with adequate safety margins.

In the light of the above, the results of the assessments carried out by the IPSN made it possible to verify mainly :

- the validity of the measurements and analyses made as regards the burn-up (based on gamma spectrometry) and the oxide layer thickness, making allowance for various uncertainties,

- the correct behaviour of the fuel plate in the presence of the swelling phenomenon, which did not lead to any loss of the integrity of the fuel cladding. In particular, it was possible to demonstrate the validity of the linear relationship between swelling and burn-up, and the consistency with results taken from the literature for plates enriched to a lower extent has been verified,

- the swelling measured (around 50 µm after subtracting the oxide layer thickness) is consistent with the predictions (54 µm) for a fission density of 1.2×10^{22} fissions/cm^3, making allowance for uncertainties.

The results obtained from the irradiation campaigns carried out in the SILOE reactor show that the behaviour of the tested fuel type is in accordance with the one given in the literature for other fuel types and designs. They indicate that the use of this fuel type for the FRM-II reactor is acceptable.

5. CONCLUSION

The French methodology for the licensing of the use of new fuels in research reactors, which is based on well defined criteria and intensive interaction with the applicants, was applied without any difficulty to the case of FRM II reactor fuel qualification.

The evaluations performed by the IPSN indicated that the experimental conditions for the IRIS device irradiations in the SILOE reactor are acceptable from the safety point of view. The assessment work carried out for GRS, which was a good example of co-operation between the two safety organizations, did not call into question the choice of the fuel type (U_3Si_2) planned for the FRM-II reactor.