RULES FOR THE LICENSING OF NEW EXPERIMENTS IN BR2 APPLICATION TO THE TEST IRRADIATION OF NEW MTR-FUELS

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ABSTRACT

New type of MTR fuel elements are being developed and require a qualification before routine operation could be authorised. During the test irradiation the new fuel elements are considered as experimental devices and their irradiation is allowed according to the procedures for experiments. Authorisation is based on the advice of a consultative committee on experiments. This procedure is valid as long as the irradiation is covered by the actual reactor license. An additional license, or an amendment, is only required if due to the experiment the risk for the workers or the environment is augmented in a significant way. A few experimental fuel plates loaded in the primary loop of the reactor will not increase this risk. The source term for potential radioactive releases remains more or less the same. The probability for an accident can be limited by restricting the heat flux and surface temperature.

1. Introduction

Fuel MTR fuel elements are being developed in order to replace high enriched fuel elements by low enriched ones, without significant loss of performance characteristics of the concerned research reactors. Before such fuels can be used for routine operation, qualification tests under representative irradiation conditions are necessary. [1], [2]

This paper describes the possibilities of BR2 for performing qualification tests for new research reactor fuel elements. Fuel elements of BR2 are of the plate type with aluminium cladding. The discussion is focused on the qualification of such fuel elements, although other types are not excluded.

The fuel plates using low enriched uranium must have a higher uranium density in order to obtain a comparable fission density. These densities are not possible using the traditional uranium aluminium alloys or cermet elements. Other compositions are being developed, such as uranium silicium and uranium molybdenum fuels. Initial tests can be done at lower fluxes. Special experimental devices for testing can be designed such that a failure of the experimental means no risk for the reactor. However qualification means in most cases that the experimental fuel plates, certainly when they are intended for use in a high flux reactor, must be irradiated as the normal fuel elements, since this is only way to obtain representative conditions. This conditions make the testing and qualification of new type of fuel elements for research reactors rather unique from the viewpoint of safety and licensing. Although a lot of operating experience from the past is available, the testing and qualifications can be compared with the situation in the early days of the development of nuclear reactors.

2. Maximum authorised power level

The total thermal power output of BR2 is not specified. The capacity of the heat exchangers limits of course the maximum thermal power that can be evacuated. The design value was 100 MW but after installation measurements indicated that at least 125 MW can be evacuated. The highest thermal power level of the reactor ever reached up to now was 106 MW.

The thermal power of BR2 is limited by a maximum allowable heat flux on the hot spot of the fuel elements. The actual thermal output depends on the number of fuel elements loaded in the core and their configuration.

The operational limit of BR2 is derived from the following conditions:

- No boiling on the fuel plates may occur during normal operation. The calculated maximum heat flux assuming the most unfavourable values for the various parameters is 603 W/cm² for the actual nominal hydraulic conditions, which are:
    - reactor inlet pressure 1.24 MPa;
    - pressure drop over the reactor 0.3 MPa;
    - reactor inlet temperature 40.0 °C.
- No damage to the fuel elements may occur during the transient following a loss of flow or a loss of pressure accident. Calculations indicate that this condition if fulfilled for a heat flux of 600 W/cm². However only the loss of flow accident is tested up to this value. For the loss of pressure accident the tests were limited to a value of 400 W/cm². [3]

The maximum allowed heat flux for routine operation is 470 W/cm² with the hydraulic conditions as mentioned above. Values up to 600 W/cm² could be allowed for special applications. A justification is required in this case.

The original BR2 Safety Analysis Report [4], which dates from May 1961, states also that surface temperature of the fuel must be limited to prevent rapid corrosion of the aluminium cladding. However, the actual thermohydraulic parameters guarantee that this conditions is fulfilled and no special attention is paid to it.

3. The procedure for approval of experiments

The irradiation of experiments must be approved by the Committee for Examination of Experiments (CEE). The CEE is composed of representatives of the operating organisation of BR2, the services for maintenance of BR2, the department for development of reactor experiments and the health physics and safety department. A representative of the authorised inspection agency is also invited to the meeting. The chairman of the CEE is a senior manager with a good knowledge of operation of research reactors, but not directly involved in the operation of BR2. The CEE has an advisory role. The conclusion must be confirmed by the general manager and by the department of health physics and safety. [5]

First stage approval

The first stage approval for an experiment can be given on basis of a number of fundamental questions. Typical examples are:

- Can the experiment be irradiated under application of the actual BR2 license? This question has been answered in a positive way for all experiments in the past, including the irradiation of a new type of fuel element.
- Are additional licences necessary for the experiment?
- Is the experiment feasible in BR2?
- Is the required irradiation program compatible with the planned operation of BR2 and with other experiments?

The project manager has to give the necessary information about the experiment such that these questions can be answered. A first stage approval authorises the detailed design of the experiment.

Second stage approval

The second stage examination of the experiment deals with the detailed design of the experiment. The project manager shall present the necessary descriptions, drawings and specifications to assess the detailed design of the experiment. The detailed safety analysis of the experiment is also an important topic for the second stage approval. The testing and commissioning program for the experiment must also be presented during the second stage. The second stage approval gives the project manager the possibility to start the construction of the experiment.

Third stage approval
Before the irradiation of the experiment could start the project manager has to obtain the third stage approval. During the meeting for the third stage approval the results of the testing and commissioning program are discussed. Another important topic for the third stage approval is the operating manual of the experiment.

Beside this three stages of approval the irradiation of an experiment, the possibility exists for a fourth stage meeting during which the results of the irradiation are being discussed.

4. Possibilities for the irradiation of new fuel elements

As stated in the introduction in order to obtain representative irradiation conditions the new fuel elements must be irradiated in the same way as the fuel elements. Irradiation in separate closed capsules, in which a failure of the experimental fuel would cause obviously hazard to the primary loop. Although it is a safe design, it is obvious that representative conditions for neutron flux, together with sufficient heat evacuation capacity, are very difficult to obtain.

Standard BR2 fuel plates could be replaced by plates with an experimental fuel composition. This gives representative irradiation conditions without the need to built special irradiation devices. The experimental fuel plates must only have the geometric form of the BR2 plates. A BR2 fuel element is made up of normally six concentric rings, each composed of three bent plates.

Another possibility is the design of a dedicated irradiation device that can contain a number of experimental fuel plates and is cooled by BR2 primary water. This possibility has less restriction on geometry of the fuel plates. Additional place can be foreseen for flux monitors. The basket takes the place of a BR2 fuel element. This solution is presented in reference [6].

If fuel plates are being used with direct on-line temperature measurement, as was done during the initial flow failure tests of BR2 [3], one has not fully to rely on the calculations for the safety assessment and irradiation is possible with smaller safety margins.

5. Safety analysis

A safety analysis must be made for each new experiment. The report must be submitted to the CEE to obtain a second stage approval. The most important issues are shortly discussed in this paragraph. Most of the analysis is also made from the experimenter's point of interest.

Reactivity

The formation of plutonium 239 influences the neutronic characteristics of the fuel plates. The reactivity changes during irradiation in a different way compared to high enriched uranium. The different fission product composition influences the delayed neutron fraction, thus changing the kinetics of the reactor and more specific the shutdown margin. Due to the greater absorption in uranium 238 the temperature coefficient will also be different.

If only a very limited number of experimental low enrichment fuel plates (a few percent of the total number of fuel plates) are loaded the influence will be small and not much of concern. Fuel elements containing low enrichment plates can not be involved in the critical approach of the reactor as they are considered as experimental devices. The effects on reactivity can become considerable in case of the use of a significant fraction of low enriched uranium.

Heat transfer and maximum temperature for fuel and cladding

Heat transfer calculations are of great importance. Since in most cases no direct measurement of the surface temperature of the fuel plates is foreseen, one relies on the calculation results to assess the safety margins with respect to maximum heat flux and meat temperature. From the safety point of view it is possible to use very conservative assumptions (low heat transfer coefficients, high gamma heating, low flow rates along the element), but the experimenters are interested to know the irradiation conditions as exact as possible.

A great number of different fuel plates influences also the global power distribution in the core.

Swelling of the fuel plate

Some fuel plates tend to swell during irradiation. A direct consequence of this swelling is a reduction in the gap between the fuel plates with a reduction of flow along the plate. Local swelling could also cause deformation of the plate. Standard BR2 fuel plates have a thickness of 1.27 mm, with a minimum space of 2.70 mm between two fuel plates. Heat transfer calculations have enough safety margin to include swelling of the plate. After each irradiation campaign of three weeks the dimension of the fuel plates must be checked using calibres.

Contamination of the primary circuit

Failure of the cladding of a fuel element causes contamination of the primary circuit. [7] Volatile fission products are suspected to be released in the primary water. Major contaminants are radioisotopes of the noble fission gases (krypton and xenon) and iodine. Experience with contamination caused by the failure of standard BR2 fuel elements indicate that such a release occurs in a slow and predictable way. A possible explanation is that the cladding is pierced at a few isolated point and the volatile fission products can enter the primary water. During further irradiation the newly formed fission products under the failed cladding reach of course immediately the primary water. However, the primary loop of BR2 is a closed circuit under pressure and the fission products remain isolated from the workers and the environment. A technical specification on the maximum allowable contamination of the primary water exists. This specification is derived from the criterion that a significant loss of primary water may not cause exhaustive contamination of the environment. Iodine-131 is the most limiting isotope. The maximum concentration which could be allowed is 400 Bq/ml. The activity of the primary water is continuously monitored and three times a week samples are analysed by γ-spectrometry. Sampling frequency is increased if the observed activity is higher than normal background level.

Burn out of a part cladding can never be excluded. This can be caused by mechanical damage to the fuel element or by blockage of the cooling. An automatic action, namely driving the control rods in the core at maximum speed (but no dropping of the rods), is foreseen to avoid further irradiation after such an major failure. The action is triggered by two scintillation counter measuring continuously the concentration of krypton-88 in the primary water. A severe contamination of the primary circuit will also cause a stop of the reactor due to high alarm on the nitrogen-16 measuring chains, normally used for power indication.

If fuel elements with low enrichment are irradiated plutonium and transuranium elements are formed, which could cause α-contamination in primary circuit. This is an advantage of very high enriched uranium. α-contamination at BR2 is at this moment not much of concern. α-activity of the primary water is not continuously monitored, although the possibility is foreseen. Only at the end of a BR2 irradiation cycle samples of the primary water are analysed for α-contamination. Irradiating low enriched fuel elements, certainly in case the irradiation is continued up to high burn-up (more than 50%), changes this situation. The risk depends of course on the retention of the transuranium isotopes by the fuel matrix once cladding has disappeared. For test irradiation of only a limited number of fuel elements with low enrichment the issue was raised during the CEE meetings. It was decided that if fission products are found in the primary water of BR2 the α-activity of the samples must also be checked together with α-spectrometry, which is a rather long and tedious measurement but giving useful information.

The source term of the maximum credible accident

An experiment shall not increase significantly the potential source term used for calculating the maximum credible accident. Otherwise, a full licence application, including public hearing, should be required. Replacing a few percent of the fuel plates by experimental plates with a different uranium content does not affect the BR2 source term. A great number of low enrichment fuel elements increases quantity of plutonium and other transuranium elements significantly once an equilibrium core composition is reached. Such a modification would require a recalculation of the consequences of the maximum accident with possibly a new licence application.

6. Conclusions

Possibility exists for BR2 to irradiate new type of fuel plates under actual operating licence condition. The test plates are considered as experimental device and the authorisation follows the procedure for experiments. This is possible as long as the source term of the potential hypothetical accident and the probability of the initiating events are not enlarged in a significant way. Fundamental parameters of the reactor core, such as neutron power distribution, kinetics, heating by gamma flux and thermohydraulics must neither be changed in a significant way. These restrictions limit the number of test plates that can be loaded without being considered as an important modification.

Replacing the whole core by low enriched fuel elements has an important influence on above mentioned characterics of the installation and a full licence application will probably be required for such a modification.

7. References

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