Reactor pressure vessel closure head replacement of the Belgian Tihange 3 and Doel 4 units – Follow-up and on site dosimetry

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1. Introduction

According to a technical report from the IAEA referenced in [1], alloy 600 components such as control rod drive mechanism (CRDM) nozzles have experienced primary water stress corrosion cracking (PWSCC) during the last 25 years. PWSCC of the CRDMs can lead to boric acid corrosion of the reactor vessel closure head (RVCH), resulting in risks of primary water leaks and therefore potentially having a significant impact on the plant safety. As some of the Belgian nuclear power plants are also concerned, it was decided to perform the RVCH and the CRDMs replacement for two Belgian nuclear power units: Doel 4 and Tihange 3. Besides the replacement of these components, the project was also the opportunity to perform the renovation of the rod position indicators (RPIs) and electromagnetic assemblies (EMAs).

In 2011 Tractebel ENGIE (TE) was designated by Engie Electrabel (EBL) as owner's engineer. The manufacturing and installation of the two new RVCHs and CRDMs was granted to AREVA NP.

Each of the manufactured RVCHs is composed of:

- A forged flange and a hemispherical dome;
- 66 penetrations for the control rods;
- Control Rod Driving Mechanisms;
- New thermal insulation.

After manufacturing of the different parts and a partial assembly in factory, the new RVCHs and CRDMs were transported to site where final assembly tasks were performed.

The replacement of the RVCHs and the CRDMs was performed during the outages of March 2015 and September 2015 for the Tihange 3 and Doel 4 entities, respectively. An ALARA evaluation, consistent with both site specific replacement works, was performed for each nuclear site, together with an intensive follow-up of the activities during the execution phase. This paper gives an overview of the preparatory works for the collective dose estimates and the dosimetric follow-up performed during the outages.

Note that old Tihange 3 and Doel 4 RVCHs were equipped with internals disconnection devices (IDDs) which allow quick refuelling. These parts were cut during previous outages of the units and are out of the scope of this study.

2. Implementation of ALARA

2.1 Objectives

The following objectives have been defined in the framework of the replacement project, in correspondence with the general objectives of the outage:

- No work incidents;

- No nuclear incidents;
- No radioactive contamination incidents;
- Minimal collective and individual dose according to the ALARA principle.

These objectives have been communicated to all workers prior to the start of the execution phase of the project.

2.2 ALARA working group

Conform to previous large component replacement projects, e.g. steam generator replacements, an ALARA working group with different people specialised in radiation protection and implementation of the ALARA principle was composed. This group was entrusted with the definition of the nuclear safety and radiation protection actions for these projects at Doel and Tihange sites.

Two important tasks were defined for this working group:

- Before the execution phase, this group defined and checked the possibilities to implement the ALARA principle. They studied, with the cooperation of the contractor, dose rates, organisation of work stations and tasks to be performed to finalize the RVCH replacement. The team also calculated and validated the collective dose estimates for both RVCH replacement projects;
- During the outage, the group ensured the dosimetric follow-up and analysed the radiological conditions (radiation and contamination levels) in the vicinity of the replacement site. They regularly checked the biological protections. Furthermore, a daily verification of the collective and individual doses was carried out to obtain a view on the daily dosimetric evolution of the project and to detect anomalies compared to the estimates. Evolutions and actions were discussed with the owner and the contractor on a daily base. After discussion, the estimates were adapted when important changes in the planning were foreseen and if non-negligible extra contributions would arise due to unforeseen tasks.

3. Estimation of the collective dose before replacement

3.1 Measurements and estimates

During the previous outages, dose rate measurements were performed around the RVCH according to Figure 1. This mapping helps to identify hot spots and, in function of the tasks performed in the vicinity of these points, extra shielding could be foreseen to reduce the collective and individual dose uptakes. The measurement campaigns showed that the dose rates for Doel 4 were lower than those for Tihange 3. In average the estimated dose rates were 30% lower for Doel 4.

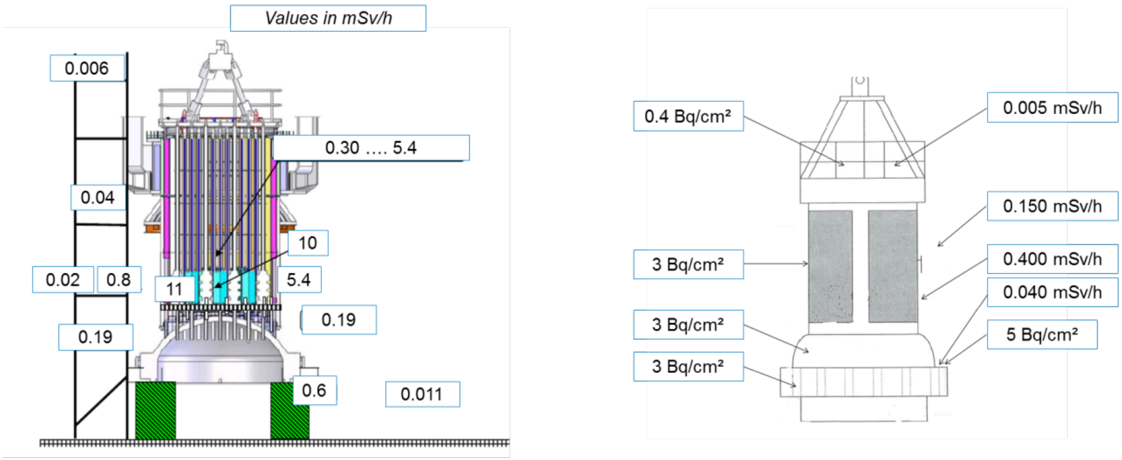

Figure 1 – Dose rate and contamination measurements of the RVCH of Tihange 3 (left) and Doel 4 (right).

These measurement points do not cover all specific work areas. Additionally, dose rate estimates were performed based on the contractor REX in combination with measurements. Due to the similarity between the Doel 4 and Tihange 3 RVCHs, the measurements taken during the execution phase of the Tihange 3 replacement project were used as REX for Doel 4.

3.2 Methodology

Based on estimated man-hours, measured/estimated dose rates and actions taken by the ALARA working group, a collective dose can be assessed. The following methodology is used:

- Definition of dosimetric phases, linked to the project execution phases. A dosimetric phase is a period during which the radiological state (dose rates defined for a specific component) of the working area remains stable (e.g. removal of the ventilation mantle, removal of the EMAs, etc.);
- Subsequently the different tasks and their corresponding work stations are defined;
- Each workstation is linked to its corresponding dose rate estimates (per dosimetric phase). The estimated average dose rate per work station and per dosimetric phase will be collected in a database (DATADOS);
- For each activity, part of the project, an estimation of the man-hours is performed based on the REX of the contractor (and Tihange 3 in the case of Doel 4);
- Every activity is linked to a:
  - Category of tasks to determine dose reduction factors (e.g. cutting, scaffolding, etc.);
  - Group of tasks to define the ALARA file (e.g. dismantling of the ventilation mantle, dismantling of the EMAs, etc.);
- EBL defined a set of dose reduction factors, based on the operational REX for specific tasks over the years. These coefficients are used to optimize the calculated collective doses and always represent a value lower than unity.

After definition of these parameters, the collective dose for each activity is calculated and a global dosimetric estimate for the replacement project is obtained.

3.3 Results

Figure 2 shows the evolution of the daily estimated collective dose for both Tihange (red) and Doel (blue) projects. Collective doses of 103.7 man.mSv and 73.9 man.mSv were estimated for Tihange 3 and Doel 4, respectively. The decrease in the collective dose estimate for Doel 4 is due to a reduction of 22% of the estimated man-hours, resulting from the REX of Tihange 3 RVCH replacement project and the lower dose rates around the old Doel 4 RVCH compared to Tihange 3 (see § 3.1).

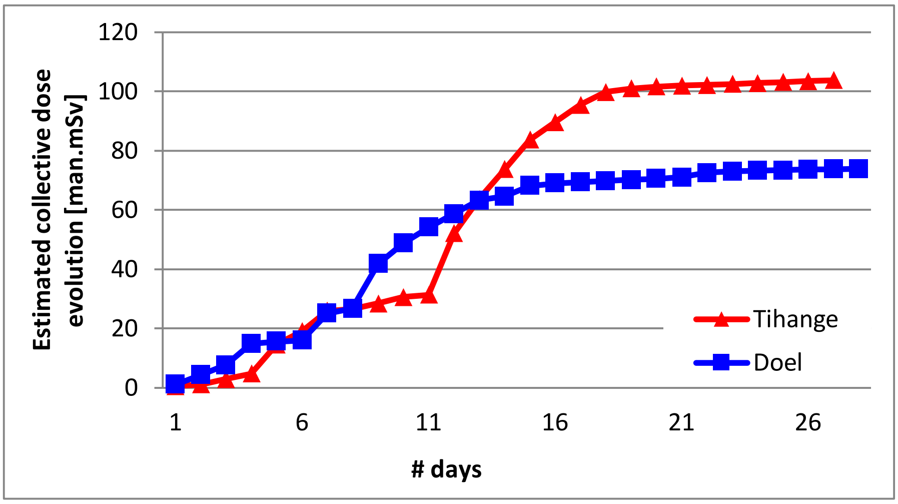

Figure 2 - Initial collective dose estimates for the RVCH replacement projects.

The red curve for Tihange in Figure 2 takes into account the following steps:

- Preparatory works (day 1 to 4): main tasks occur at relatively long distances from the old RVCH which is completely shielded. Consequently, the collective dose is small;
- First dismantling tasks (day 5 to 8): due to the dismantling of the outer ventilation cover and the RPIs, the RVCH self-shielding is reduced and tasks are performed in a higher dose rate area;
- Dismantling of EMAs and introduction of the new RVCH (day 9 to 11) into the reactor building: the removal of the lower shroud and the thermal insulation contributes significantly to the collective dose. Especially the removal of the lower ventilation mantle induces a high collective dose uptake in the proximity of the old RVCH dome and CRDM adapters;
- Dismantling of CRDMs (day 12 to 17) and start of the new RVCH assembly: assembly activities are performed in close proximity of the old RVCH and CRDMs. Consequently, dose rates at the work stations are higher and the collective dose increases significantly;
- End of the new RVCH assembly and evacuation of the old RVCH (day 18 to 27): the old RVCH is extracted from the reactor building and transported in a shielded container. Once evacuated, dose rates around the new RVCH decrease.

The blue curve for Doel in Figure 2 takes into account the following steps:

- Preparatory works (day 1 to 3): preparatory tasks of the Doel project are performed with lower dose rate estimates but are more concentrated. Compared to Tihange, extra tasks were also performed. As a consequence a higher collective dose is achieved in the preparatory phase;
- First dismantling tasks (day 4 to 6): the dismantling of the outer ventilation cover, electrical disconnection and dismantling of the RPIs. As dose rates around the old RVCH are lower compared to Tihange, a lower daily collective dose is estimated. This also explains the less steep slope of the blue curve compared to Tihange;
- Dismantling of EMAs (day 7 to 8): the main EMA dismantling work stations are located at the top level of the RVCH where lower dose rates are present due to the shielding effect of the EMAs and CRDMs;
- Dismantling of CRDMs (day 9 to 14): work stations to dismantle CRDMs are in close proximity of high radiation zones (RVCH dome, CRDM adapters, etc.). Consequently, a fast rise of the collective dose is observed. However this rise is less steep compared to the Tihange project as dose rates were estimated to be lower. Moreover no collective dose is acquired due

to the assembly of the new RVCH as it is not introduced in the reactor building at that moment;
- Evacuation of the old RVCH and assembly of the new RVCH (day 14 to 28): the old RVCH is evacuated from the reactor building prior to the new RVCH introduction. Hence the assembly results in a less collective dose uptake.

In general both curves show a comparable evolution of the collective dose. At the beginning of the project a first small increase of the collective dose is observed. This increase begins earlier for the Doel project. Then curves present a second rise of the daily collective dose before becoming less steep until the end of the project. The total duration for both projects is similar. Typically, the Doel project should take more time due to its serial approach (evacuation of the old RVCH before assembly of the new RVCH). However, this increase of time was compensated by a reduction of man-hours.

The second increase is steeper for the Tihange project, especially between day 11 and 17 (day 8 till 12 for Doel). This difference can be partially explained because of the higher dose rates measured at the Tihange power plant. This strong increase can also result from the methodology used for the RVCH replacement. In Tihange the new RVCH was assembled during the disassembly of the old RVCH. Consequently, the dose rates at the work stations of the new RVCH were higher due to the proximity of the old RVCH. For Doel, the new RVCH was only introduced after evacuation of the old RVCH. The collective dose due to the assembly of the new RVCH hence was lower.

4. ALARA follow-up

4.1 On-site follow-up

During the execution phase of the replacement projects, the TE ALARA team acted as a direct link between the TE project team (and its contractors) and the EBL radiation protection team. This allowed efficient and faster communication between the different actors.

The TE ALARA team ensured the following tasks:

- Monitoring and follow-up of the dosimetric estimate in function of important changes in planning or activities that occur during the execution phase;
- Follow-up and feedback on daily and collective dosimetry data;
- Providing feedback and advice for corrective measures;
- Ensuring compliance with rules and instructions that are part of the ALARA procedures;
- Measurements of waste containers leaving the controlled area, prior to transport;
- Measurements of the waste containers after storage.

Figure 3 presents the ALARA procedure which was in application during the execution phase of the project. The radiation protection staff of the owner performed measurements prior to the start of works at the work stations. At the beginning of a dosimetric phase, these measurements were performed together with the TE ALARA team. Figure 3 also lists the different actions that could be considered if unexpected dose rates or contaminations were detected. Inversely, if no contamination or unexpected dose rates are observed, works can start.

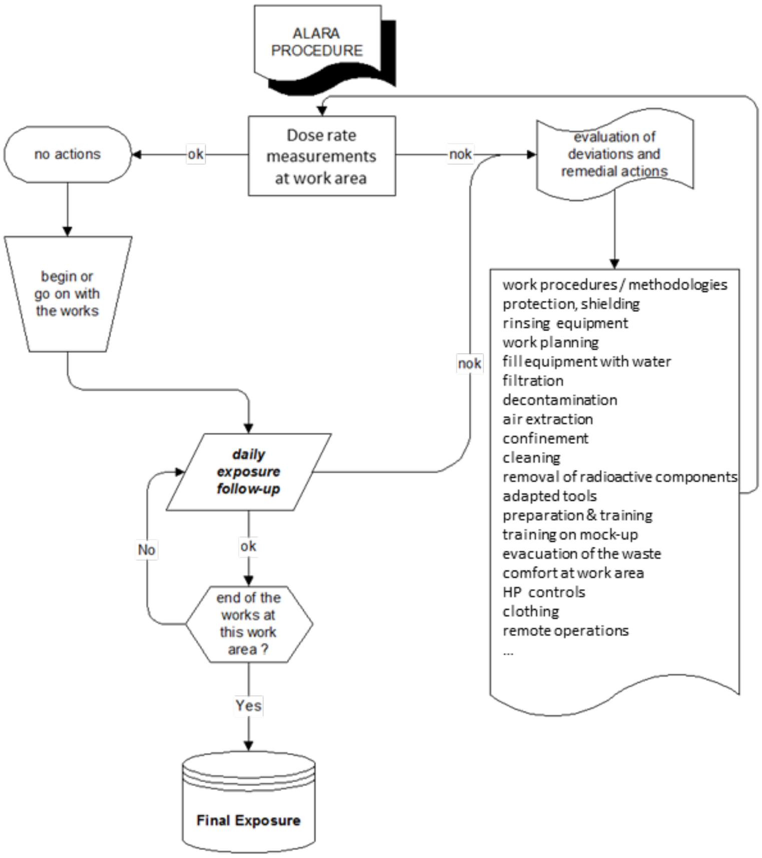

Figure 3 - Flow chart of the ALARA procedure implemented for the replacement projects.

4.2 Recommendations

Both prior to and during the execution phase, the ALARA group gave several recommendations in order to optimize the collective dose:

- The reactor pool was kept filled at all times to minimize the contribution of the reactor core structures to the ambient dose rate levels;
- Cartographies with the dose rates at the level of the scaffolding were presented at the entrance of the working area;
- Additional shielding was foreseen in case hot spots were detected;
- An active sensitization of workers during the execution phase;
- Clear indications at high dose rate areas.

5. Dosimetric follow-up

A daily dosimetric follow-up was performed during the execution phase of the project. It consisted of:

- Daily consultation and processing of individual and collective doses;
- Evaluation of the works progress;
- Regular measurements performed by the TE ALARA team and the radiation protection officers of the owner.

5.1 Tihange replacement project

During the execution phase, some of the EMAs were blocked and had to be manually dismantled in close proximity of the RVCH dome. This resulted in a significant collective dose contribution. Based on estimated man-hours and measured dose rates, a collective dose of 9 man.mSv was estimated for the dismantling of these EMAs. The collective dose after the dismantling of the blocked EMAs was finally limited to 3.62 man.mSv due to optimization by using extra shielding at the scaffolding platform and RVCH dome.

Because of elevated dose rates at the level of the RVCH storage container, a temporary lead wall was built in the storage building to reduce the dose rate levels outside of the storage building. This extra task represents a collective dose of 0.9 man.mSv. Today, the lead wall is replaced by a concrete wall to ensure that site regulations are permanently complied with. The dosimetric results coming from this last action have not been included in the curves but represent a collective dose of 1.2 man.mSv (2 man.mSv was estimated prior the execution phase).

Figure 4 illustrates the collective dose evolution during the RVCH replacement of Tihange 3 (purple curve). The green curve represents an update of the initial estimate prior to the project, taking into account the delays due to the blocked EMAs and other delays that occurred during the project. Compared to these estimates, the purple curve shows daily collective doses lower than the estimated ones. The total project collective dose result is 76.3 man.mSv.

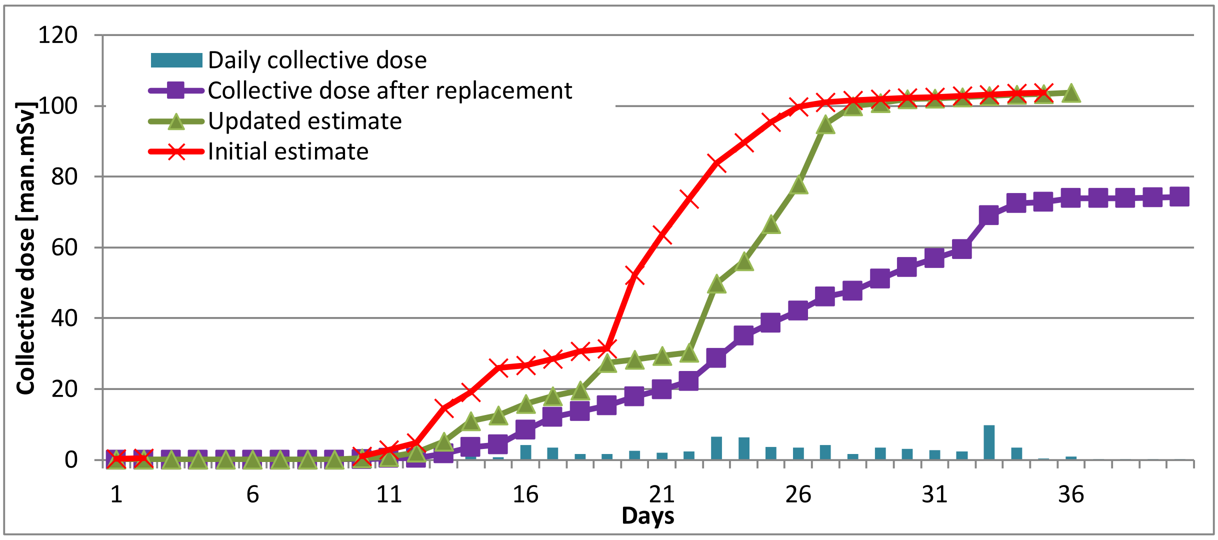

Figure 4 - Comparison between collective dose after replacement and estimated collective dose for the Tihange 3 project.

5.2 Doel

During the execution phase, a delay of one week appeared due to a problem with a bi-metallic weld on the new RVCH. During this period only a limited number of tasks were allowed close to the old RVCH. The only task performed was the removal of blocked EMAs. Based on the limited number of blocked EMAs and the dose rate measurements, no collective dose estimation was performed.

Figure 5 illustrates the collective dose evolution during the RVCH replacement of Doel 4 (purple curve). The green curve represents an update of the initial estimation prior to the project, taking into account the delay due to the issue with the bi-metallic weld. Compared to the estimates, the final collective dose was 52.02 man.mSv/h, i.e. 30% lower than the estimates. Based on the project conditions, this can primarily be linked to the positive influence of lower dose rates at the different work stations.

An important contribution to the collective dose for the Doel project was the decontamination of the RVCH after having found high levels of contamination (wipe samples up to 10 mSv/h in contact). The decontamination, initiated to reduce the risk of further spread of contamination and internal contamination of the workers, represents 6 man.mSv or about 12% of the total collective dose consumed during the execution phase.

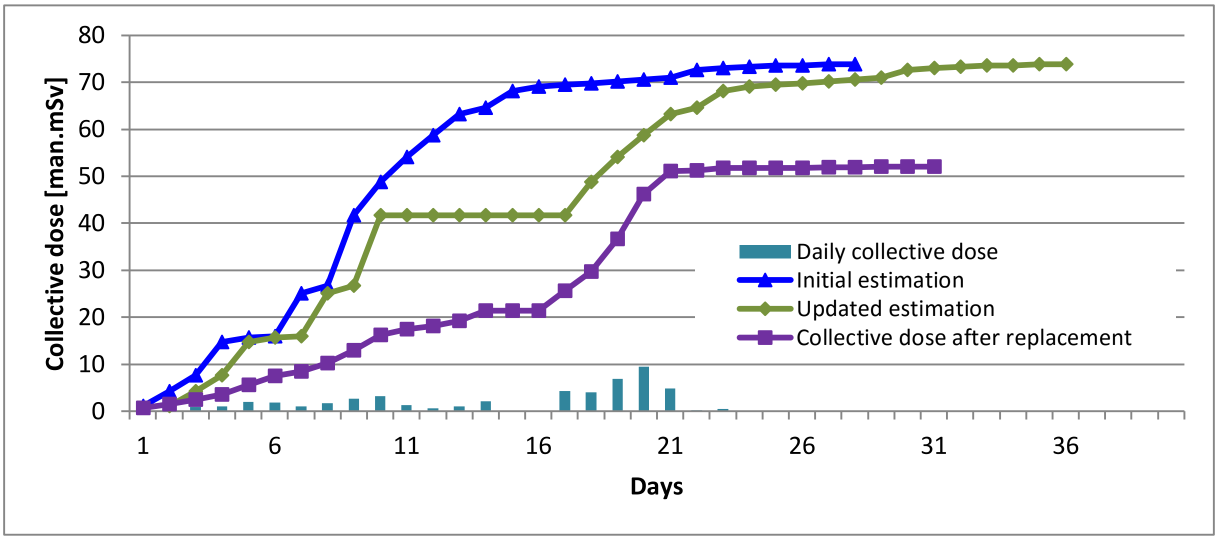

Figure 5 - Comparison between collective dose after replacement and estimated collective doses for the Doel 4 project.

6. *Lessons learned*

Some conclusions can be highlighted, based on issues that occurred during the execution phase:

- Prior to the transfer of the old RVCH towards its storage container, dose rate measurements around the old RVCH should be performed to determine whether transport conditions will be met. An assessment of the required shielding should be made if dose rates were too high;
- A back-up plan for dose intensive tasks should be available (e.g. for the disassembly of blocked EMAs, issues with the CRDMs cutting device, etc.);
- After cutting of components with high risks of contamination, a radiation protection officer should be informed to check whether no spread of contamination occurred.

7. *National and international comparison*

7.1 National comparison

In 1999 the RVCH of the Tihange 1 unit was replaced. This project however was significantly different from those performed in 2015, resulting in a significant higher collective dose during the 1999 replacement project.

For the Tihange 1 replacement, the CRDMs had to be re-used. Consequently, a decontamination of the EMAs and CRDMs prior to their installation on the new RVCH was required, resulting in more dose intensive tasks.

The total collective dose for the Tihange 1 replacement project was 275 man.mSv, being a factor 3.6 higher compared to the Tihange 3 project (see also Figure 6).

7.2 International comparison

In Figure 6, a comparison between several international RVCH replacement projects is given (ref. [2], [3] and [4]), starting from the earliest (Bugey 5, France, 1994) to the most recent project (Doel, Belgium, 2015).

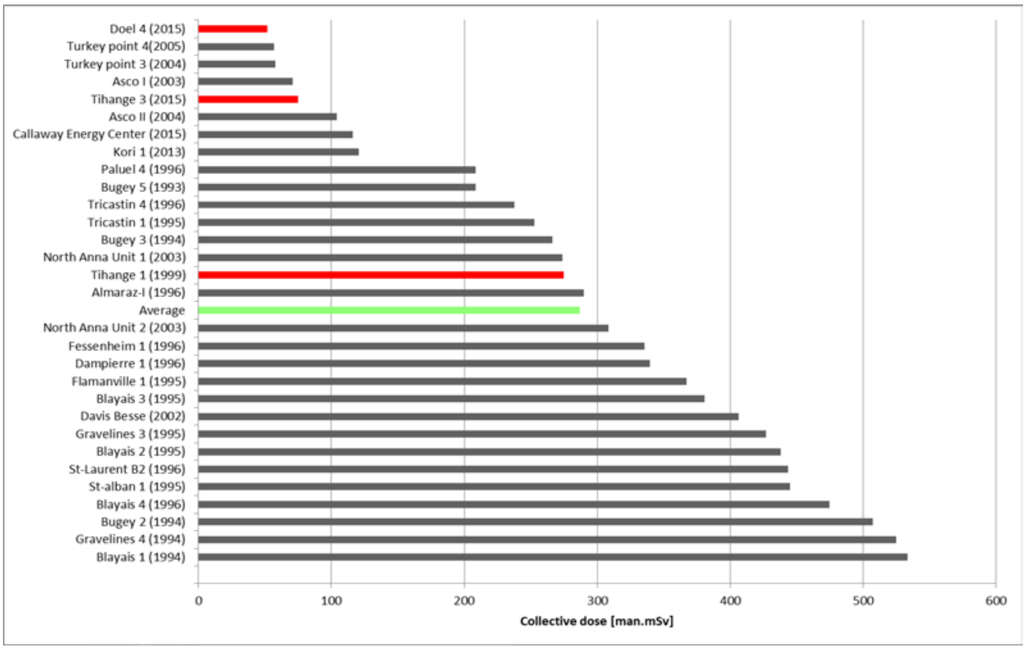

Figure 6 - (Inter)national comparison of RVCH replacement projects. In red, the Belgian replacement projects and in green, the average value of all reported replacement projects [2][3][4].

In general, a decrease in collective dose is observed for more recent replacement projects. This can be explained by:

- REX of previous projects;
- Optimisation of the tasks and techniques, including qualified methodologies that reduce the time necessary for dose intensive tasks (e.g. remotely operated cutting tool for CRDMs).

Comparison between the different projects is difficult because there are significant differences between replacement projects (e.g. serial or parallel approach for the dismantling). Moreover the radiological conditions of the RVCH can vary strongly in function of the concerned nuclear power plant.

8. Conclusion

For both the Tihange and Doel replacement projects, the objectives have been met. The Tihange and Doel projects resulted in collective dose of respectively 76.3 man.mSv and 52.02 man.mSv. The Doel project ended with 32% less collective dose compared to the Tihange project which is explained by the difference in approach, lower dose rates and the REX of the Tihange project.

Based on international data, the dosimetric results of the most recent RVCH replacement projects of Doel and Tihange are in line with expected collective dose results.

9. *References*

[1] Stress Corrosion Cracking in Light Water Reactors: Good Practices and Lessons Learned, IAEA Nuclear Energy Series, No. NP-T-3.13.

[2] NATC ISOE Information Sheet No. 2003-08 – United States pressurized water reactor (PWR) reactor head replacement dose benchmarking study.

[3] Occupational Exposures at Nuclear Power Plants – Annual reports – ISOE.

[4] ETC ISOE Information Sheet No. 09 – Reactor Vessel Closure Head Replacements (1994 – 1996).