AUTHORISATION TO IRRADIATE TWO U_3Si_2 PROTOTYPE FUEL ELEMENTS IN THE RA-3 RESEARCH REACTOR

Waldman Ricardo
NUCLEAR REGULATORY AUTHORITY - ARGENTINA

24th International Meeting on Reduced Enrichment for Research and Test Reactors, RERTR-2002, Bariloche, Argentina.

Abstract

The Argentine RA-3 research reactor (with U_3O_8-Al LEU MTR fuel type elements and in the process to increase its power from 5 MW to 10 MW since October 2002) is operated by the National Atomic Energy Commission (CNEA).

After evaluating the safety studies submitted by CNEA, the Argentine Nuclear Regulatory Authority (ARN) authorised the irradiation of two U_3Si_2-Al prototype fuel elements named P-06 and P-07, in the RA-3, in September 2000 and September 2001 respectively. These irradiations are part of the qualification programme as manufacturer (CNEA).

This report contains a brief description of the regulatory process the ARN carries out in order to approve major modifications or new experiments in research reactors; it also summarises conditions in force for operable core configurations, considers a definition of prototype fuel element and lists the main characteristics of the RA-3 research reactor. Then, the process involved in the authorisation to irradiate the prototypes P-06 and P-07 is particularly analysed.

Finally, and in case an authorisation to irradiate a prototype fuel element of a non-qualified material (such as U-Mo) in the RA-3 is requested, the regulatory aspects that should be taken into consideration are analysed. This would be the first time a question of this nature is submitted to the ARN.

Authorisation of Major Modifications and New Experiments

The needs of carrying out a major reactor modification or a new experiment can arise from a variety of reasons. Ageing, improvement of the research reactor safety or loading of already qualified fuel elements are examples of major modifications; increase of the reactor utilisation or irradiation of prototype fuel elements are examples of new experiments.

In the case of a modification or a new experiment with significant consequences for safety (i.e. changes in safety or safety-related systems, in operational limits and conditions or the appearance of new accidental scenarios), it must be analysed by a Safety Committee of the Operating Organisation and approved by the ARN.

When this happens, the corresponding general safety aspects are discussed between the Operating Organisation and the ARN at an early stage. The Operating Organisation must submit for evaluation the corresponding documents describing the planned modification or new experiment, its justification, the safety studies, the commissioning programme and, depending on the case, a license application. Further on, the Safety Analysis Report of the installation must be updated.

Conditions for an Operable Core

AR Standards are not prescriptive but of compliance with safety objectives. The way such objectives are achieved is based on the adequate engineering judgement, on the operator's qualification and on appropriate way of making decisions of the organisation.

In order to prevent accidental situations or fuel element failures, Argentine Guides recommend conditions related to neutronic, thermal-hydraulic, chemical and irradiation aspects during the operation of a research reactor.

Some objectives and conditions (from now on referred to as "conditions for an operable core") are:

- limits for the shutdown margin for any shutdown system must be adopted. The shutdown margin should be greater than 3000 pcm for any operational situation and at least 1000 pcm with all its safety rods inserted except the one having the highest reactivity worth, which is assumed completely withdrawn (stuck rod criterion),
- a limit for the reactivity excess must be adopted. The ratio between shutdown margin and reactivity excess should be higher than 0.5 for any operational situation,
- limits for the reactivity associated to experiments must be adopted (200 pcm with a rate of 20 pcm/s for any removable experiment during operation and 1200 pcm for any fixed experiment during operation are recommended values),
- in any hydraulic mode of operation, under steady state conditions, local boiling is not allowed in the primary coolant system. Conservative values for the power peaking factor and inlet temperature must be considered for calculations (3.5 and 45 °C are recommended values for the RA-3),
- maximum fuel element burn-up must be adopted (50% in ^{235}U contents in U_3O_8 fuel elements is recommended).
- the fuel element cladding must be protected from corrosion. For such purpose during operation, a maximum cladding temperature, a maximum water conductivity and an adequate pH range must be considered (for the RA-3, 110°C for aluminium cladding, 1 μS/cm for water conductivity and 5 to 7 for pH are recommended values),

Considerations for the definition of a Prototype Fuel Element

Throughout this document, it will be considered that a fuel element is a *prototype* when according to ARN judgement, one of the following conditions is fulfilled:

- the meat material has not been qualified,
- the manufacturer has not been qualified,
- a significant design modification of the fuel element is proposed (for example an important increase in the ^{235}U contents, in the coolant channels width or in the plate thickness).

As concerns meat material, it is qualified when the process implying irradiation and testing of mini-plates, plates and prototype fuel elements is completed. In general, such process is carried out in the frame of an international programme, in which participants share the results obtained.

For the particular case of fuel elements using U_3Si_2, the ARN considers that this material is qualified up to a density of 4.8 g/cm^3 in U, and adopts the whole set of recommendations contained in the NUREG-1313 document for the processing of this material.

The conclusion about the qualification of the U_3Si_2 is arrived after evaluating the process carried out in the frame of the RERTR programme, as well as the performance of this material in the research reactors operating at present. It was also taken into account that it is the meat material most frequently (and satisfactorily) used in reactors converted to low enrichment, and proposed for new research reactors.

CNEA manufactures fuel elements usually loaded in critical assemblies and research reactors in Argentina. At first, it manufactured U-Al, (U-Al)-Al fuel elements, and at present it produces MTR type LEU U_3O_8-Al fuel elements. Algeria, Egypt, Iran and Peru also use fuel elements fabricated by CNEA for their reactors.

In order to qualify as fuel element manufacturer for those materials, CNEA had been following the before mentioned normal procedure of producing and irradiating mini-plates, plates and prototype fuel elements, through its participation in the RERTR programme. A prototype U_3O_8-Al fuel element was irradiated in the RA-3 research reactor. In some cases, higher burn-ups than those recommended were achieved and all the irradiations were carried out successfully.

At present, CNEA is following the programme to qualify as manufacturer of U_3Si_2-Al and U-Mo fuel elements. Irradiation of prototypes P-06 and P-07 of U_3Si_2-Al, in the RA-3 research reactor, is part of such qualification process.

Main Safety Issues Related to the Irradiation of Prototype Fuel Elements

In Argentina, safety studies to be issued by the Operating Organisation to irradiate prototype fuel elements in a research reactor must contain:

- information of the meat material qualification, or qualification programme including information about the material behaviour under irradiation in steady state or accidental conditions,
- information of the manufacturer qualification including characteristics, technical specifications and specifications for the manufacturing process,
- the quality assurance system description,
- if necessary, additional hydraulic and mechanical results from tests,
- neutronic and thermal-hydraulic studies with the prototypes loaded into the core in different locations (fulfilment of conditions for an operable core),
- re-evaluation of accidental conditions with prototype fuel elements loaded into the core in different locations,
- adoption and justification of operational limits and conditions for each prototype during irradiation (i.e. maximum burn-up and maximum heat flux),

- surveillance programme applied to prototypes during the irradiation process as part of an early alert system designed to detect fuel element failure,
- description of the actions to be taken in case of detection of any prototype failure. Withdrawal from the reactor must be considered, as well as isolation and further management.

Comments about the Authorisation to Convert a Core

The ARN considers that in a research reactor the substitution of standard fuel elements by others that are already qualified, is a major modification to the installation.

Under such condition, the Operating Organisation must submit to the ARN, the corresponding safety studies for its authorisation. The documents must demonstrate, as was mentioned before, that the operable core conditions are fulfilled for any configuration proposed; they must also contain an analysis of the corresponding transient and accidental situations, proposed and justified operational limits and conditions for the already qualified fuel elements, and information about the surveillance programme to be applied to them.

It could be mentioned that when a significant modification to the RA-3 was carried out in 1990, due to ageing and to low enrichment conversion (substituting (U-Al)-Al by U_3O_8-Al in the fuel elements), the ARN issued a new Operation Licence.

Brief Description of the RA-3 Research Reactor

The RA-3 is a pool type research reactor operated by CNEA since 1967. It is located at the Ezeiza Atomic Centre, at 30 km from the city of Buenos Aires. Its initial operation power was 5 MW and is in the process to increase it to 10 MW since October 2002.

It has MTR type fuel elements and the meat is U_3O_8-Al 19.75% enriched in the ^{235}U isotope. The standard fuel elements have two outer and 17 inner plates, and the control fuel elements have only 14 inner plates. Each plate has an initial nominal mass of 15.26 g of ^{235}U. Each control fuel element can locate a control and safety rod (a fork-type set of two absorbing plates moving together) with Ag-In-Cd (80%-15%-5%) as absorbing material.

A typical core configuration comprises 21 standard fuel elements, 4 control fuel elements and it is completely surrounded by graphite blocks as reflector. The shutdown system consists of four safety rods.

The coolant flows in downward direction and at 10 MW the primary cooling system will consist of three primary coolant pumps and three heat exchangers. The water in the secondary system is cooled in cooling towers. There are siphon-breakers, delay tanks and flap-valves as safety engineering features.

Each fuel element has a nozzle which enables its location in any of the 30 positions of an Al grid. The fuel element outer plates are cooled by the flow passing through small holes in the grid.

Process to authorise the irradiation of the P-06 and P-07 silicide fuel elements

At the beginning of 2000, CNEA informed to ARN its decision to irradiate two U_3Si_2-Al prototype fuel elements (P-06 and P-07), fabricated by CNEA as part of its qualifying process as manufacturer, in the RA-3 research reactor. The main characteristics of the prototypes were the following:

Table I – Characteristics of P-06 and P-07 U_3Si_2 prototype fuel elements

Identification	P-06	P-07
^{235}U enrichment	19.78%	19.78%
Number of plates per fuel element	19	20
Plate cladding	Al	Al
Plate dimensions (mm)		
Overall length (external)	735	735
Overall length (internal)	655	665
Meat length	619	615
Overall width	70.8	70.5
Meat width	60.0	60.0
Total thickness (external)	1.50	1.50
Total thickness (internal)	1.50	1.35
Meat thickness	0.51	0.61
Channel thickness between two plates	2.70	2.60
Density of U (g/cm^3)	4.8	4.8
Weight of ^{235}U per plate (g)	17.9837	21.371

During the early discussion with CNEA, the ARN established that the P-06 should start being irradiated first, and after verifying that the behaviour under irradiation was initiated as foreseen, the P-07 would be loaded for its irradiation. As no significant changes in fuel element geometry design were found, it was not considered necessary to require specific hydraulic or mechanical tests.

The following conditions were required to CNEA by the ARN to authorise the irradiation of the prototypes:

- fulfilment of the recommendations mentioned in the NUREG-1313 document related to the processing of U_3Si_2 material,
- an audit of the quality system for the manufacturing process,
- fulfilment of operable core conditions. Safety studies must take into account uncertainties in fuel elements geometry, nuclear parameters, correlations, models and so on,
- re-evaluation of accidental conditions with the prototype fuels loaded into the core (flow redistribution, LOFA, LOCA, fuel element channels blockage and reactivity insertion accidents),

- Application of the fuel element surveillance programme to the prototype fuel elements consisting of a visual inspection and an analysis of water samples coming from them (sipping), in order to detect fission products (early alert system of fuel elements failure).
- Evaluation of prototype fuel elements irradiation as a new experiment, by the safety committee,

After evaluating the corresponding safety studies (see below), authorisation to start the irradiation of the P-06 (September 2000) and P-07 (September 2001) was issued by the ARN.

In order to authorise the RA-3 reactor operation at 10 MW, the ARN analysed the related documentation including safety studies for the irradiation of P-06 and P-07 at this higher power level.

Conclusion of the Safety Assessment Related to Prototype Irradiation

The documents and safety studies submitted by CNEA to start irradiation of the P-06 showed that the conditions required for a new experiment were fulfilled. Nevertheless, in view that it was a prototype with greater contents of ^{235}U than standard U_3O_8 fuel elements, the following additional condition was required:

- To start the P0-6 irradiation in a peripheral position of the RA-3 core, and to move it to an inner position when its burn-up was higher than 14.5% in ^{235}U (for this condition, ^{235}U mass per plate is similar to that of a fresh U_3O_8-Al fuel plate).

In March 2001 the 14.5% burn-up condition was achieved and the P-06 was allowed to move to an inner position. Since then, from the point of view of fuel management strategy, it was considered as a standard U_3O_8 fuel element.

Due to the fact that the irradiation of the P-06 went on as foreseen and that some uncertainties mentioned in the safety studies were removed with new experimental data, no additional requirements were considered necessary in order to start the P-07 irradiation.

Comments About Irradiation of a Prototype with a non Qualified Material in the RA-3

It is possible that CNEA will be interested in irradiating a U-Mo prototype in the RA-3, as part of the qualification process for such material, which is being carried out in the frame of the RERTR programme.

If such were the case, it would be the first time that the ARN would be involved in authorising the irradiation of a prototype fuel element manufactured with a non qualified material in an Argentine research reactor.

The stages to be followed by CNEA in order to obtain such authorisation arise from what was described above for new experiments.

CNEA should ask for such authorisation, submitting to ARN the documentation required for its evaluation:

For the material

- results and recommendations arising from the material qualification programme,

- recommendations arising from the analysis of failures occurred during the irradiation of mini-plates, plates and/or prototype fuel elements having U-Mo.

For the manufacturer

- programme to qualify manufacturing processes,
- results of the audit to the quality system,
- safety studies demonstrating that it is possible to irradiate a prototype fuel element or a device having U-Mo fuel plates in an adequate RA-3 reactor configuration, (i.e. that the irradiation will take place in compliance with the conditions for an operable core and with proposed and justified operational limits and conditions, in such a way that no fuel element failure is expected),
- safety studies in transient and accidental situations,
- a proposal to isolate the experimental device or prototype and adequately cool it in case it failed during irradiation.

Besides, the ARN can require ad-hoc conditions such as:

- specific hydraulic and mechanical tests,
- initial irradiation of the device or prototype in a peripheral location,
- a specific surveillance programme during its irradiation in the reactor,
- on-site measurements to verify the correct width of cooling channels,
- instrumentation of a plate,
- post-irradiation specific measurements.

Summary and conclusions

A request of authorisation to irradiate two prototype U_3Si_2 fuel elements in the RA-3 was submitted by CNEA to ARN. Such request demanded a process of evaluation of safety documentation ending in the required authorisation.

At this time, two prototype fuel elements, P-06 and P-07, are being irradiated in the RA-3 research reactor as part of the qualifying programme of CNEA as manufacturer of U_3Si_2 fuel elements. The irradiation started at 5 MW, it goes on since October 2002 at 8 MW and will continue at 10 MW until 55 % of ^{235}U burn-up is achieved. Up to now, the prototypes under irradiation behave as foreseen.

In case that CNEA is interested in irradiating a U-Mo prototype in the RA-3 reactor, as part of the qualification process for such material, being carried out in the frame of the RERTR programme, CNEA must fulfil the conditions established for new experiments as well as ad-hoc conditions that can require the ARN.