EVALUATION OF AN EXTERNAL EXPOSURE OF A WORKER DURING MANIPULATION WITH WASTE PACKAGES STORED IN BOHUNICE RADIOACTIVE WASTE TREATMENT CENTRE

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Abstract
The paper briefly describes current state of radioactive waste (RAW) management as well as RAW treatment and conditioning technologies used in Bohunice Radioactive Waste Treatment Centre. Radioactive Waste management includes pretreatment, treatment, conditioning, storage, transport and disposal of RAW. Presented paper deals with the evaluation of an external exposure of a worker during manipulation with fibre-reinforced concrete container (FCC) stored under shelter object. The external exposure of a worker was evaluated using VISIPLAN 3D ALARA code.

Keywords
Waste package, radioactive waste, VISIPLAN 3D ALARA, effective dose, external exposure

1. INTRODUCTION

Radioactive waste arises from a number of activities involving the use of radioactive materials, such as the operation and decommissioning of nuclear facilities and the application of radionuclides in industry, medicine and research. Radioactive waste is also generated in the cleanup and remediation of sites affected by radioactive residues arising from various operations or accidents, and can arise in the processing of raw materials containing naturally occurring radionuclides. The nature of this waste is likely to be such that its safe management must take into account radiation safety consideration. In addition to the waste that must be managed and eventually disposed of, some of the materials originating during the aforementioned activities are of value and may be reused or recycled [1].

2. RADIOACTIVE WASTE

In general, different kind of waste arises within all human activities. Above mentioned activities (e.g. nuclear energy, medical instruments, etc.) connected with radioactivity produce RAW which either contains radionuclides or is contaminated by radionuclides in a due process. At the present, the most radioactive waste arises from nuclear power industry. However, while comparing RAW to other kind of waste, for example from classical power engineering, there is relative small volume of such wastes. Therefore, the overall amount of RAW is relative small, but their specific property – radioactivity makes it difficult to manipulate this particular waste.

In the Slovak Republic (according to the Act No. 541/2004 Coll. 1.) radioactive waste shall mean any unusable material in gaseous, liquid or solid form, which due to content of radionuclides or due to the level of their contamination with radionuclides cannot be released into the environment [2].

3.1 Radioactive waste classification

Radioactive waste may arise in wide range of concentrations of radionuclides and in a variety of physical and chemical forms. These differences result in an equally wide variety of options for proper management and classification of the waste.

In the Slovak Republic classification of radioactive waste is based on their ability to be disposed and is defined in the Decree of Nuclear Regulatory Authority of Slovak Republic No. 53/2006 Coll. I., *setting the details of requirements for handling nuclear materials, radioactive waste and spent nuclear fuel.* According to this Decree RAW is divided into following categories [2]:

a) **Transient radioactive waste,** the activity of waste decreases during storage below the limit value enabling its release into environment.
b) **Low and Intermediate level radioactive waste,** the activity of waste is higher then limit value allowing its release into the environment and the produced residual heat of which is less than 2 kW/m^3:
   1. **Short lived** RAW is waste which after the conditioning meets the limits and conditions of safe operation for the surface repository of RAW and the average mass activity of alpha nuclides is less than 400 Bq/g.
   2. **Long lived** RAW is waste which after the conditioning does not meet the limits and conditions of safe operation for the surface repository of RAW or the average mass activity of alpha nuclides is equal or higher than 400 Bq/g.
c) **High level radioactive waste,** the produced residual heat of waste is equal or higher than 2 kW/m^3 and such waste cannot be disposed in the surface repository of radioactive waste.

3. EVALUATION OF SCENARIOS ASSOCIATED WITH WASTE PACKAGE MANIPULATION

As was mentioned above, the presented paper deals with the evaluation of an external exposure of a worker performing the manipulation with waste packages stored within the shelter object in the area of a nuclear facility. Two modelled scenarios associated with FCC manipulation stored within the shelter are described in following chapters.

3.1 Bohunice radioactive waste treatment centre

Bohunice Radioactive Waste Treatment Centre (BTC RAW) is a facility for treatment and conditioning of radioactive waste into appropriate form for the final disposal. It was built in between 1993-1999. Processing facilities are designated for conditioning and treatment of liquid and solid radioactive wastes originating during decommissioning of Bohunice A1 nuclear power plant (NPP), from operation of V2 (NPP) in Jalsovske Bohunice and NPPs in Mochovce. Apart from the mentioned RAW, BTC RAW is used for treatment and conditioning of institutional radioactive waste coming from the entire Slovakia [2].

BTC RAW comprises of following facilities used for treatment and conditioning of compressible solid wastes, solid and liquid combustible waste, solid incombustible and non-compressible waste and liquid wastes:

- high-pressure press,
- cementation facility,
- incineration facility,
- separation facility for solid wastes,
- facility for concentration of liquid wastes.

The final product in the whole process of treatment and conditioning of radioactive waste in Slovakia is a FCC (waste package) with dimensions 1.7x1.7x1.7 m filled with grout or with freely loaded solid waste fixed in cement mixture, designated for disposal in National Repository of Radioactive Waste in Mochovce.

3.2 Model design

The shelter object was built next to the main building of BTC RAW. The dimensions of the shelter are approximately 30x8 m with height of 6 m. Twenty-seven waste packages should be stored within the shelter. The assumed distribution of individual waste packages stored inside the shelter is depicted in Fig. 1.

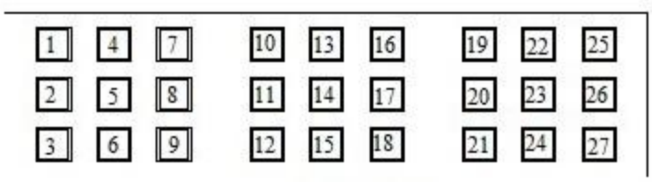

Fig. 1 Assumed position of individual packages in the shelter

All waste packages are modelled as individual cubes with dimension of 1.70 m with wall thickness of 10 cm. Total activity of individual packages is in range of 18.33 – 55.89 GBq. All activities are based on data acquired from FCC accompanying sheets. Waste form is modelled as homogenous grout contaminated with radionuclides ^{137}Cs and ^{60}Co. Representation of ^{60}Co in individual packages is in range between 0.22 and 1.88 %. Activities and share of radionuclides ^{137}Cs and ^{60}Co in individual packages are shown in the table below. Assignment of total activity value to the individual waste packages was performed using random distribution.

Tab. 1 Activities and representation of isotopes Cs-137 and Co-60 in individual packages

FCC No.	Total Activity [10^{10} Bq]	Portion of ^{137}Cs [%]	Portion of ^{60}Co [%]	FCC No.	Total Activity [10^{10} Bq]	Portion of ^{137}Cs [%]	Portion of ^{60}Co [%]
1	3.85	99.38	0.62	15	2.21	99.61	0.39
2	5.59	99.30	0.70	16	3.16	99.37	0.63
3	3.17	99.33	0.67	17	2.38	99.64	0.36
4	1.83	99.29	0.71	18	3.13	99.36	0.64
5	2.03	99.20	0.80	19	2.04	99.32	0.68
6	2.52	99.27	0.73	20	3.25	99.29	0.71
7	1.87	99.30	0.70	21	2.91	99.78	0.22
8	3.04	99.32	0.68	22	2.06	99.31	0.69
9	5.29	99.34	0.66	23	3.36	99.22	0.78
10	2.31	99.28	0.72	24	2.68	98.12	1.88
11	4.42	99.46	0.54	25	4.00	99.23	0.77
12	2.43	99.32	0.68	26	2.45	99.29	0.71
13	2.01	99.34	0.66	27	3.28	99.18	0.82
14	3.26	99.30	0.70				

3.3 Description of used code VISIPLAN 3D ALARA

Computational code VISIPLAN 3D ALARA was chosen for the evaluation of an external exposure of a worker performing assigned activities. VISIPLAN, which was developed in Belgium, is appropriate tool for evaluation of external gamma and x-ray exposure. This tool enables modelling of real situations hence obtained results can be beneficial for nuclear management practices.

The method used in VISIPLAN is based on a point-kernel calculation with a build up correction, where volume source is divided into the point sources. The photon fluency rate at a dose point is than determined by superposition of partial dose contributions from particular point sources:

$$\phi = \int_V \frac{S.B.e^{-b}}{4.\pi.r^2} dV \qquad (1)$$

Where: S – source strength per unit volume,

B – build-up factor,

b – dimensionless term, which represents the attenuation effectiveness of a shield,

r – distance from a point source and

V - source volume.

Point sources are called “kernels” and the process of integration, where the contributions to the dose from each point is added up, is called “point-kernel” method.

3.4 Description of FCC manipulation scenarios.

Two scenarios connected with FCC manipulation stored within the shelter are analyzed in the paper. The both scenarios are similar. They differ only in the number of packages stored within the shelter object. The first scenario takes into account 27 FCCs while the second only 24 FCCs.

The task of a worker in the first scenario is to transport the container No. 13 into main BTC RAW building using the HYSTER machine, where the container is loaded onto a truck and transported into National RAW Repository in Mochovce. At first, the worker has to relocate FCCs No. 15 and No. 14. The worker puts these containers temporary on the right side of the shelter and then transports container No. 13 into BTC RAW building. After that the worker returns the containers No. 15 and No. 14 to their original places.

The task of a worker in the second scenario is the same as in the first scenario, with one minor exception where only 24 FCCs are stored within the shelter. This scenario assumes empty place on the right side of the shelter (position of FCCs No. 25 – No. 27 in the first scenario). The worker has to relocate the containers No. 15 and No. 14 on the empty place within the shelter and then he transports FCC No. 13 into BTC RAW building.

4. OBTAINED RESULTS

The following two chapters describe obtained results from the both scenarios associated with FCCs manipulation within the shelter in the area of a nuclear facility.

4.1 Scenario 1 – 27 FCCs stored within the shelter

Tab. 2 includes obtained results from the first scenario. As shown in this table, the worker receives effective dose of 19.58 µSv per 35.50 minutes. The worker receives the highest dose during the loading and transportation phase of package No. 13 into BTC RAW.

Tab. 2 Obtained results from the first scenario

Task description	**Task duration [min]**	**Received individual effective dose [µSv]**
Approach and movement of package No. 15	6	2.39
Displacement of package No. 14	6	4.34
Loading and transport of package No. 13	11	5.70
Return of package No. 14 to its original place	6.50	3.81
Return of package No. 15 to its original place	6	3.34
TOTAL	**35.50**	**19.58**

The worker is in different positions during the manipulation phase, therefore the value of a dose rate is changed significantly. When the worker approaches the shelter the value of the dose rate increases from 1.20 to 25 µSv/h and when is he loading the FCC No. 13 the value of dose rate between the containers is up to 51 µSv/h. Four modelled trajectories describing the movement of the worker are depicted in the next figure (Fig. 2).

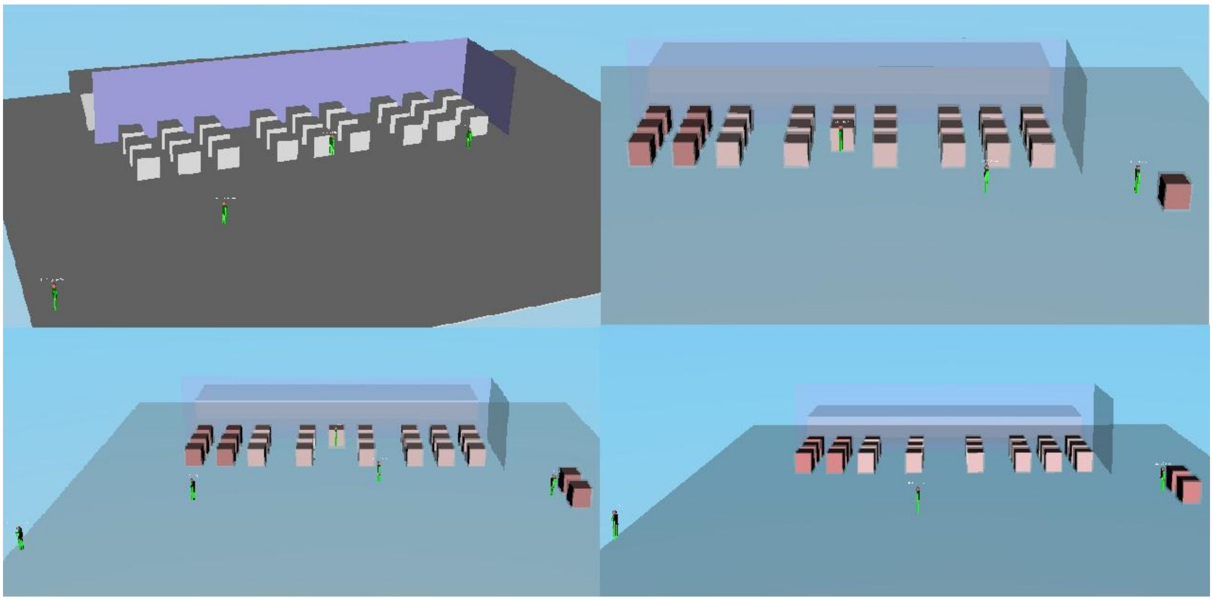

Fig. 2 3D trajectories of the scenario No. 1

4.2 Scenario 2 – 24 FCCs stored within the shelter

Tab. 3 contains obtained result from the second scenario. As shown in this table, the worker receives effective dose of 12.10 µSv per 23 minutes. As in the previous scenario, the worker receives the highest dose during the loading and transportation stage of package No. 13 into BTC RAW.

Tab. 3 Obtained results for the second scenario

Task description	Task duration [min]	Received individual effective dose [µSv]
Approach and loading of package No. 15	3	0.89
Displacement of package No. 15	3	1.70
Loading and transportation of package No. 14	6	2.90
Loading and transportation of package No. 13 into the main BTC RAW building	11	5.80
TOTAL	**23**	**12.1**

Dose rate in the shelter surroundings is almost the same as in the first scenario. When the worker is in front of the shelter the value of dose rate is up to 25 µSv/h and when is he loading FCC No. 13 the value of dose rate in this place is about 50 µSv/h. While the worker is relocating the containers to empty spot the value of dose rate in this place is in range from 29 µSv/h to 40 µSv/h. Five modelled trajectories describing the movement of the worker are depicted in the Fig. 3.

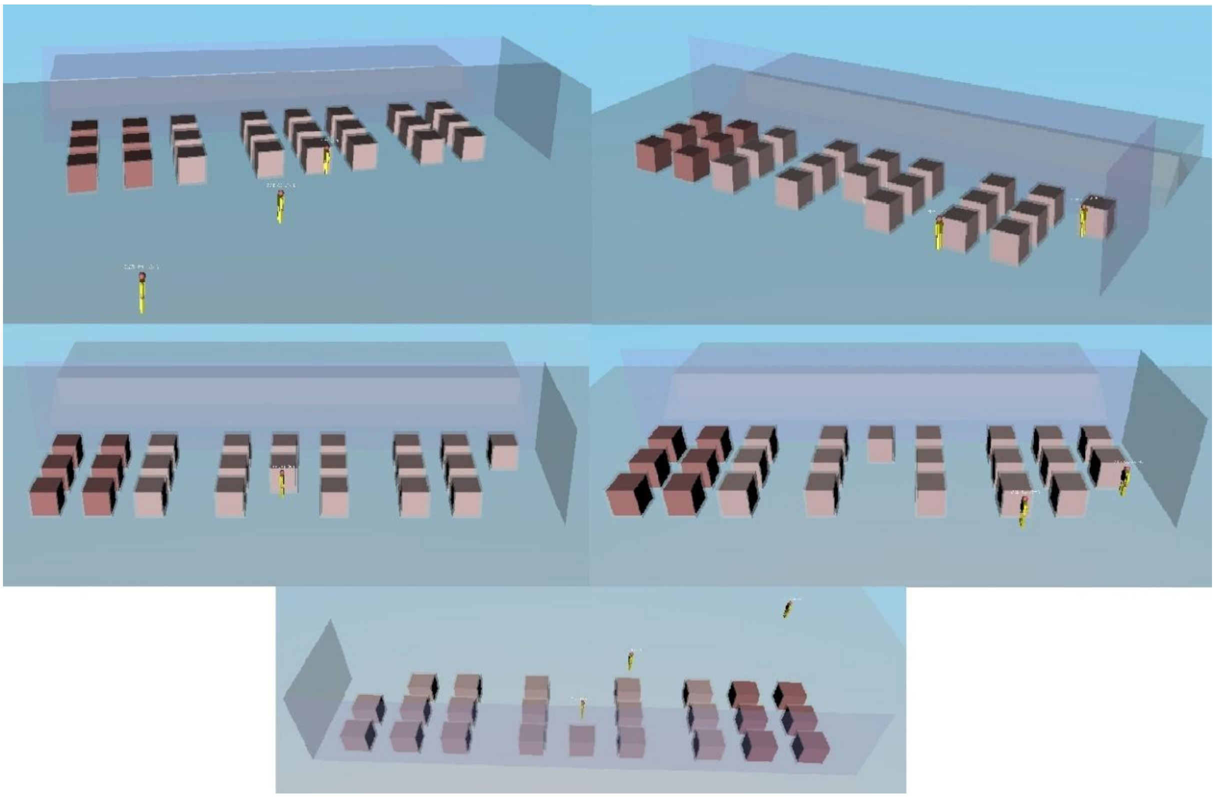

Fig. 3 3D trajectories of the scenario No. 2

5. CONCLUSION

The worker manipulating with the containers receives effective dose of 19.58 μSv during 35.60 minutes in the case of the first scenario, while in the second scenario it accounts for 12.10 μSv during 23 minutes. In Slovak Republic there are approximately 200 waste packages transported into National Radioactive Waste Repository in Mochovce annually. The worker would receive annual effective dose value of 3.92 mSv in the first scenario and 2.42 mSv in the second scenario considering similar procedures (distances, task duration, total activities of FCCs, etc.) of every transported package. In comparison, the second scenario seems to be more advantageous considering ALARA principle as the first scenario. However in this scenario less FCCs are stored within the shelter. Mentioned values meet legislatively given limits in Slovak Republic, in which value of 20 mSv [4] is defined as the maximum allowed dose received by a worker annually.

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