BR2: 50 YEARS AND STILL GOING STRONG

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ABSTRACT

Two important decisions have been taken in order to ensure successful and safe future operation of the BR2 reactor.
The forthcoming decennial safety reassessment will be undertaken with the intention to ensure another 10 years of operation from mid-2016 on. Particular efforts will be concentrated on the two following aspects: Long Term Operation (LTO) and Design Review.
In order to gain more operational flexibility, including the ability to increase the annual capacity factor from 2016 on, a 'proactive' replacement of the Be-matrix has been decided. This operation will also allow for better conditions to conduct a number of in-service inspections and install some design upgrades.

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 and an INSARR mission by IAEA.

2. The initial operation period

The design of the reactor was undertaken in the late 1950's by a mixed Belgian-American team according to specifications established by SCK•CEN and safety criteria existing at that time in the USA. The construction took less than five. The first license to operate was established in 1963 by a royal decree with a time limit of 25 years.

3. The first refurbishment and the second operation period

At the end of 1978 it was decided to replace the beryllium matrix and to proceed with a general overhaul of the installation. A detailed inspection programme revealed failures on some equipment's due to ageing, like corrosion of some bolts of the primary circuit inside the reactor pool. A visual and ultrasonic inspection of the aluminium vessel was also executed and gave satisfactory results. A maximum allowable fast fluence was established for the beryllium matrix, which consequently became the life-limiting component of the installation. A first surveillance programme based on surveillance specimens was launched for the beryllium.

4. The second refurbishment

In 1995 the beryllium matrix reached its established fluence limit. After the managing board had established that the BR2 reactor was an essential tool to accomplish the mission of SCK-CEN, it was decided to proceed with an extensive refurbishment of the installations.
To ensure that all important aspects would be addressed in the refurbishment programme, a comprehensive evaluation process started already in 1991 in close collaboration with the regulatory body. The key issues were:

- risks assessments to verify that the safety goals would be met and to define back fitting or upgrading actions, and
- ageing evaluations and inspections to assess the remaining life of particular equipment's and to define the necessary mitigation actions. The safety goals themselves were checked against present modern standards.

From these studies and inspections resulted the refurbishment action plan. The prioritisation of all possible refurbishment actions was the result of a PSA level 1+ assessment whose prime objective was to estimate the significance, the potential consequences and the consequent acceptability of all accident sequences considered.

The actual refurbishment action plan comprised upgrading's and modernisations, inspections, extensive maintenance and safety and reliability studies required by the licensing authorities.

5. The operating license and periodic safety reassessments

In 1986, after expiration of the initial authorization for operation for 25 years, a royal decree was issued concerning the authorisation for operation. From now on a quinquennial safety review was requested (a procedure similar to the decennial safety reviews imposed on power reactors).
For BR2 in particular an overall safety reassessment was conducted. The regulatory body asked for a number of safety evaluations, which in their turn lead to ageing considerations concerning the equipment's involved:

- assessment of the possibility for common mode and common cause failures,
- evaluation of the consequences of a rupture of the aluminium vessel
- enhancement of the reliability of the automatic isolation valves of the containment building in case of accidents.

From then on, Safety Review and Licensing has become an on-going occupation with periodic hold-points. The 1991 review was rather straightforward and limited in content, as the second refurbishment period was already foreseen for around 1996.
The 1996 review coincided with the second major refurbishment shutdown and was a major effort. In 2001 the scoped was again limited after the major effort produced in 1996.

The 2006 review was a full scope safety reassessment and some files took up to 2011 to be completed. The major work items were:

- Updating the SAR: major modifications concerning organisation, technical specifications, incident analysis … . A new volume was added to include quasi-permanent experimental devices (e.g. the PWR simulating loop Callisto).
- Follow-up of the surveillance programs: the Be-matrix (visual & dimensional inspection inside the channels), the Al-vessel (mechanical testing of surveillance samples and in-service inspection), specific components of quasi-permanent irradiation devices (e.g. the in-core pressure tubes of a PWR simulating loop).
- Renewals: an important one took place for the control Rods where the displacement mechanism and digital position indication were modernized and the movable n-absorbing parts in Cd were replaced by Hf parts.
- Inspections: e.g. the primary circuit, leak-tightness of the remaining beam-tubes.
- Studies: worthwhile to mention are

Fuel Conversion: status, outlook, fuel cycle evaluation …
Explosion risks: hydrogen risks inside the containment
Radioactive Effluents: minimisation, mitigation

- Safety Culture: the emphasis was on training and knowledge management & transfer.
- Physical protection: serious upgrades with regard to the present international standards.

6. The forthcoming decennial safety review (PSR16)

In 2006 the Belgian Safety Authority decided that from then on BR2 would be subjected to decennial safety reassessments (in line with the procedure used for power reactors). The prolongation of the operating license can be granted in 2016 on basis of a safety reassessment to be conducted prior to the end date of the existing operation license extension, including the most important (safety related) part of modifications/upgrades to be executed at the installation.

SCK has taken the important decision that the forthcoming decennial safety reassessment will be undertaken with the intention to ensure another 10 years of operation from mid-2016 on. This decision for continued operation of BR2 reactor in the period 2016 - 2026 is based on the following arguments:

- Continuity of irradiation programs: RI production activities, most prominently for Mo-99 and the scientific-technical irradiation programs, in particular some particular fuel programs which typically run over several years,
- Active presence of SCK•CEN on the international scene of MTR reactors,
- Maintain the internal competence with regard to the operation of a large irradiation infrastructure and carry out complex irradiation experiments

For the 2016 Safety Reassessment, the Safety Authorities request two major aspects to be considered:

- long term operation (LTO): this concerns a programme to manage the ageing of the installation (in accordance with the relevant IAEA documentation).
- re-evaluation of the design: a programme to modernize or upgrade the installations (“agreed design upgrades”) on basis of a safety re-evaluation of the initial design and the previously carried out upgrades and modernizations.

The challenge is the preservation of the whole installation in good conditions, i.e., guarantee Safety with regard to the present & evolving international norms, assure availability for performing all tasks in the envisaged time period, and all of this in an acceptable manner (considering all aspects: safety, economics, environment, public acceptance…).

To meet this challenge, various measures have been implemented or executed:

- Personnel: maintain the required manpower, assure knowledge management and transfer
  . Implementation of a renewed training-plan
  . Reinforcement with regard to the major challenges: operation, maintenance, reactor core load management
  . Systematic approach for the knowledge transfer
- Organization: optimized use of the limited resources
  . Creation of a new unit PAM - “plant asset management” - to analyse and manage the ageing process of the installation in a systematic manner
  . Start integration of the BR2 QA system into the SCK•CEN IMS.
- Technical field: evaluate the risks associated with ageing and take appropriate countermeasures. A first analysis of the ageing risks in main SSC (systems, structures and components) of the primary circuit of BR2 was performed.

7. The Be matrix change-out

Taking into account the perspective to operate until 2026, a strategic decision to preventively replace matrix has been evaluated.

The Be matrix influences the operation of BR2 in 3 manners:
- Mechanical integrity: risk of ‘premature’ degradation,
- Max admissible fast fluence: roughly proportional to the produced energy,
- Max anti-reactivity in the poisoned matrix: limitation of the shutdown duration in between cycles.

A risk analysis was performed for the Be-matrix with the time horizon of 2026. This analysis considered not only the safety aspects but also availability and efficient use of the BR2 installation. The operating license gives 2 failure mechanisms:
- the occurrence of a crack formation which gives an increased risk for blockage of the mobile absorbing part of a control rod or perturbed cooling of a fuel plate by loose pieces of material. In that case the operating license doesn't allow further operation with this Be matrix,
- the maximum allowed radiation damage, expressed in terms of a limit in fast fluence.

Estimation of the service life of the Be matrix:
- The remaining service life of the Be matrix can be estimated based on the foreseeable utilization (MWd/year). Depending on the envisaged utilization program, the service life of the present Be matrix will end 2021 - 2023. It appears that with the remaining lifetime of the Be-matrix, operation of reactor through next decennial PSR period (2016-2026) is not possible.
- due to the ever increasing He-3 poisoning of the Be-matrix, a sufficiently reduced operating regime to reach mid-2026 is actually not practicable due to the limitation of the maximum admissible shutdown duration.
- there is an increasing risk for a premature end of life of the Be-matrix due to excessive cracking before the limit in fast fluence is reached. The increase of this risk can be estimated on basis of the results of the periodic inspections; but this risk cannot be eliminated.

Therefore, in order to reach 2026 with reasonable confidence, a ‘premature’ replacement of the matrix has been decided and is already technically prepared.

The major benefits expected from this Be-matrix change-out, are:
- increased flexibility in operation until the next decennial safety review.
- highly reduced degradation risk of the Be matrix until mid-2026.

The prolonged reactor shutdown and the accessibility of the reactor vessel provide an opportunity for major revision of critical components. Those are identified by the LTO methodology and concern:
- components required to be in service during reactor operation,
- to components inaccessible with matrix loaded.

One legally required inspection whenever the Be-matrix is unloaded is the in-service inspection of the BR2 Al vessel.

The date of the Be-matrix change-out has been chosen to coincide with the forthcoming safety reassessment; this date also appears optimum in terms of business opportunities. The duration should be obviously be limited: the best way to guarantee this is a comprehensive and timely preparation.

The planning and preparation of the Be matrix change-out is largely based on the experience gained from the 2 preceding Be matrix change-outs. SCK has good confidence that the Be-matrix change-out can be performed without major risk for prolonged shutdown duration.
A detailed road map has been established and work item descriptions have been issued.

8. PSR16 – LTO

Periodic safety review was initiated 01/07/2012 and is organized as a 3 phase process: Methodology, Analysis and Implementation, with the following milestones:
-> end 2012: scope, methodologies …
-> mid 2015: analysis and evaluations
-> mid 2016: finalization and action plan, Q&A process with the Safety Authorities.
-> mid 2019: implementation.
BR2 specific: implementations requested by the stress-test evaluation and those which can only be performed while the Be-matrix is unloaded will have to be executed during the Be-matrix change-out.

The review is focused on 14 'safety factors'. These safety factors are regrouped in 5 major domains: The Installation, Safety Analysis, Performance and REX, Management and Organization, Environmental Impact.
With regard to the general IAEA recommendations, a graded approach will be handled.

Here below a short description of the content of the 14 PSR safety factors is given:

Installations

1. Plant design: review of the plant design with respect to modern standards and practices.
2. Status of the safety systems and components: Graded approach according to IAEA recommendation; incorporated in the plant asset management (PAM) project.
3. Qualification of safety equipment's: Failure mode effect criticality analysis as part of the PAM project. Additional input is coming from the stress test evaluation.
4. Ageing and long term operation (LTO): Time factor as integral part of the PAM project.

Safety analysis

5. Deterministic safety analysis: application of modern methods to the existing safety cases.
6. Probabilistic safety analysis: benchmark of the PAM conclusions with high safety significant components identified in the PSA.
7. Robustness against internal and external events: further analysis of the stress-test findings.

Performance and return of experience (REX)

8. Safety performance: strengthening of current evolution towards quantitative performance goals for all units.
9. Feedback from comparable installations.

Management and organization

10. Organization and administration: Incorporation of BR2 management system in the general SCK Integrated Management System (IMS).
11. Procedures: review to increase the user-friendly character; follow-up by the data-bank ‘training on the job’.
12. Human factors: conclusions and lessons learned from the systematic risk analysis of standard and non-standard operations. Updated evaluation of the Safety Culture.
13. Accident management: based on the findings from the stress-test exercise.

Environmental impact

14. Radiological environmental impact: Special attention on the impact of new activities.

9. PSR16 –Design Upgrades

Design upgrades are being identified by a gap-analysis. Starting from the initial design basis (design limits of parameters, design for operational states, design for accident conditions) the following systems are specifically being evaluated in first priority: the SSC's (structures, systems or components) "important to safety" of the type "safety systems" (protection system, safety actuation system, safety system support systems).
More specifically the following systems are concerned:

- Reactor core and reactivity control system
- Reactor shutdown system
- Reactor protection system
- Reactor coolant system and related systems
- Means of confinement
- Radiation protection systems
- Fuel handling and storage systems.

The information on new requirements for these systems comes from various sources:

- the relevant IAEA documentation,
- the basic PSA study and its various addendums,
- conclusions from the stress-test evaluation,
- REX from the BR2 operational history,
- the previous safety reassessments,
- conclusions and recommendations from the PAM analysis.

The gap-analysis handles the following 5 'criteria':

- Combination of inherent and passive safety-characteristics ('safety features') and 'engineered safety features'. Special attention is given to 'engineered safety features' which only act during 'anticipated operational occurrences' en in 'DBA's'.
- 'Design for reliability'. Most importantly redundancy and the single failure criterion. For incidence, the 'single failure criterion' can be implemented by building in 'fail safe behaviour' or 'diversity'.
- 'Defence in depth': This concept should provide graded ('enveloped') protection against various reactor transients, including transients resulting from equipment failure and human error and from internal or external events that could lead to a DBA.
  In particular, the single failure criterion will be reviewed by ensuring the fulfilment of each of the basic safety functions (as defined by the IAEA).
- Common mode or common cause failures: This aspect, already evaluated in the various extensions of the PSA, is once more being critically reviewed.
- Human Factors: Aspects like ergonomics and user-friendly procedures are being considered.

10. Conclusions

SCK•CEN has decided to approach the forthcoming decennial safety reassessment with the firm intention to continue operation the BR2 reactor for another 10 years period.
The present and foreseeable utilization programme is the main driver for this decision.
The surrounding capabilities, in particular the Hot Cell complex, are a major asset for further utilization of BR2 as a basic tool for the conduction of a number of programmes.
Notwithstanding its age, BR2 is still fit for further operation, due continuous maintenance and timely replacements of ageing equipment's and two major refurbishments.