Steam Generator Replacement of the Belgian Doel 1 unit: follow-up and on site dosimetry

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1. Introduction

After six successful steam generator replacements (SGR) at the Belgian nuclear power plants, Electrabel (EBL) committed Tractebel Engineering (TE) with the seventh one. Time had come to make Doel 1 unit (392 MWe) ready for future operation. Electrabel chose to replace the steam generators during the months of November and December 2009. Bad weather conditions and the presence of asbestos fibres in the insulation were extra difficulties to overcome besides the specific works needed for the replacement of the steam generators.

An ALARA evaluation, consistent with the specific on-site works, was performed and an intensive follow-up of the activities was done during the course of 2009. Due to a strict prevention policy and the dedication of the different contractors, low exposure levels were achieved. As a result, this project ranks amongst the best dosimetry results obtained in Belgium, and in the world. The figure below shows the Doel nuclear power plant. Doel 1 is the reactor building first from right.

Figure 1 - Doel nuclear power plant.

Doel 1 is the oldest Belgian nuclear unit. Indeed, Doel 1 was put in operation in 1975 [1]. Doel 1 is part of a twin reactor: together with Doel 2 it shares some circuits and systems. The equipment of Doel 1 are almost the same as those of Doel 2. The steam generator replacement of the Doel 2 unit took place in 2004. The primary circuits of both units are separated and consequently the chemistry and radioactive deposits are different.

The old steam generators of Doel 1 served for 35 years, and because of multiple repairs during the last years of service and considering the conceivable life time extension of the unit, a steam generator replacement was justified. The steam generators replacement project has been combined with a power upgrade of 10%.

The Doel 1 unit was built in the seventies and due to the time spirit, a steam generator replacement was not considered at that time. The door of the reactor building is not big enough to exit and enter the old and new steam generators and handling inside the reactor building was not considered. These problems were also encountered during the SGR of Doel 2 in 2004. To overcome them, Tractebel Engineering figured out a solution: lifting the steam generators of their cells through the ceiling of the reactor building. The same solution was used for the SGR of Doel 1.

Figure 2 - Overview of the lifting operation of the old steam generators.

Opening the roof of the reactor building demands special ALARA care, besides the preparation of mechanical works. Following acts had to be fulfilled:

- Shutdown of the reactor;
- Emptying the core: all fuel elements had to be moved to the fuel storage pools outside of the reactor building;
- Temporary closure of the reactor building;
- Reactor building always in under pressure. By this means, there is always a stream of air that goes inside the reactor building but never from the inside to the outside and possible contaminations are kept inside the reactor building.

2. Implementation of ALARA

2.1. ALARA working group

For the steam generator replacement project, EBL and TE composed a working group with different people specialised in radiation protection and the implementation of the ALARA principle. This group was entrusted with the implementation of nuclear safety and radiation protection (including ALARA) applicable at the Doel and Tihange sites.

This group had 2 tasks:

- During the pre-study phase, this group defined and verified the possibilities to implement an ALARA policy. They started studying the dose rates, different possibilities for shielding materials, adapting the water configurations of the primary circuit to the outage works, estimating the effective dose, preparing the follow-up of the dosimetry, defining the objectives, …
- During the SGR outage, the group assured the dosimetric follow-up and analysed the dosimetric condition on the work floor. They regularly verified the radiological status of the unit and controlled the biological protections. A daily control of the collective and individual doses was carried out to obtain a view on the dosimetric evolution of the doses to detect anomalies compared to the estimates. Adaptations of the estimates were done when important changes in the planning were assumed.

2.2. Longtime based efforts for implementation of ALARA

The Doel 1 unit is the oldest nuclear reactor for production of electricity in Belgium. Due to years of good maintenance and precautions in the field of radiation protection, EBL successfully controls the dosimetric conditions of the unit.

EBL tries to reduce the contamination of the primary circuit, the atmospheric contaminations, the dose rates, and radioactive waste. Moreover, a site limit of 10 mSv during 52 sliding weeks is effective for the EBL personnel.

The use of local zones implies a strong dosimetric follow-up of activities on locations where high dose rates are registered.

2.3. Definition of the objectives

First of all the working group defined some objectives regarding safety and radiation protection. The defined objectives were the following:

1. No work accident;
2. No nuclear incident;
3. No radioactive contamination incident;
4. SGR radiation dose lower than the radiation dose of the SGR of Doel 2 (<195 man.mSv).

3. ALARA preparation for the SGR

3.1. Pre-study: measurements, simulations and definition of biological protections

Before the beginning of the practical work, a few topics and useful precautions had to be defined so that a simple and easy overview could be obtained:

- The project was divided into dosimetric phases. A dosimetric phase is a time period during which the state of the unit stays stable: no change or movement of the existing sources is considered. The phases were defined depending on the emptying of certain circuits, the presence of lead protections and the configurations of the old and new steam generators;
- Subsequently the work places were defined. Every planned activity was linked to certain work places needed to achieve the goal of the activity;
- Every activity was coupled to a task number. Due to this all the activities could be easily grouped;
- At the work places that were critical for this project, measurement points were defined. After multiple measurement campaigns, spread over 2 outages, in different configuration states of the steam generators and the follow-up of dose rates at specific points, a large set of practical data was acquired. A lay out of the specific measuring points is shown in figure 3;
- By means of wipes tests of the man holes of the steam generators and on-site gamma spectroscopy it was possible to determine the source term;
- EBL defined a set of dose reduction coefficients based on their experience over the years with other projects. The coefficients were used to optimize the calculated doses.

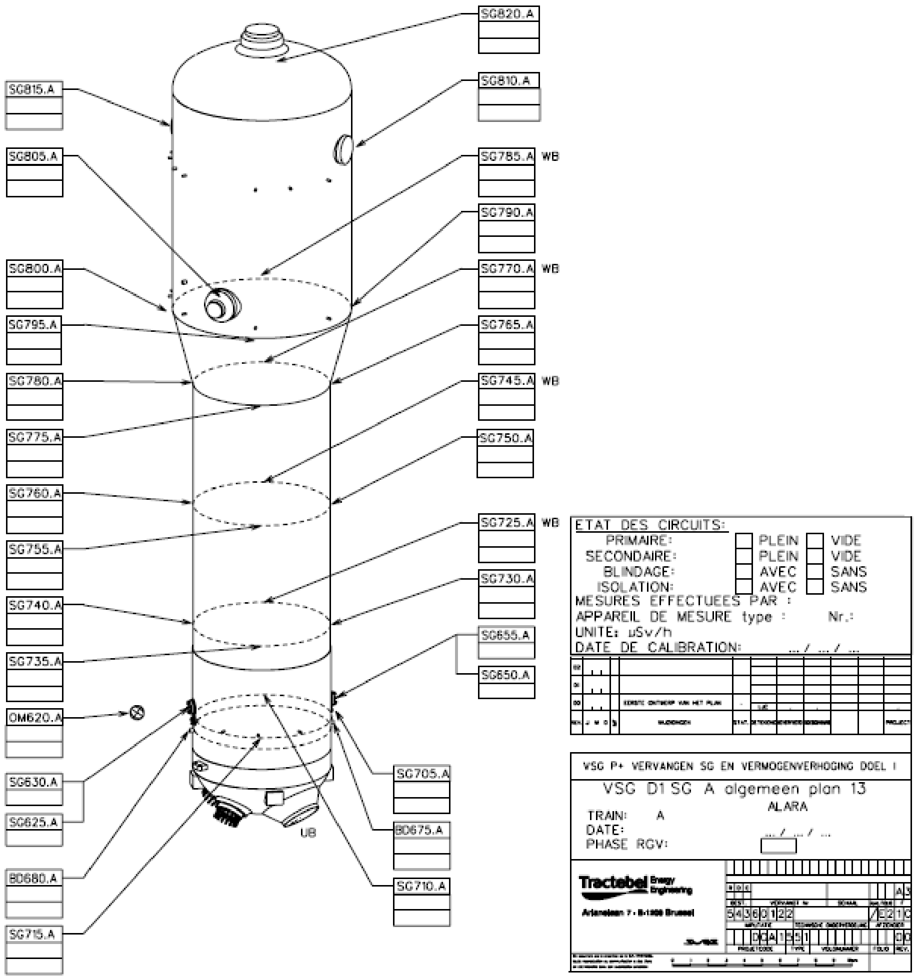

Figure 3 - Layout measurement campaign around steam generator.

It was not always possible to measure all required dose rates during the measuring campaigns. By means of simulations with QAD-CGGP software [2], the missing dose rates were calculated. The dosimetric phases that could be measured more or less during the outages were compared to the calculated dose rates.

Considering the results of the measurement campaigns, which resulted in 30 % higher doses compared to Doel 2, and the planning of the works, the biological shielding was defined: 110 tons of lead were installed during the outage.

An extra issue during the preparation of the works, was the insulation of the old steam generators. The insulation probably contained asbestos fibres. TE and EBL decided to take this uncertainty into account and measures were taken to prepare asbestos works in the reactor building. Consultation between the ALARA working group and the asbestos working group, lead to the construction of an asbestos tent in the steam generator cells. Due to the fact that the steam generators were placed in cells these walls served as an asbestos confinement. The top and the bottom of the cells were bound by a construction of scaffolds and plastic sails. The tent was kept under pressure, to ensure no further spread of asbestos fibres. The ALARA working group helped to define the location with the lowest doses, rest zones, and entrance and exit of the tent were adapted to these findings.

After calculation of the dose for every activity a dosimetric estimation was obtained. This objective was higher than the initial objective (radiation less or equal to the radiation dose of the SGR of Doel 2). One of the reasons was the 30% higher dose rates in the steam generator cubicles compared to the Doel 2 unit. The dose rates were also found in another configuration: at Doel 2 the highest dose rates were found at the SG legs and the area of the SG man holes and the lower part of the SG. Doel 1 showed higher doses around the SG legs and the SG cubicle. These factors had an extra influence on the asbestos works: the asbestos fibres could be found around the primary and secondary part of the SG.

Asbestos works were never before carried out in a Belgian unit: in comparison with the initial insulation works, more work, time and people and a bigger uncertainty influenced the estimate in a negative way for reaching our goal.

The objective was fixed at 375 man.mSv. The figure below shows the dosimetric estimate. In the beginning we see a strong increase of the dose due to the installation of the shielding and scaffoldings. Afterwards the removal of the asbestos insulation, the primary cuttings and preparations of the lifting activities induce a further increase. Once the old steam generators had left the reactor building the dose rates dropped significantly.

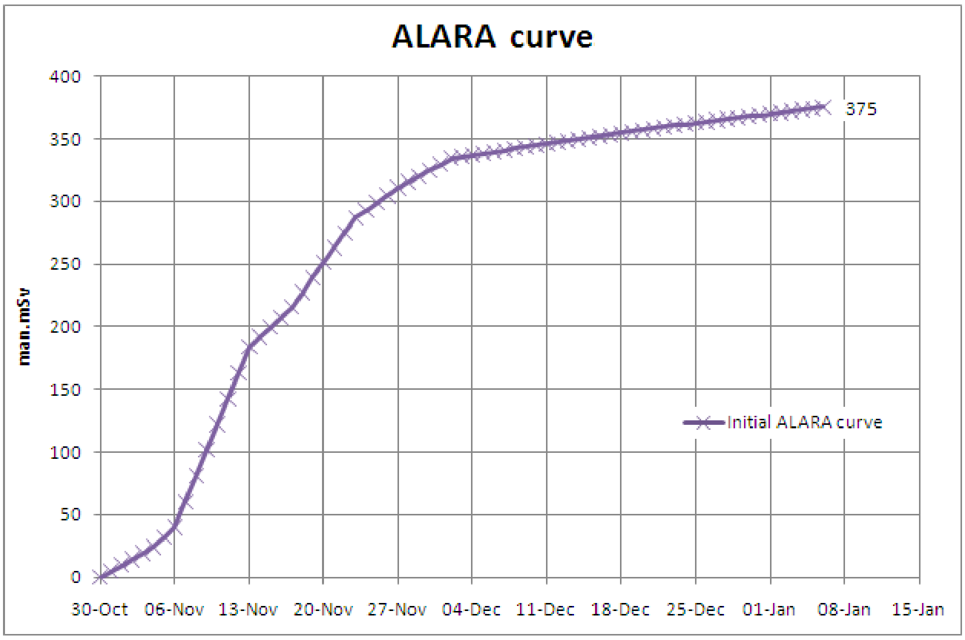

Figure 4 - Initial ALARA curve.

4. ALARA follow-up

4.1. On site follow-up

During the outage, TE had an ALARA team on site. The team had a direct link with EBL radiation protection team, which contributed to an efficient exchange of information. The TE ALARA team was composed of 2 – 3 members who assured the dosimetric follow-up and analysed the dosimetric condition on the work floor. They regularly verified the radiological status of the unit and controlled the biological protections. The collective and individual doses where daily controlled to obtain a view on the evolution of the doses to detect anomalies with the estimates, and eventually the estimates were adapted. They also controlled if the direct recommendations were applied by the different contractors of the SGR project.

4.2. ALARA procedure

In case the inspections lead to different results than those expected (measured or calculated) or when the doses exceeded the expected values, the following ALARA procedure was applied.

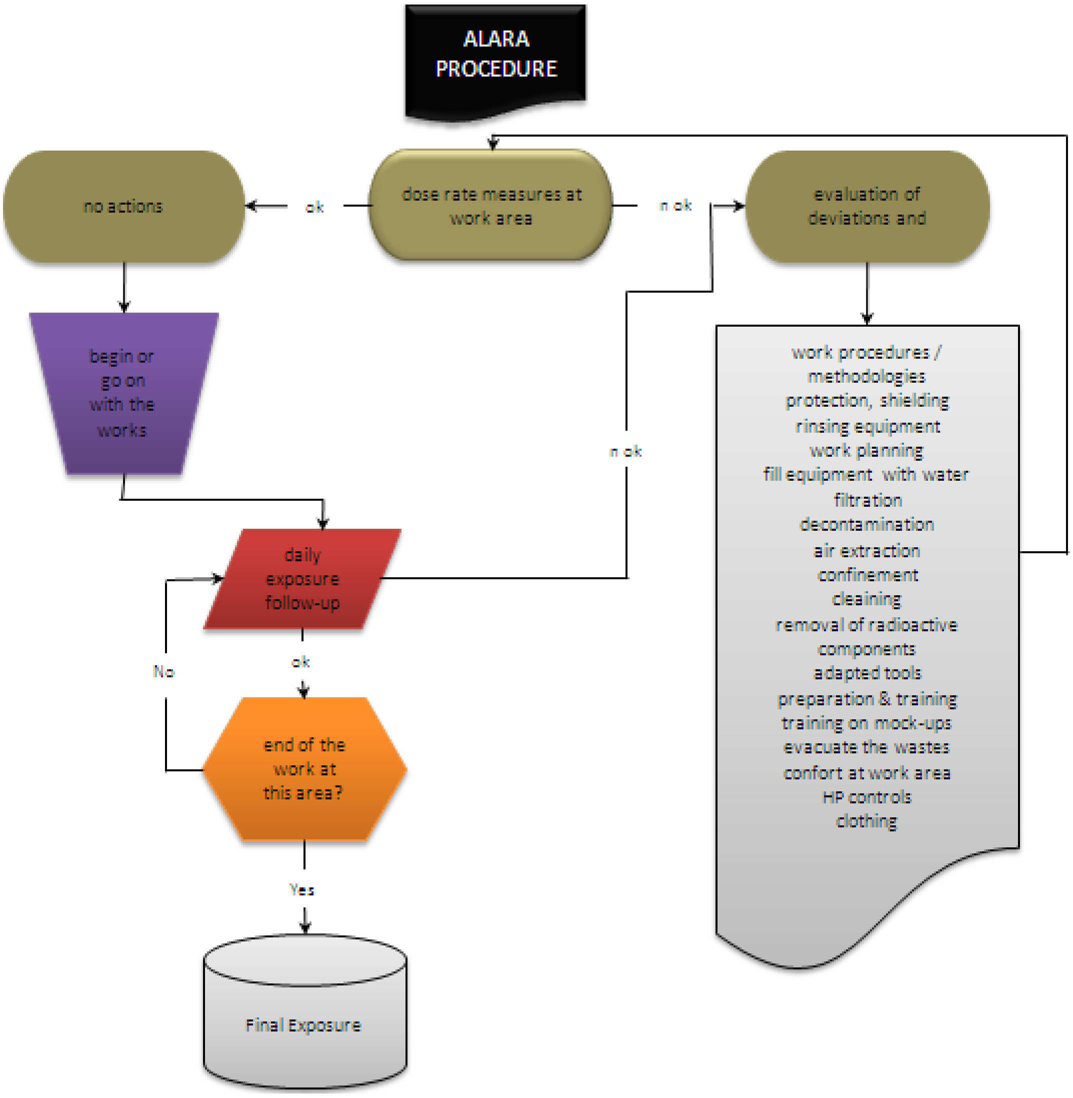

Figure 5 - Flow chart of the applied ALARA procedure.

5. Recommendations of the working group

Following recommendations were retained by the working group and implemented to lower the doses:

- Optimisation of the chemistry of the primary circuit during the shutdown sequence of the plant: i.e. scheduling of the oxygenation of the primary circuit for cooling down. Due to this approach, the cobalt peak could be scheduled during the time that nobody was working in the steam generator cells;
- Optimisation of the maintenance of the primary and secondary circuit, by simply keeping them filled up with water;
- Specific lead shielding to optimise the effect of the shielding;
- A specific daily ALARA follow-up to prevent situations with high doses and to assure a quick and adequate intervention if needed.

6. Dosimetric follow-up

The ALARA working group did a daily follow-up of the dosimetry during the outage. Daily consultation of the doses, evolution of the works and regular measurements were done by the working group. The figure below shows the evolution of the defined dose objective and the adaptations during the outage.

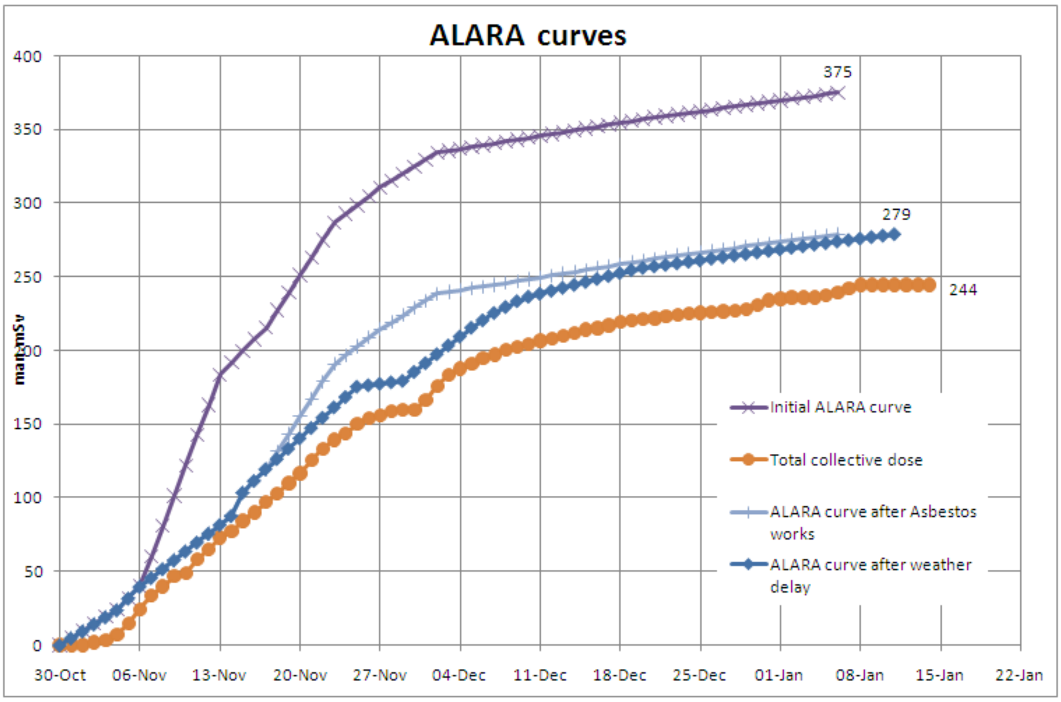

Figure 6 - Evolution of the doses during the steam generator replacement of the Doel 1 unit.

The purple curve ( ) is the initial dose objective. A strong increase is seen in the beginning of the curve (6 November – 13 November). This increase is due to the asbestos works. Afterwards another increase is seen but this is due to the foreseen SGR works. The orange curve ( ) shows the evolution of the doses incurred.

The objective was adapted 2 times. The reasons herefore are the following:

- The light blue curve ( ) was calculated during the asbestos works. A good preparation of the works and the workers lead to good efficiency during the works and the asbestos fibres were found in very good condition (no insulation degradation, see picture below). As a consequence, the cleaning phase could be reduced significantly;

Figure 7 - Condition of the asbestos fibres in the insulation of the old steam generators.

- A second adaptation was done during the end of November. This adaptation is represented by the dark blue curve ( ): due to bad weather conditions, the worst in the last decade in Belgium, it was not possible to lift the old steam generators during 5 days. The speed of the wind passed over 15 m/s and all the works were stopped. Everything in course was terminated and the new works were prepared but still valuable time was lost. This impacted the dosimetry negatively because the work zone still had to be checked daily.

7. Return of experience

The following points were found very helpful regarding the dosimetry:

- The adaptation of the configurations of the steam generators regarding the planning lead to lower the doses. The steam generators stayed as long as possible filled up with water;
- The steam generator opening was delayed until all preparation works were done;
- Visual control by means of local cameras by radiation protection and safety team;
- The use of lead walls instead of lead shielding in contact;
- Decontamination of the primary circuit by abrasive sponges (very effective and not dose consuming).

8. Doel 1 SGR compared with others

8.1. Belgian results

Over the years the work techniques evolved and the return of experience helped to adapt all the processes needed to carry out a steam generator replacement project. This evolution can be seen in the dosimetric results but also in the length of the projects. The figures 8 and 9 below show an overview of the dosimetric results of the 7 Belgian steam generator replacement projects. In figure 8 a significant decrease in the dosimetric results can be seen. This is due to the fact that the techniques were still rather new and execution of such a large project always brings a certain uncertainty in the calculations of the doses. For the last 2 steam generator replacement projects, the trend of accumulating experience and still adapting the processes involved continues. But when comparing Doel 2 and Doel 1 a little increase in the dosimetric results for the latter one is observed. The reasons herefore are various. Although Doel 1 and 2 are similar the dosimetric conditions are different, and dose rates were 30 % higher in the steam generator cubicles and a new type of work had to be carried out, an asbestos removal job. Although the installation of more lead in comparison to its use at Doel 2 was taken as a precaution, the end result was still a bit higher than the Doel 2 result.

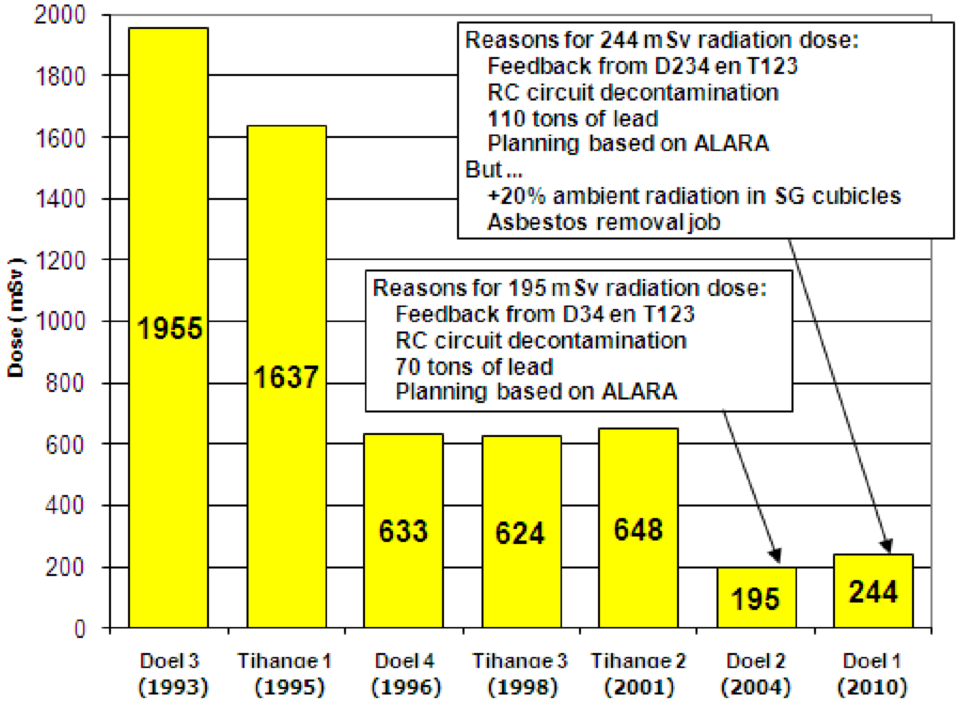

Figure 8 – Overview global dosimetric results.

Figure 9 shows the evolution of the doses during the different steam generator replacement projects in Belgium. The first 2 projects had a longer outage and the collective doses show daily a strong increase. Afterwards a strong dose reduction is seen: Doel 4 has the best dosimetric result in Europe. Then the length of the projects is reduced and dosimetric results stay more or less the same. In the end, the lowest results are seen for Doel 1 and 2. They have only 2 steam generators while the other units have 3 steam generators, but the Doel 1&2 exposure still is lower than 2/3 of the Doel 4 exposure.

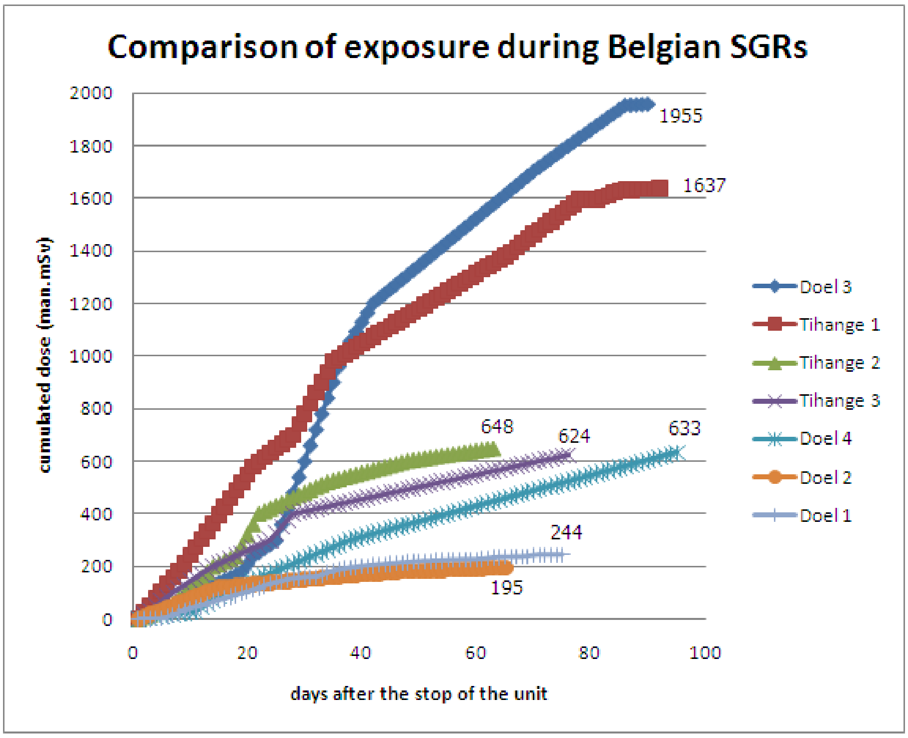

Figure 9 - Overview of the evolution of the doses.

8.2. International results

Figure 10 gives an overview of some results of steam generator replacement projects carried out over the last years ([3] and [4]). Same results can be seen as stated above: over the years the collective doses decreased a lot. Doel 1 and 2 have the lowest dosimetric results.

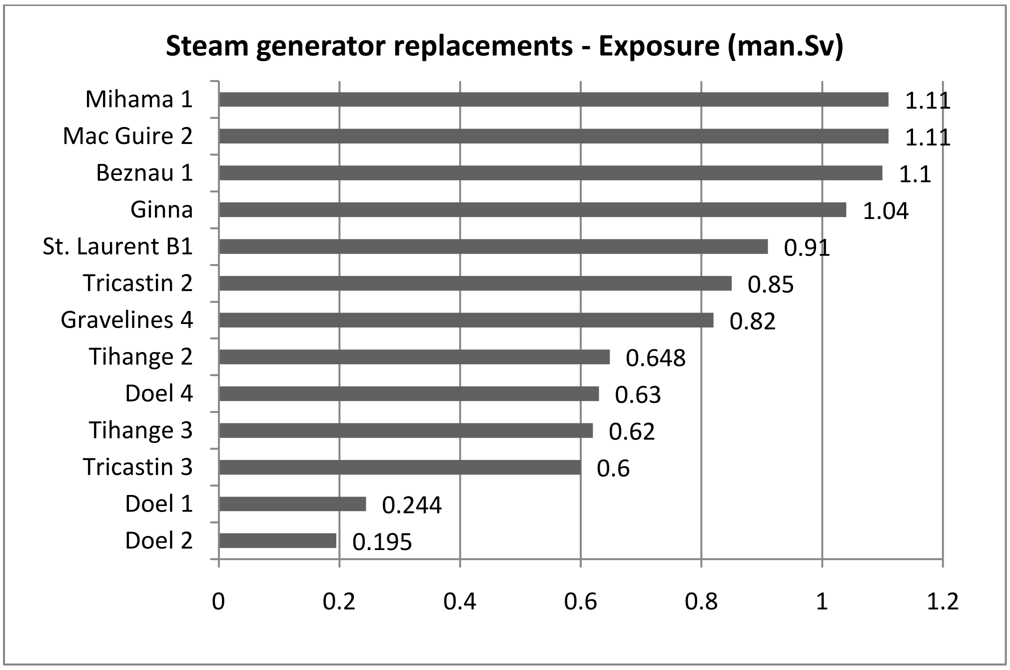

Figure 10 - Overview of the exposure of the different steam generator replacement projects.

9. Conclusion

Over the years the return of experience kept growing for this kind of projects. As a result a decrease in the dosimetric results can be seen. Still the Doel 1 unit achieved a higher result than the Doel 2 unit. Reasons herefore are diverse: Doel 1 showed 30% higher dose rates in comparison with Doel 2 and significant dose rates were registered at different locations. An asbestos removal job had also to be carried out. Such a job was never carried out in a Belgian unit before at such a large scale. But nevertheless the dosimetric result of Belgian Doel 1 unit still remains one of the best results compared to international data.

10. References

[1] National Report - Fifth meeting of the contracting parties of the convention on nuclear safety – FANC.

[2] QAD-CGGP software (RSIC CODE PACKAGE CCC493).

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

[4] Remplacement des générateurs de vapeur dans les centrales nucléaires belges. Dosimétries des chantiers « RGV » - Annales de l’Association belge de Radioprotection, Vol. 28, n°3, 2003.