Ageing management of the BR2 research reactor

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INTRODUCTION

At the Belgian nuclear research centre (SCK•CEN) several test reactors are operated. Among these, Belgian Reactor 2 (BR2) is the largest Material Test Reactor (MTR). This water-cooled, beryllium moderated reactor with a maximum thermal power of 100 MW became operational in 1962. Except for two major refurbishment campaigns of one year each, this reactor has been operated continuously over the past 50 years, with a frequency of 5-12 cycles per year. At present, BR2 is used for different research activities, the production of medical isotopes, the production of n-doped silicon and various training & education activities.

CONTEXT

As for all other nuclear reactors in Belgium, the Belgian safety authorities requested a Long Term Operation (LTO) program for BR2 [1]. This request was made within the framework of the next 10-yearly periodic revision, which considers the period 2016-2026 (PVR2016).

In September 2011, it was decided to address the LTO issue by means of a Plant Asset Management (PAM) project [2]. However, the objective of this project is not limited to complying with the LTO requirements made by the safety authorities. The same program is also set to improve the maintenance and operation of the entire BR2 installation.

PAM METHODOLOGY

Objective

The objectives of the PAM project are firstly to obtain a structured overview of the installation, combined with an objective evaluation of the Systems, Structures & Components (SSCs) which are part of this installation. Secondly, the PAM should consider an integrated, graded approach combining elements from operations, maintenance, design upgrades, inspections and ageing management (including obsolescence).

Approach

The methodology of the PAM project considers three distinct phases. Each of these phases has its own objectives, milestones and deliverables. The three phases are:

- Asset Configuration Management (ACM);
- Installation Concept Management (ICM);
- Work order Management & Skills (WMS).

Each of these three phases will be discussed separately in one of the sections below.

ASSET CONFIGURATION MANAGEMENT

Listing assets

The inventory of the mechanical and electrical assets is created starting from the flow diagrams, the safety report and the descriptive manual of the installation. This is done by members of the PAM team, who have a background in nuclear engineering or Reliability Centered Maintenance (RCM).

Each part of the inventory is verified by another member of the PAM team, in order to have a first control of the content and quality of the list. Later on, when the report of all the assets is created, the complete list is reviewed by BR2 personnel outside of the PAM team.

Evaluating assets

The assets of the BR2 installation -also referred to as SSCs- are evaluated based on three parameters: safety, operational impact and replacement cost. The evaluation is done by a multidisciplinary team (PAM, operations, maintenance, safety department, etc.). During this process a single failure of the SSC is considered, taking into account redundancy of SSCs, where applicable.

For each one of the three parameters different possible scores are considered:

a) Safety:
- Score 0: safety critical SSCs;
- Score 1: SSCs with implication on safety;
- Score 2: SSCs without any safety function.

b) Operational impact:
- Score 1: this corresponds to a cost or loss of revenue of more than € 1 000 000,00.
- Score 2: this corresponds to a cost or loss of revenue of more than € 100 000,00, but less than € 1 000 000,00.
- Score 3: this corresponds to a cost or loss of revenue of less than € 100 000,00.

c) Replacement cost:
- Score 1: the SSC is considered to be irre-placeable;
- Score 2: the replacement or repair costs are larger than € 100 000,00;
- Score 4: the replacement or repair costs are smaller than € 100000,00, but larger than € 10000,00;
- Score 6: the replacement or repair costs which are smaller than € 10 000,00.

For each one of the SSCs, the product of the scores per parameter is calculated. This product (total impact score) will later on determine which maintenance category the SSC is assigned to. Those SSCs with the lowest product are assigned to the most intensive maintenance program. This corresponds to the graded approach [3].

During the scoring of non-redundant assets with different functions and consequences, the lowest score of the possible effects is considered. The

Code	System	AC A	AC B	AC C	AC D	Total	AC A [%]	AC B [%]	AC C [%]	AC D [%]
A	Buildings	25	40	5	5	75	33%	53%	7%	7%
B	Reactor	25	28	33	58	144	17%	19%	23%	40%
C	Primary Circuit	44	268	5	145	462	10%	58%	1%	31%
D	Pool and canal	19	25	33	129	206	9%	12%	16%	63%
E	Secondary Circuit	12	32	47	111	202	6%	16%	23%	55%
F	Experiments Circuit	0	9	7	37	53	0%	17%	13%	70%
G	Radiation monitoring	34	27	101	24	186	18%	15%	54%	13%
H	Electricity	31	23	28	60	142	22%	16%	20%	42%
K	Water and gas supply	1	4	38	161	204	0%	2%	19%	79%
L	Compressed air	7	28	11	151	197	4%	14%	6%	77%
M	Ventilation	11	21	1	92	165	7%	3%	25%	56%
N	Heating	5	40	13	22	80	6%	50%	16%	28%
Q	Solid waste disposal	0	0	0	3	3	0%	0%	0%	100%
R	Liquid waste disposal	2	93	16	38	149	1%	62%	11%	26%
S	Gas waste disposal	2	30	0	4	36	6%	83%	0%	11%
Total		**218**	**668**	**378**	**1040**	**2304**	**9%**	**29%**	**16%**	**45%**

Table I. Overview of assets' evaluation results, according to the specifications of "Evaluating Assets".

different scores are not combined, as the additive effect is not considered.

INSTALLATION CONCEPT MANAGEMENT

Define Asset Classes

Based on the total impact scores, four Asset Classes (ACs) are defined.

a) Asset Class A (scores 0 till 4): a detailed risk analysis is performed, including a time-dependent evaluation of the failure modes (ageing [4]) and the related measures, which are determined by means of a RCM plan for maintenance, ageing and modernization.
b) Asset Class B (scores 5 till 18): a global risk analysis is performed.
c) Asset Class C (scores 19 till 24): corrective main-tenance is applied. However, the impact is limited by a pre-defined repair/replacement procedure.
d) Asset Class D (scores 25 till 36): corrective main-tenance is applied.

An overview of the results of this exercise can be found in Table I.

For AC A -and to a minor extent for AC B- the RCM approach as it is described in [5] serves as a basis. During this exercise, the references [6,7,8] are considered for all the ACs.

Probablity score	Qualitative meaning	Relation to MTBFa
1	Very probable	MTBF ≤ 3 years
3	Probable	3 < MTBF ≤ 10 years
10	Improbable	10 < MTBF ≤ 30 years
30	Very improbable	MTBF > 30 years
1000	Impossible	MTBF ≈ ∞

a. MTBF = Mean Time Between Failure

Table II. Used probability scores and their qualitative interpretation.

Risk profile	Relation to risk
Red	risk = 0
Orange	0< risk ≤ 180
Yellow	180 < risk ≤ 240
Green	Risk > 240

Table III. Relation between risk and risk profile.

Determine maintenance concepts & risk profiles

The maintenance measures for an asset are determined by combining the general maintenance concept and the specific risk profile of an asset. This risk profile is the outcome of the abovementioned risk analysis. In order to determine risk starting from the total impact score (see "Evaluating assets"), an evaluation of the probability or frequency of failure is required. As it is difficult -considering the age and specific character of the installation- to determine this in a quantitative way, a qualitative approach is followed. In Table II an overview is given of the used probability values and their qualitative interpretation.

As mentioned previously in this paper (see "Define Asset Classes"), only the SSCs of AC A and AC B are subjected to a risk analysis. As such, only these assets obtain a detailed risk profile. The assets of AC C and AC D obtain a general risk profile, which is Yellow for those of AC C and Green for those of AC D. In Table III an overview is given of the different risk profiles.

Once the risk profiles are determined, the maintenance tasks can be assigned, based upon the maintenance concept. This states that the combination of all the maintenance measures for an asset -of either AC- should assure that the intended original[1] risk of an asset is maintained.

A thorough discussion of the different maintenance measures lies beyond the scope of the present paper, however, its results are summarized schematically in Figure I.

[1]Original = upon design or construction.

WORK ORDER MANAGEMENT & SKILLS

The main objective of the WMS phase is to integrate the maintenance policy resulting from the previous PAM phases in the daily operation of BR2. This means that the maintenance measures need to be prepared, by e.g. transferring them into maintenance procedures, and executed.

Due to the fact that the scales used for impact and probability are discrete, and the fact that the maintenance policy is determined in a general manner, not all of the proposed maintenance measures can be implemented in a strict way.

Several factors might prevent such a strict implementation, of which a few are mentioned below:

a) Technical feasibility: certain proposed maintenance measures might simply not be feasible because of e.g. design features of the asset itself or of the installation around the asset;

b) ALARA: the cumulated dose which is related to a proposed maintenance measure might be so high that they cause a too large overall exploitation risk;

c) Safety: there might be a too high industrial safety risk attached to a proposed maintenance measure;

d) Technical relevance: due to e.g. design features or spare parts management a proposed maintenance measure might not be relevant.

At the moment that a strict implementation of a proposed maintenance measure is doubtful, its specifications are challenged in a dedicated committee. This committee combines i.a. maintenance, operational, PAM, safety competences. The specifications of a proposed maintenance measure can only be modified upon unanimous agreement of this comity.

From the moment that a proposed maintenance measure has been modified –if so required– it is considered to be a selected maintenance measure.

When a selected maintenance measure is transferred into a maintenance procedure, it is always verified whether different measures cannot be combined into one procedure. This combination can consider both different measures for one asset as similar measures for different assets. In this way, a first step towards an optimized implementation is considered during the preparation of the selected maintenance procedures.

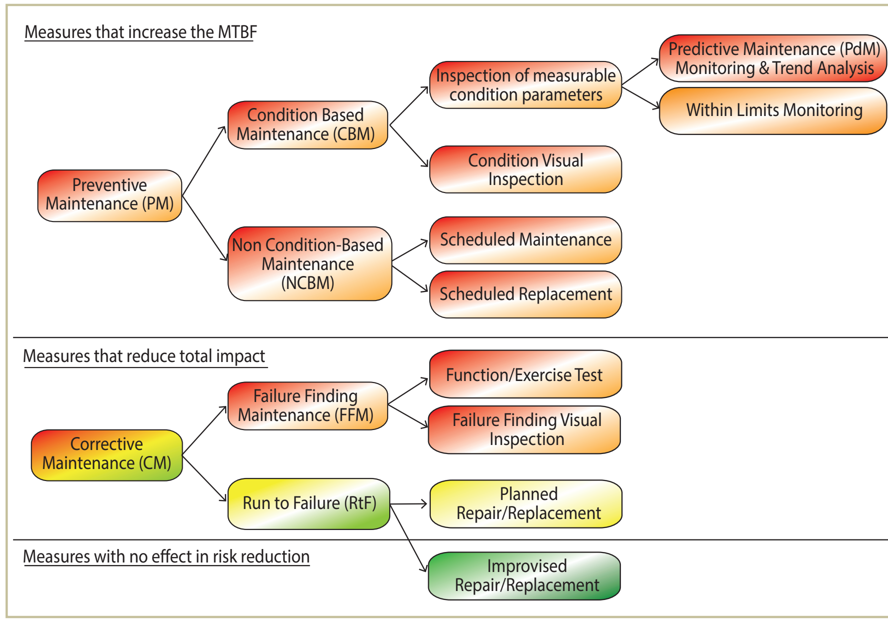

Figure 1. Schematic representation of which maintenance measures are to be performed for the different risk profiles.

The impact of the implementation is assessed on beforehand by means of a double gap analysis:

a) Human resources: which skills are required, and to which amount, by the total set of maintenance measures defined by PAM?

b) Existing procedures: which amount of the selected maintenance measures is already covered by existing maintenance and operation procedures.

In this way, the impact of the new set of maintenance measures on the maintenance teams is identified. Consequently, the required management actions regarding re-organization and human resources can be determined.

LTO DESIGN UPGRADES

The basic philosophy of the PAM methodology is to maintain (or return) the risk related to the exploitation of the BR2 installation at (to) the original installation design risk level. For certain assets, this cannot be obtained by the set of selected maintenance tasks alone. In such cases, LTO design upgrades are required.

The process to identify LTO design upgrades considers the following elements:

1) *Reducing residual risk:* Due to several boundary conditions (installation/process specifications, financial impact, human resources, industrial safety, radiological impact, environmental impact, etc.), it might be decided not to implement all of the maintenance actions for a particular asset. The risk related to the considered asset is not reduced to the preferred level by the set of selected maintenance measures, hence, certain residual risk remains.
The first input to the process of identifying possible LTO design upgrades focuses on reducing the abovementioned residual risk. This is based on the differences between the lists (per asset) of the proposed and selected maintenance measures.

2) *External impact:* In certain specific situations, assets of the BR2 installation might be exposed to a risk arising from an external event or other equipment. The term "external impact" is only used when certain elements or influences -which are not related to the function of the asset or the process it takes part in- that have not been considered during the design of the asset introduce a significant risk to the asset or its function.

3) *Common Cause Failure (CCF):* When the BR2 installation was designed, certain assets or functions were executed in a redundant manner in order to reduce the total risk to an acceptable (design) level. However, as some Common Cause Failures (CCFs) were not known at that time, the preferred risk level was not achieved. By taking CCFs into account as LTO design upgrades, the originally foreseen design risk level can be attained.
During the PAM process, attention

is given to the detection of CCFs. In case a CCF is identified, this is mentioned in the ICM report of the considered asset. During the Probabilistic Safety Assessment (PSA), CCFs have been registered as well. In this framework, a CCF is considered to be a failure that leads to:

- Loss of redundancy of a safety function;
- Loss of multiple levels or defense-in-depth of a safety function.

4) *Obsoleteness:* Due to e.g. ageing, legal, technical or economic reasons, an asset or a technology might become obsolete. This obsoleteness creates a risk for the exploitation of the asset and of the entire BR2 installation. As a result, eliminating obsoleteness of a technology or an asset leads to a reduction of the risk linked to the exploitation of BR2. Consequently, when obsoleteness is identified by means of the PAM process, maintenance, operations, best practices, engineering judgment, safety authorities, etc., this should be registered as a design upgrade opportunity.

5) *Human failure:* When the BR2 installation was designed, the issue of human failure was not yet fully recognized. As a result, this aspect was not properly evaluated when the original risk level was established. By taking human failure into account as an input to LTO design upgrades, the originally foreseen design risk level can be attained. Cases of human failure can be detected during several processes: PAM, maintenance, operations, safety tours, etc.

RECOMMONDATIONS

The installation of a PAM approach implicates that the future maintenance will be organized based on a graded RCM approach. However, in the past, the maintenance of a nuclear reactor was founded on a combination of technical experience and strict directives of safety authorities. As a result, the implementation of a PAM program requires a new way of working, hence, this implementation needs to be considered as a "change project".

Since a PAM project is often developed online with the installation in operation, its preparations might interfere with the daily tasks of the maintenance and operations departments. This element, combined with the fact that the development itself is limited in time, indicates that such a program is best to be led by a separate team. However, it is mandatory to install and maintain a close and open collaboration with the involved departments. This is because they own a large part of the technical, operational and safety know-how. Transferring this know-how into the PAM project is a time-consuming process, which needs to be recognized and organized on beforehand.

During the development (ACM and ICM phase), it is vital to maintain a robust, theoretically correct approach. However, it is important to recognize that there are (at least) two risks attached to such an approach:

a) If the distance between theory and technical practice becomes too large, the former appears irrelevant. As a result, the support of the entire PAM program could disappear.

b) A strict implementation, without recognizing practical issues, leads to an impractical, unusable maintenance program. This risk rises as the amount of impact scores per parameter diminish.

As a result, in order to assure that the developed PAM program will indeed be implemented, sufficient moments at which any stakeholder can challenge the specifications of the maintenance tasks need to be foreseen.

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REFERENCES

[1] S. Coenen, B. Tombuyses, F. Van Wonterghem, "Strategienota "Long Term Operation" van de Belgische onderzoeksreactoren", 2011-05-20-SCO-5-4-1-NL (20/05/2011)

[2] S. Van Dyck, "NBR2-2020: kaderdocument", SCK•CEN BR2/SVD/NBR22020/001, version 2.2 (November 2011).

[3] IAEA, "The use of a graded approach in the application of the safety requirements for research reactors", Safety Standard DS351 (20/11/2009)

[4] IAEA, "Ageing management for research reactors", SSG-10 (Vienna, 2010)

[5] IAEA, "Application of Reliability Centred Maintenance to optimize operation and maintenance in nuclear power plant", IAEA-TECDOC-1590 (May 2007)

[6] IAEA, "Guidance for optimizing nuclear power plants maintenance program", IAEA-TECDOC-1383 (December 2003)

[7] IAEA, "Implementation strategies and tools for condition based maintenance at nuclear power plants", IAEA-TECDOC-1551 (May 2007)

[8] IAEA, "Maintenance, periodic testing and inspection of research reactors", Safety Guide NS-G-4.2 (Vienna, 2006).