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ONGOING ACTIVITIES AT BR2 WITH REGARD TO CONVERSION

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ABSTRACT

The paper starts with a short description of the BR2 reactor, focusing on the core particularities and on the characteristics of the presently used fuel elements. The long lasting participation of BR2 in the RERTR program is recalled. In particular the recent intensification of the collaboration triggered by the progress in the LEU fuel development is outlined. Some initiatives taken by BR2 on the particular important subject of burnable absorbers are described: optimization studies for various fuel types and efforts initiated with the fuel manufacturer for the inclusion of Cd-wires or the use of borated side-plates in the BR2 fuel design. The capabilities of BR2 for the testing and qualification of LEU fuels are shortly described; BR2's involvements in past LEU development irradiation tests are recalled.

1. BR2: Core Particularities and Major Characteristics of the Present Fuel Elements

BR2 is one of the World principal high-flux Materials Testing Reactors, operated by the Belgian Nuclear Research Center SCK●CEN at the Mol site. The main use is scientific-technological irradiation programs concerning nuclear fuels and materials. The second use, taking increasingly more importance, is radio-isotope production and silicon doping.

BR2 has a compact HEU core which is composed of an assembly of inclined beryllium prisms, each of them presenting a cylindrical bore. Due to this specific design, the BR2 fuel elements are assemblies of concentric cylindrical tubes. They have a 762 $\pm$ 12.5 mm active fuel length, derived from the length of the beryllium matrix. The diameters of the available bores in the beryllium matrix determine the outer diameters of the fuel elements: either 84 or 200 mm.

The standard 84 mm channel fuel element (type VIn) is made from 6 different fuel plate formats, corresponding to six concentric tubes. Each cylindrical fuel tube is an assembly of 3 equal incurved fuel plates. These fuel plates are mechanically fixed by the roll swaging technique into three grooved solid radial webs. The fuel plates are fabricated by the picture frame technique. The nominal meat thickness is 0.51 mm, with two aluminum alloy cladding layers of 0.38 mm each. The water gap between the plates is 3.0 $\pm$ 0.3 mm.

The present standard BR2 fuel element contains 400 ± 6 g ^{235}U: 28 vol% UAl_x with 90-93% enriched uranium, 66 vol% aluminum and 6 vol% void. The uranium content per unit area of a fuel plate is 0.060 g $^{235}U/cm^2$; this corresponds to a uranium density of 1.27 g $Utot/cm^3$.
The inner fuel tube of each fuel element encloses a free volume available for irradiation purposes. This volume can be increased by removing one or more inner fuel tubes. An inner unfueled guide tube can be added to allow axial movement of an experimental rig. An absorber screen can be added to harden the neutron spectrum.

The presence of burnable absorbers in the fuel meat is an essential feature of the BR2 fuel elements. The burnable poison content has been optimized several times: presently we use 3.8 g boron under the form of boron carbide and 1.4 g samarium under the form of samarium oxide, both homogeneously mixed into the fuel meat.
Due to the presence of the burnable absorbers the burn-up at discharge and the maximum fission density are considerably increased: this results in a better economical use of the available uranium.
Another major benefit of the use of burnable absorbers is the possibility to constitute a large inventory of fuel elements with various partial burn-ups. This allows adapting the local irradiation conditions not only by modifications of the configuration but also by adaptations of the burn-up of the driver fuel.
The mean thermal flux in the reactor is somewhat decreased for the same power level because the increase of the uranium loading required by the addition of the burnable absorbers has increased the under-moderation of BR2.

Some advantages of the standard VInG dispersion fuels with burnable absorbers over the initially used alloy fuels are well illustrated in fig.1. Besides the increased cycle length and the reduced motion range of the control rods, the irradiation conditions for experiments are much more stable.

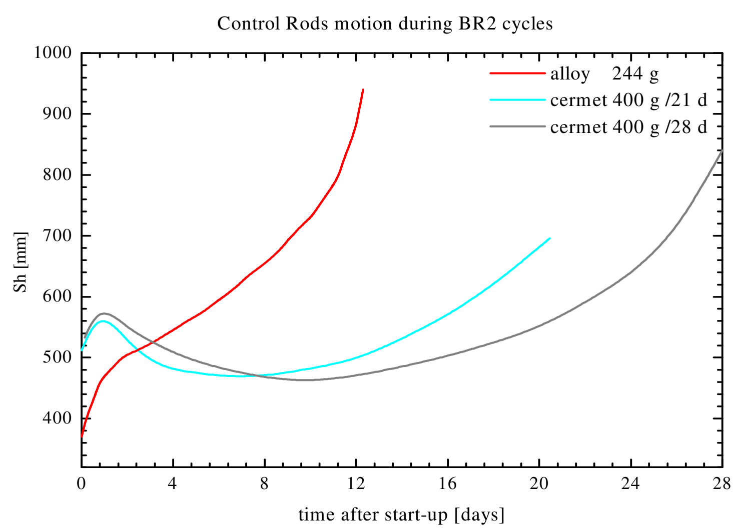

Fig.1: reactivity evolution (shown as control rod bank movement) during some typical BR2 cycles with various fuel types.

The objective of the BR2 operation is to satisfy the irradiation conditions requested by the experimental load, and to do this by guarantying safe operation and by making optimal economical use of the available fuel elements.

One major particularity of BR2 that allows doing so is that there is no standard core configuration, but an essentially variable core loading from cycle to cycle: the number, the channels and the burn-up of the loaded fuel elements are optimized in function of the experimental requests. The nominal operation power also varies from cycle to cycle.
About 6 fresh standard fuel elements are required for the core load of each new cycle (6 is the minimum value for the presently used configurations). Fuel elements irradiated during one standard cycle typically have a burn-up of ~15% and due to the presence of the burnable absorbers are the most reactive. They form the so-called second batch in the BR2 fuel element inventory. Because at least 6 of those high reactive fuel elements (burn-up ~ 15%) have to be loaded in the central crown of each new core load, the fuel elements of the 2nd and 3rd batch (respectively ~ 15% and ~ 30% burn-up) have to be 'produced' by irradiation of fresh elements during previous cycles.
Consequently the supply of fresh fuel elements with a rate of 6 fresh standard fuel elements per operating cycle is obligatory for maintaining the equilibrium of the fuel stock (the number of partially burned elements in the various batches of the inventory).

If the BR2 reactor would run out of fresh fuel elements, two more last cycles with partially burned fuel elements containing the remaining burnable poison (B_4C) could be operated respectively with decreasing cycle lengths, i.e. the available MWd of the partially burnt fuel elements are only 'effectively' usable in combination with the availability of fresh fuel elements.

2. Active Collaboration with the RERTR Program

A first collaboration agreement between the Belgian Nuclear Research Centre SCK●CEN and the RERTR program was signed in 1985.
Since then BR2 representatives have attended on a regular basis the yearly RERTR conferences; a number of papers dealing with the requirements on LEU fuel for being acceptable for the conversion of BR2 have been presented.
More recently in 1999 the governments of the United States and Belgium exchanged diplomatic notes regarding the BR2 fuel supply and conversion. In the resulting agreement (in the form of verbal notes) Belgium has engaged itself to convert the BR2 reactor as soon as an adequate fuel has been developed and becomes available from a qualified manufacturer. As long as this is not the case the United States have engaged themselves to supply the BR2 reactor with HEU on the condition that all requirements of the Schumer amendment are satisfied.
Also in this agreement the United States recognized that there was 'at that time' (i.e. 1999) no suitable LEU fuel that could be used in the BR2 reactor. At that time the qualified LEU fuel was based on dispersed U3Si2 with a density up to 4.8 gUtot/cm³.
Belgium has also participated in the international workshop "Best practice on nuclear security at research reactor facilities using direct use material and at research reactor facilities in general", held in Oslo, October 17th to 19th 2007, where a paper was presented reconfirming the Belgian position.

BR2 was one of the initiators of the yearly ENS conference on Research Reactor Fuel Management (RRFM) and is presently assuring the chairmanship of the program committee. Like the yearly RERTR meetings, these international topical meetings also bring together the various stakeholders and contribute to the progress on research reactor conversion to LEU.

The development of high density LEU fuels has made important progress in the last years. In particular the qualification of the dispersed UMo fuel system with densities up to ~ 8.5

gUtot/cm³ is making substantial progress although irradiation tests at very high heat-fluxes still are to be performed.
In this context the US-Belgian collaboration has intensified and became more active (or even proactive) since autumn last year:

- some bilateral meetings have taken place to define what actions should be undertaken,
- BR2 attended a USHP reactor group meeting at ORNL in January this year,
- a common conversion feasibility study was initiated together with ANL,
- some tentative conversion schedules were discussed.

In the meantime the conversion feasibility study is on its way and a first follow-up meeting will take place at Argonne National Laboratory right after this conference.
BR2 is also in regular contact with its fuel supplier to be informed about the actual progress in manufacturing high density LEU fuels.

3. Initiatives Taken by BR2 on the Particular Important Subject of Burnable Absorbers

As shown above burnable absorbers are an essential component of the BR2 fuel elements. However the nature, amount and disposition of these absorbers are characteristic of a particular type of fuel and the objectives of the concerned reactor.
At the beginning of the fuel assembly life time the burnable absorbers compensate the excess reactivity. During irradiation, the burnable absorber isotopes are transmuted into other isotopes which should have lower neutron absorption cross section. The consumption of the burnable absorber has therefore a positive effect on the reactivity that counterbalances the combined effect due to the depletion of the fuel and the accumulation of fission products. When the burn-up of elimination is reached, the burnable absorber isotopes should ideally be consumed completely in order to limit burn up penalties.
Another advantage from the point of view of safety: The burnable absorbers reduce the overall control rods motion and consequently allow reducing power peaking.

Therefore in the case of BR2, before starting actual feasibility studies on conversion, an optimization of the burnable absorbers in the fuel assemblies for each considered LEU fuel system must be performed.

Knowing this, BR2 has undertaken a project entitled: Improved BR2 fuel cycle with optimized burnable absorber (Cd wires, borated side-plates …). This year the neutronic studies conducted in the framework of this project generated a Master Thesis by a student from the BNEN/ENEN nuclear education network. More details about these studies will be given in another paper at this conference [1]. Let's note that the more detailed evaluations are being focused on those solutions for which the manufacturing feasibility has been/is being checked.

Concurrently BR2 is in the process of launching together with its fuel supplier a project to incorporate Cd-wires in the grooves of the side-plates or using borated aluminum for the side-plates in a future fuel element fabrication campaign. The introduction of Cd-wires would imply a slight modification of the geometry of the fuel element.
Both types of burnable absorbers which are preferentially studied should be well suited for a future LEU fuel element. A choice for one type of burnable absorber should be made before the end of this year. It is the aim to already manufacture a few HEU elements equipped with the chosen absorber type in order to perform a measurement program on the reactivity evolution of these elements, to confirm the calculated results and thereby already somehow

'qualify' these burnable absorbers for the future LEU fuel element. There is still the open question whether or not these Cd-wires will have to be cladded.

4. Capabilities of BR2 for the Testing and Qualification of LEU Fuels

BR2 can offer various possibilities to perform selection and/or qualification irradiations programs for candidate high density LEU fuel systems. A major advantage is that heat fluxes up to 500 W/cm² are allowed and can be realized during irradiation, thereby reaching conditions which can be considered as envelope for nearly all high power research reactors.

Since 1999 BR2 has performed MTR fuel plate irradiation tests under contract. The first tests were performed by incorporating the fuel plates to be tested in standard fuel elements of BR2. In each case three plates to be tested formed the outer ring of the 6 concentric rings of the standard fuel element. This can be repeated with other fuel compositions and the heat fluxes can be adjusted by the choice of the irradiation channel, the loading of the neighboring channels and, within some limits, the choice of the operating power.

In order to enhance the capabilities of BR2 in the field of MTR fuel testing and qualification, a dedicated irradiation device has been designed. The objective was to provide BR2 with a reusable device for the irradiation of fuel plate under representative conditions,
The first version of this device, called FUTURE-MTR (FUel Test Utility for REsearch reactors) has been built in 2000 and was presented at RRFM-2002 [2].
In its basic version this device allows the irradiation of 3 fuel plates. The central fuel plate can be replaced by a dummy plate or a plate carrying dosimeters.
This irradiation basket has been used for the irradiation of 2 full-size dispersed UMo fuel plates for the French R&D program on high density LEU fuels [3].
With only minor design changes a similar type of irradiation device can be build for a different number of fuel plates. Recently a design for 4 plates has been finalized.

The major advantages of this device compared to the ‘mixed-type’ fuel elements used previously (i.e. by incorporating the fuel plates to be tested in standard fuel elements) are:
- the possibility for unloading the plates in between reactor cycles for inspections and measurements,
- the possibility to continue the irradiation of some plates after the removal of a failed plate,
- a larger choice of irradiation conditions for the plates to be tested,
- a reduced risk to BR2 in case of swelling or failure of a fuel plate.

For the irradiation of mini-plates BR2 could easily use one of the standard irradiation devices for Mo-99 targets. The presently used devices can accommodate both plate-type and tube-type fissile targets for the production of Mo-99. These devices can be loaded/unloaded while the reactor is operating. Nothing prevents us to use one of these devices for the irradiation of mini-plates with appropriate dimensions.

More recently BR2 designed a dedicated loop for the qualification of the start-up fuel (based on dispersed U3Si2) of the JHR project of CEA. This loop, called EVITA, is presently under construction and should be installed in BR2 early next year.
SCK●CEN has a specialized department for the design of dedicated irradiation devices and the EVITA loop is a typical project that this department can handle.

Moreover SCK●CEN has also comprehensive PIE capabilities. This is an important advantage considering the present days difficulties to ship irradiated fissile materials.

5. Conclusions

The position of BR2 with respect to the goals of the RERTR program (presently integrated in the GTRI initiative) has been consistent since its first involvment in the program and will remain so. The ongoing progress in high density LEU fuel development has lead to an intensified participation of BR2 in the program.

The BR2 reactor has some particularities which distinguish this reactor from nearly all other high power MTR reactors: a variable core configuration, fuel elements with optimized burnable absorber content, variable operating power … . These characteristics must be taken into account when performing conversion feasibility studies. Being aware of this, BR2 has launched a project to develop proactively an optimized burnable absorber system that is of direct interest for the future conversion of the BR2 reactor.

Of interest for the LEU fuel developers is the fact that SCK●CEN has all the capabilities required to test/qualify the various high density LEU fuel systems presently under development and thereby contribute to the global goal of the program.

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