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The BR2 Reactor: the challenges for continuous operation way into the 21st century

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The BR2 reactor is one of the major MTR-type reactors in the world, operated by the Belgian Nuclear Research Centre SCK●CEN. The paper describes the efforts undertaken to keep the BR2 reactor in operation while maintaining the safety level at the highest standard. The last (2006) and forthcoming (2016) decennial safety reassessments are described, focussing on subjects of interest also to other operators. The present and future utilization is outlined as well as the actual operation policy. The challenges for the fuel cycle are briefly tackled. Finally some conclusions on the life expectancy are given.

1. Introduction

The BR2 reactor is a 100 MWth research reactor operated by the Belgian Nuclear Research Centre SCK-CEN. It is one of the major MTR-type reactors in the world and the major infrastructure of SCK-CEN. First operation with an experimental loading started in early 1963. Since then the reactor has been intensively used for fuel and materials testing for various reactor projects in national and international framework and for the production of radioisotopes for the major companies active in this field. The reactor has undergone two major refurbishments, various safety reassessments, an INSARR mission by IAEA and various reorganisations. The paper gives an overview of the major challenges for continuous operation way into the 21st century. These challenges cover many domains such as safety, ageing, utilisation, fuel cycle, knowledge management, regulatory environment, public acceptance …

2. The periodic safety reassessments

2.1. The legal framework & regulatory environment

The regulatory environment for BR2 has fundamentally changed since the late 1990's as the reactor is now under the supervision by the the same safety authorities which also regulate the power reactors.

There are presently 3 agencies supervising the BR2 operation:
- the Federal Agency for Nuclear Control (FANC): the Belgian government agency entrusted with the protection of the population, workers and the environment against the dangers of ionising radiation,
- Bel V: a technical expert group, subsidiary of FANC. Assigned site inspectors from BEL V regularly visit BR2,

- SCK•CEN's Internal Service for Prevention and Protection on the Job (IDPBW) and its subgroup, the BR2 nuclear safety group, which acts as a local site inspector and is directly responsible for physical control with respect to BR2.

Basically the license to operate isn't limited in time but comprehensive decennial safety reassessments are foreseen for the prolongation of the license provided a number of new requirements are being satisfied.
In this general framework safety review and licensing is an ongoing occupation during the intermittent time periods between successive reassessments, with periodic hold-points (regular follow-up visits by the assigned site inspectors, specific authorisations for the start-up of each cycle, regular walk-downs, …).

2.2. The 2006 decennial safety reassessment

The 2006 safety reassessment resulted in number a work items and associated milestones/deadlines.
These work items, agreed upon with the Safety Authorities, concern various types of activities (studies, inspections, surveillance follow-up, refurbishment actions, knowledge management, incident analysis, …) and have to be completed according to the deadlines; for some items this may take several years but ultimately everything will have to be completed by the end of 2010.
The timely completion of these tasks as well as their acceptance by the Safety Authority condition the prolongation of the authorisation for operation of the BR2 reactor.

The SAR had to be completely overhauled including a complete review of the technical specifications incorporating requirements for availabilities, test frequencies, maximum outage duration (in a way it is handled by nuclear power reactor operators) and in-depth incident analyses resulting in lessons to be learned. A new volume was added to the SAR to include the quasi-permanent experimental devices like the CALLISTO loop and a number of radioisotope production rigs. These devices fall now under the responsibilities of the BR2 operation and are included in the overall BR2 maintenance, testing and inspection plan.

Follow-up and updated evaluation of the major surveillance programmes have to be presented:
there are 2 basic surveillance programmes concerning the basic components of the BR2 reactor core: the Be-matrix and the Al-vessel.
The Be-matrix has already been replaced twice and the degradation mechanisms are by now well understood. Because the matrix, materialising the irradiation channels' is relatively easily to inspect, the surveillance programme is mainly based on visual & dimensional inspection inside the channels, detailed determination of the fluences and a comparative analysis with the behaviour of the two previous matrices.
For the Al- vessel the surveillance programme is mainly based on mechanical testing of surveillance samples, detailed determination of the fluences of the vessel and the samples, estimation of the remaining lifetime (at least until the next decennial safety reassessment).

Some irradiation devices also fall under the surveillance requirements. This concerns devices which are almost permanently loaded and therefore their major in-pile components accumulate rather important fluences. When these components have safety functions and especially if they also are subject to pressure and/or thermal loads their 'safe lifetime' has to be estimated. This mainly concerns aluminium and stainless steel pressure tubes (e.g. IPS stainless steel pressure tubes of the CALLISTO loop) and is performed by computational evaluations supported by in-service inspections according to the case.

An important inspection programme is carried out for the primary circuit according to an agreed upon code and acceptance criteria. Special attention is given to supports, hangers, crossing sleeves through walls and the major block valves.

The neutron guides also have to be inspected. Although not utilized anymore, a number of beam-tubes are still present. They surround the vessel at mid-plane level and pass through the pool walls. In order to eliminate the risk of pool leakage some tubes will be removed, others will be secured.

A number of renewal and modernisation actions are going on in the field of instrumentation.

The electrical supplies for safety related equipments are being upgraded. Special attention is given to the identification and elimination of interferences with non safety related equipments in order to enhance reliability.

The major components of the control rods have to be replaced:

- replacement of the displacement mechanisms and introduction of digital position indicators.
  This action was initiated to avoid ageing problems with the former mechanisms and was combined with an upgrading of the position indicators.
- replacement of the movable neutron-absorbing parts of the control rods:
  The former n-absorbing parts were based on cladded Cd tubes. The technical specifications define a limit on the Cd burn-up. Our stock of Cd tubes was running out and no suitable co-extrusion press available for a new fabrication campaign could be found. A search for alternatives (other fabrication methods, other n-absorbing materials …) led to the decision to replace the Cd-Al tubes by Hf tubes. The replacement of all neutron-absorbing parts is foreseen for early 2010.

The Authorities have also asked to reassess the status of the cranes in the BR2 complex: Inventories and evaluation of all safety related components, safety requirements, the regulations to be followed and the overall status of the equipments. Afterwards elaboration of the required improvements, implementation and updating of a periodical inspection programme will have to be performed.

The PSA was updated (failure probabilities, fault tress …) on basis of the operating experience gained and the modifications of the installation that have occurred during the last ten years. The updated PSA study is used to formulate proposals for improvements by analysis of the dominant minimal cuts and evaluation of the “importance measures”.

A re-evaluation of the hydrogen explosion risks inside containment-building from PWR loop simulating loop CALLISTO (inventory, risk zones, detection and protection means, absence of ignition sources, legislation) has taken place. Dose-reduction should be achieved by cleaning/decontamination of the CALLISTO circuitry and/or local shielding of hot-spots.

The radioactive effluents disposal system has to be upgraded: evaluation of the status of the circuitry, collecting reservoirs and procedures in relation with the updated reglementations, identification of potential shortcomings, elaboration of improvements and implementation. The objective is to optimise the whole network for a safe and economic management.

Besides the ageing of the installation there is also the ageing of persons and the resulting renewal of personnel. This leads to a number of related requirements concerning 'knowledge':
- knowledge management: document management system, improved archiving.
- feedback/learning from past experience (REX): improved registration and analysis of incidents and nearly-incidents, fault tree analysis of incidents, analysis of incidents reported in the ISS and IRSRR data bases for lessons to be learned.
- knowledge transfer and training, with particular attention for education programmes on safety and safety culture and for competence management with regard to the renewal of the staff.

2.3. Outlook on the next decennial safety reassessment 2016

The next reassessment will most probably concern a global requalification of the BR2 installation in combination with the fuel conversion (see paragraph 5 here below).
This process will start around 2012 and will be planned in three phases: conversion feasibility, technical validation and safety assessment, licensing procedure.
Presently a global project plan is to be established detailing these three phases in order to allow the Safety Authorities to follow the whole project in a timely manner from the earliest stage.

The various aspects of knowledge management will certainly receive enhanced attention, as well as human and organisational factors and certainly safety culture.
Proactively SCK●CEN performed a safety culture audit in 2007 along several lines (an EdF question list, interviews with key staff based on IAEA’s SCART guidelines, observations, interviews and technical audit, recordings of the previous year). The conclusion was reassuring:
“BR2 operating organisation establishes policies in accordance with national requirements and IAEA recommendations giving safety matters highest priority and promoting a strong safety culture.”

However it was also stated that Safety Culture is a continuous effort and there is always room for improvement, for instance in the field of “human factors relating to experiments” where reactor operators and experimenters have to interact.

3. The present utilization of BR2

During its lifetime BR2 has always been used primarily for the typical MTR applications: irradiation of fuels and materials. However the specific R&D fields and considered reactor types have changed over time.
Nowadays the basic justification for continuous operation of the BR2 reactor is still based on the technical-scientific programmes which need fuel & material irradiation.
The basis is formed by the internal R&D programs related to the needs of the Belgian power reactors (all PWR's). This is complemented by the Belgian participation in various European programmes (e.g. the framework programs, PCRP's, the European Fusion Association EFDA …).
In addition to that there are bilateral and international Programs on contractual basis (collaborations, irradiation services …).
The major irradiation devices for these programmes are the CALLISTO loop (a simulation of PWR conditions with 3 in-pile sections), the Mistral device (reusable materials irradiation device loaded inside a BR2 driver fuel element), various pressurized water capsules and associated calibration & cycling devices, the EVITA loop (an MTR fuel testing loop).

The second major utilisation of the BR2 reactor are commercial irradiations for the production of radioisotopes and the neutron transmutation doping of silicon. These activities have taken increasing importance and presently generate a significant contribution to the operating costs.
Although there are regularly initiatives to develop new radioisotopes the major ones still are Mo-99 from fissile targets and high specific activity Ir-192. Lately the worldwide crisis on Mo-99/Tc-99m generators availability has lead to an increased pressure to increase the operation time of BR2.
This clearly has demonstrated the importance of continuous operation of BR2 for the support of the nuclear medicine.
The request for NDT-Si production, although being subject to the global economic cycles, has a basically increasing trend as the number of applications fields is increasing. The tendency also goes to increased diameters of the silicon ingots and BR2 has responded to that by installing a new production installation outside of the reactor vessel in order to accommodate diameters up to 8 inch.
For these various production activities BR2 is equipped with a number of nearly permanently loaded irradiation devices with well characterized irradiation conditions.

4. Present operation

Since the restart in 1997 after the second major refurbishment the operating schedule of the BR2 reactor has been limited to about 120-140 days per year, essentially 5 standard cycles (of 21 or 28 efpd) with some short additional cycles for specific irradiation tests, with a annual production of ~ 7000 MWd.
The present operating schedule is coordinated on European level with the two other major MTR reactors which have a significant production of radioisotopes, more particularly Mo-99.

Since then there have been no serious incidents and no significant indication of serious problems related to degradation processes, ageing or increasing safety risks.

5. The fuel cycle

The BR2 reactor still uses HEU. However since around 2006 there is an important evolution in the development of higher density LEU fuels. In particular the dispersed UMo fuel system with a density of ~ 8 - 9 gUtot/cc is now in the qualification phase.
For this reason the US-Belgian collaboration on conversion has intensified since autumn 2007.

- a common conversion feasibility study was initiated together with ANL,
- common efforts for the qualification of high density UMo fuel are being set-up,
- a draft conversion schedule has been developed,

- recently collaboration with other European stakeholders was started to execute a qualification programme of the dispersed UMo fuel system at high heat-fluxes up to high burn-up.

Based on these efforts the actual conversion of the BR2 reactor is foreseen for 2016.

Concerning the back-end of the fuel cycle BR2 has a long lasting contract for the evacuation of the spent fuel to the La Hague plant with a subsequent return of vitrified waste. This waste is then taken care of by NIRAS/ONDRAF (the Belgian national organisation for the management of radioactive waste) and stored in a temporary repository build for the waste of the power reactors.

6. Conclusions

After a second major extensive refurbishment executed in the mid-90's of last century and the continuous efforts consented since then, the BR2 installation can be considered technically fit for the lifetime of the third beryllium matrix. On basis of the present and foreseeable operating schedule this leads beyond 2020.

The operating license doesn't define a specific lifetime but requires periodic safety assessments in order to prolong the authorisation for operation. The last decennial reassessment has been conducted with the perspective of another 10 years of operation. The next decennial safety reassessment is scheduled for 2016.

The SCK●CEN Board of Directors has recently asked for a proactive evaluation on what it takes to operate beyond 2016

In the strategic planning BR2 is still considered as one of the major assets of SCK●CEN and should be operated until a new major installation, the MYRRHA ADS presently under study, can take over.