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Occupational Radiation Exposure of Workers during the Dismantling of VVER-440 Reactor Pressure Vessel

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1. Introduction

Nuclear power is the biggest energy source in Slovakia, IAEA stated that the electricity production share in Slovakia by nuclear power plants (NPP) was over 52% in 2021 [1]. One of the two operating plants in Slovakia is Jaslovské Bohunice V2 Nuclear Power Plant. V2 NPP will reach the end of its operation in the following 20 years, and it is important to already plan its decommissioning in detail. This work is focusing on the topic of dose assessment to workers during dismantling of reactor pressure vessel (RPV) at Jaslovské Bohunice V2 with decommissioning plan for conceptual immediate dismantling, to see if it is possible for workers to safely dismantle RPV without potential health risks.

The Jaslovské Bohunice NPP is a complex of three nuclear power plants located at one site: A1, V1 and V2. Out of these three, V2 is the only plant that is still in operation. The V2 power plant comprises two units, each with a VVER-440/213 pressurized water reactor. The V2 reactor units were commissioned in 1984 and 1985, and they are expected to remain operational until 2045 [1]. The A1 and V1 units are currently at later stages of their decommissioning which should provide important knowledge and expertise for future decommissioning and dismantling of currently operating V2 reactor unit. At the time of their decommissioning and for the first few years after the final reactor shutdown, radioactive inventory and dose rates in reactor structures are mostly influenced by relatively short-lived nuclides, mainly ^{55}Fe and ^{60}Co, which makes them the most important nuclides when considering immediate dismantling of NPP [2].

All main parts of the RPV body are made of noble CrMoV steel, grade 15CH2MFA, resistant to temperature aging and radiation damage. RPV thickness at the height of the reactor core is 14 cm and there is an inner 9 mm thick stainless-steel plating (clad lining) as corrosion prevention [3]. The height of this type of RPV is 11800 mm and its inner radius is 3560 mm. The six inlet and six outlet pipe connections are located at different heights on the vessel. The exact dimensions of RPV are shown in Fig. 1 [4].

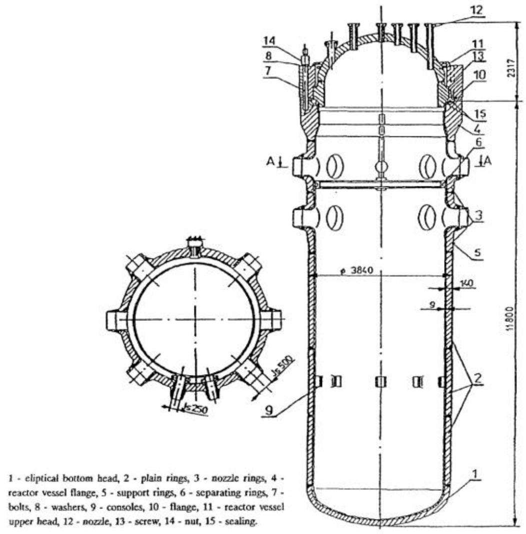

Fig. 1. Reactor pressure vessel of VVER-440/213

2. Methods and Results

Software used to perform the calculation of external exposure during dismantling of the VVER-440 reactor pressure vessel is VISIPLAN 3D ALARA, which is a dose assessment program that was developed by SCK CEN [5]. VISIPLAN uses the point-kernel dose calculation method. The code is based on a 3D model that includes material, geometry and sources. This software allows users to perform dose assessment for fragmentation of RPV by showing estimated individual and collective dose for all needed dismantling tasks.

Fig. 2. Simplified VISIPLAN model of reactor pressure vessel

The source term of active radionuclides input in VISIPLAN is for direct dismantling without safe enclosure after the end of operation (60 years). The radionuclide source term was created based on the data provided by MCNP calculations in the referred study [2]. The model of VVER-440 RPV with applied operation source term from Table I is showed in Fig. 2.

Table I: Radionuclide source terms from MCNP calculations for VVER-440 RPV after 60 years of operation

Nuclide	Activity (Bq)
^{55}Fe	4.81×10^{14}
^{60}Co	1.90×10^{14}
^{63}Ni	8.99×10^{13}
^{54}Mn	6.56×10^{13}
^{59}Ni	8.34×10^{11}
^{94}Nb	4.76×10^{11}
^{14}C	7.55×10^{6}

In this paper, the cutting of RPV was influenced by the size of 208 L drum for nuclear waste. This drum's usable inside dimensions are 84.5 cm (height) × 57.2 cm (diameter). 12 cutting groups are considered to perform fragmentation of the cylindrical part of RPV. Each group consists of 6 workers in distance of 30 cm from the component and one radiation protection officer (RPO) with 100 cm distance from the component. Selected cutting speed was 15 mm/min which was decided by using conservative approach to choose the slowest cutting speed. The workload calculated based on cutting speed shows that it takes 804 minutes to finish fragmentation of one part of RPV, and with RPO workload, the total work time for one fragmentation gets doubled.

Table II: Dose data for one group of workers performing the RPV fragmentation

Task No.	Task description	Duration (min)	Dose - rate (mSv/h)	Task - dose (mSv)	Accumulative dose (mSv)
1	Cutter 1	134	3.30E+01	7.40E+01	7.40E+01
2	Cutter 2	134	4.90E+01	1.10E+02	1.80E+02
3	Cutter 3	134	4.80E+01	1.10E+02	2.90E+02
4	Cutter 4	134	3.60E+01	8.00E+01	3.70E+02
5	Cutter 5	134	5.30E+01	1.20E+02	4.90E+02
6	Cutter 6	134	2.90E+01	6.40E+01	5.50E+02
7	RPO 1	804	2.50E+01	3.30E+02	8.80E+02

The dose to one working group during the RPV fragmentation calculated by VISIPLAN is shown in Table II. The dose-rate per each cutting task is displayed by Fig. 3. The collective dose for all workers is 1.07×10^{4} man-mSv, and the collective work time during fragmentation is 321.6 man-hours if there is no radiation shielding barrier.

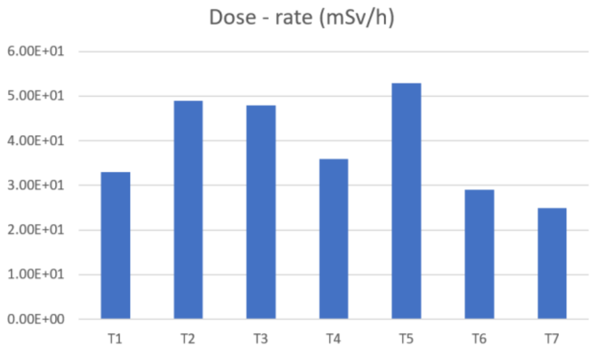

Fig. 3. Dose-rate per each cutting task for cutters and RPO

3. Conclusion

The dose assessment performed by VISIPLAN 3D ALARA planning tool showed that immediate decommissioning and dismantling of RPV is hazardous because during each task the occupational exposure dose limit for workers was exceeded (50 mSv per year and 100 mSv per five years). Based on the results, in order to ensure the safety of decommissioning workers, it is advised to delay RPV dismantling for several years until the activity of ^{55}Fe and ^{60}Co with half-lives of 2.737 years and 5.27 years, respectively, substantially decreases with time.

Acknowledgement

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