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# Assessment of the radiation impact of steam generator dismantling on the workers, public and environment

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ABSTRACT

Prediction of the exposure of workers and the impact on the public and environment is necessary for the planning of the decommissioning tasks. Planning and realisation of the dismantling process have to take into account many factors. This results in the creation of possible dismantling scenarios. Moreover, the input data such as nuclide composition and activity content often vary. In the case of a steam generator, the contamination level can differ even within the same nuclear power plant. The paper describes and applies the methodology used for complex analysis of the steam generator dismantling process in nuclear power plants using the VVER-440 reactor types.



## 1. Introduction

During decommissioning of nuclear power plants, numerous tasks regarding the dismantling of technological equipment have to be solved. One of the biggest issues represents the dismantling of the so-called *large components*. In general, these may be defined as any parts of the nuclear facility that may be removed without being cut and conditioned in a non-standard package for disposal or storage and require specific consideration by the local regulators due to their weight, volume or the extent of their radiological contamination (Organisation for Economic Co-operation and Development – Nuclear Energy Agency, 2012). According to this definition, the following components of the nuclear power plant (NPP) with a pressurized water reactor can be considered as large parts: reactor pressure vessel, reactor internals (core basket, protected tube unit, reactor cavity and reactor cavity bottom), pressurizer and steam generator. All of these components are parts of the primary circuit of NPP, which results in the high activity level. This is caused by either the neutron activation (reactor pressure vessel and reactor internals) or contamination by activation and fission products (steam generator SG and pressurizer).

Currently there is already practical experience with the finished projects of dismantling and segmentation of SGs:

- German NPP Gundremmingen (3 secondary SGs) (Steiner et al., 1997).
- German NPP Greifswald (only low contaminated SGs for testing purposes, the other SGs are stored at Interim Storage North) (The Greifswald Decommissionig Project), (Rehs).
- Spanish NPP José Cabrera (Martín and Rodríguez).
- American NPP Rancho Seco (Hickman).

Detailed analyses regarding the estimation of exposure during dismantling of the contaminated components were also carried out:

- Italian NPP Enrico Fermi (the analysis focused on the internal exposure during cutting the SGs, piping and pressurizer) (Bonavigo et al., 2010).
- Lithuanian NPP Ignalina (the analyses focused on the calculation of external and internal exposures during cutting different reactor systems (Simonis et al.), (Ragaišis et al., 2015) (Simonis et al., 2015).

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However, the following issues can be identified:

- Some of the documents provide general information only, or
- the experience and analyses are dealing with different types of components (e.g. vertical construction of SGs or other specific components).

The above mentioned documents dealing with practical experience or analyses are therefore hard to be applicable in the case of horizontal SGs used in NPPs with VVER-440 reactor type.

In Slovakia, the NPP V1 in Jaslovské Bohunice is currently in the 2nd decommissioning stage with planned duration between 2015 and 2025 (National Nuclear Found, 2012). Within this stage, the large components will be cut in-situ and the fragmented parts will be stored and/or conditioned and disposed in the repository (Nuclear and Decommissioning Company). In this NPP, the VVER-440/230 reactor type (Russian type of pressurized water reactor) was used. This type of pressurized water reactor (PWR) was built in the former Soviet Union (Armenia, Russia and Ukraine), Finland and Eastern Europe countries (former Czechoslovakia, Hungary, former German Democratic Republic and Bulgaria). Each unit of NPP V1 had a gross electrical output of 440 MW and standard operation was terminated after 28 years (1978–2006 and 1980–2008).

The lack of information regarding the dismantling and segmentation of steam generators in NPPs with VVER-440 reactor type can be explained by the following facts (International Atomic Energy Agency, 2015):

- Some of the NPPs are still operational (Czech Republic, Finland, Hungary, Russia and Ukraine).
- The deferred dismantling applied in some NPPs or the dismantling process is under development (Armenia and Bulgaria).
- The different dismantling strategy applied (e.g. in the German NPP Greifswald the SGs were removed as one piece and are stored at the Interim Storage North, direct cutting was only tested on the low contaminated SGs).

The study in this paper therefore presents the proposed steam generator dismantling scenarios and deals with their complex analysis considering external and internal exposures as well as the impact upon the public and environment.

## 2. Methods

### 2.1. Technical description of steam generator

The subject of the analysis is the steam generator used in each of the 6 loops of the primary circuit within one unit. The SG is depicted in Fig. 1 and consists of the following main parts:

- SG casing – total mass 113.4 tonnes, part of the secondary circuit.
- Heat exchange tubes – 5536 U-tubes, total mass 34.7 tonnes, contaminated part of the primary circuit.
- 2 collectors – total mass of both collectors 25.4 tonnes, contaminated part of the primary circuit.

The total length of SG is 11.8 m, the outer diameter is approx. 3.4 m.

From the construction point of view the vessel is made of carbon steel 22K; the collector material as well as the heat exchanging tube material is titanium stabilized austenitic steel with 0.08% of carbon, 18% of chromium, 10% of nickel and less than 1% of titanium (International Atomic Energy Agency, 1997).

### 2.2. General preconditions

To assess the radiation impact of SG dismantling, the knowledge of numerous parameters is crucial (parameters associated with the dismantling scenario of SG, radiological data – level of activity and nuclide composition). However, the nuclide composition (nuclide vector) is mostly set as an average value for the whole group of technological equipment. In the case of radiological characterisation of NPP V1 this vector is the same for the whole primary circuit. Moreover, the level of activity is in many cases only an estimated value based on the in-situ measurements combined with the analysis of the samples. Given the fact that the contamination process is very complex and strongly dependent on the chemical conditions of the coolant, electro-chemical properties of the material as well as on the chemical properties of the radionuclides (Severa and Bár, 1991), the calculation results using these input data would be approximate only. In this case, two approaches can be applied:

- Development of the methodology which allows quick recalculation of the results after the radiological parameters are particularised.
- Application of the conservative approach – to ensure that the results will not be underestimated.

Based on these assumptions, the calculation methodology described in the next chapter can be developed and applied.

### 2.3. Applied methodology

The methodology developed reflecting the aforementioned facts comprises the following sequence of steps:

1. Definition of extensive sets of parameters associated with the material composition and geometric dimensions of SG parts, and of the parameters associated with cutting and fragmentation of the parts of SG including the distance of the workers from the component being cut.
2. Creation of the possible dismantling scenarios considering site-specific conditions and experience from similar international projects.
3. Development of geometrical, radiological and material models of the considered dismantling scenarios. In each scenario, the activity of all radiation sources is set as 1 Bq of $^{60}$Co. This nuclide is one of the most abundant activation products in NPPs with PWR reactors closed after standard operation (International Atomic Energy Agency, 1998). Moreover, this nuclide is easy to measure by $\gamma$-spectrometry (International Atomic Energy Agency, 1998), (International Atomic Energy Agency, 2009).
4. Calculation of the dose rates and processing of the results – set of the so-called *conversion factors* [(mSv/h)/1Bq$_{Co\text{-}60}$].
5. Calculation of the dose rates and of the collective effective doses using conversion factors and variable parameters (nuclide vectors, activity content, workload).
6. Calculation of internal exposure for each relevant exposure pathway.
7. Assessment of the impact of the dismantling on the environment and public.
8. Overall comparison and evaluation of the considered scenarios.