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ARTICLE

Conditional clearance of radioactive demolition waste in motorway scenario

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The paper describes the model application of conditional clearance radioactive demolition waste arising from decommissioning of nuclear power plants and the calculation of individual effective dose absorbed during construction and operation stage of motorway. Large quantities of materials with very low level radioactivity may occur during the decommissioning of NPPs after the end of its lifetime or after a nuclear accident. Part of the decommissioning waste consists of the contaminated demolition waste, which is necessary to be processed and stored on a designated storage sites or disposed. The construction of such stores or repositories requires significant financial and material resources. Possible solving of this issue is conditional clearance of very low level radioactive waste and its reuse in construction of roads, where they are incorporated for 50 to 100 years. This period is necessary for natural radioactive decay of radionuclides to the levels applicable for unconditional clearance. The foundation of a road represents a significant potential for recycling of concrete rubble from the decommissioning. Calculation of external exposure was performed by means of VISIPLAN 3D ALARA, internal exposure due to inhalation was calculated by AMBER 5.4. The outputs of calculations are the individual effective dose absorbed during working activities from all relevant exposure pathways. Final results include clearance levels - specific mass activities of demolition waste designated for clearance.

Keywords: ***conditional clearance; decommissioning; dose rates; exposure pathway; clearance levels; motorway construction; VISIPLAN 3D ALARA***

1. Introduction

Process of decommissioning of nuclear facilities is characterized by a production of radioactive waste and especially very low level radioactive waste (VLLW). The same goes for the decommissioning after a nuclear accident. One of the possibilities of dealing with large amounts of low level radioactive materials arising from decommissioning is conditional clearance - recycling and reuse of materials in nuclear or non-nuclear industry. Radioactive demolition waste (RDW) can be cleared after meeting designated conditions and then used solely for intended purpose. These materials are characterized by a content of radionuclides with relatively short half-life and low concentration. From a radiological point of view, after relatively short period of time this waste is similar to conventional waste.

Clearance of the material is defined as a cancellation of all radiological restrictions for future use outside nuclear facility. Risks associated with the clearance of radioactive material into the environment must be at a negligible level. That means that expected effective dose received by workers due to all relevant exposure pathways must not exceed 10 μSv/y. This limit is in accordance with Slovak legislation [1] and international recommendations [2,3].

Possible option for utilization of conditionally clearable RDW is its incorporation into foundation of motorway constructions, embankments and roads made of fresh concrete produced using concrete rubble. Lifetime of mentioned road constructions exceeds requirements for decrease of radioactivity to an unconditional clearance levels. In certain sections, large amounts of contaminated material can be placed in road mounds. Size of the foundation depends on the size of the road. In the case of motorways, foundation is about 25 m wide and up to 8 m high. Width and height of part of foundation made from cleared material is determined by radiological calculations. The requirement is that cleared material would not be impacted and corrupted during excavation, i.e. during placing of a portal for traffic sign, construction of canal or protective walls, laying of control and signal cables and other activities. Basic geological and hydraulic requirements for laying RDW are determined by: properties of underlying layers, water regimes and climatic conditions.

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2. Exposure pathways

In the contaminated environment human beings (and other organisms) can be exposed to radionuclides both internally and externally. Essentially, there are three main exposure pathways: ingestion, inhalation, external exposure. External irradiation and inhalation need to be considered for the workers, whilst exposure pathways associated with the inhalation, external irradiation and deposition of suspended dust need to be assessed for the public [4]. The aim of the presented paper is derivation of clearance levels for general public (workers in this case). We considered both external irradiation and dust inhalation exposure pathways. Calculation of external exposure was performed by means of VISIPLAN 3D ALARA [5], internal exposure due to inhalation was calculated by AMBER 5.4. The VISIPLAN 3D ALARA planning tool has been developed and designed by SCK•CEN as a dose assessment tool to calculate the dose in a 3D environment for work scenarios. AMBER is a flexible software tool that allows the user to build their own dynamic compartmental models to represent the migration and fate of contaminants in a system. It has been effectively used for calculation of annual doses to critical group of people [6].

3. Scenario description

Model represents 100 m long, 20 m wide and 3 m high road section. For the purpose of modeling the model was split into 2 equal sections. Part of cross-section of the road is displayed in **Figure 1**.

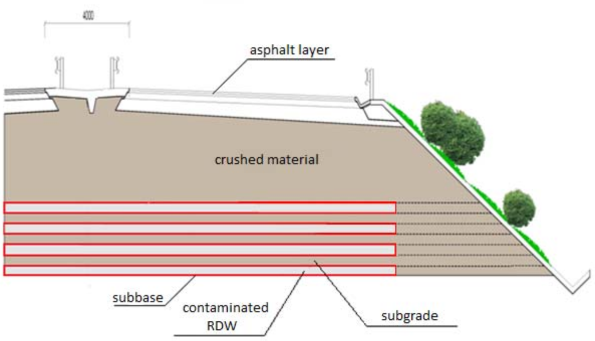

Figure 1. Cross-section of the road

In the first section, layer of contaminated material was applied. In the second step, contaminated material was overlayed with layer of non- contaminated rubble and simultaneously the second section was covered with contaminated material. During construction, layers of contaminated and non-contaminated material alternate on both sections. Each layer is 30 cm thick. The building process continues repeatedly until 8 layers are laid, 4 of which are RDW. Finally, entire road is covered by 20 cm thick layer of asphalt, so final thickness of the construction is approximately 3 m [7]. The basic idea of proposed design is recycling of large volume of concrete debris in a safe manner.

For the purpose of calculations, the following source of ionizing radiation was assumed:

- Specific mass activity of concrete rubble 1000 Bq/kg is assumed,
- Radionuclides ^{60}Co,^{137}Cs and ^{54}Mn are taken into account in performed analysis because of their high concentration in contaminated concrete rubble (based on radiological characterization of V1 NPP in Jaslovske Bohunice, which is currently under decommissioning),
- Build up factor for air is considered.

Figure 2 displays part of road modeled in VISIPLAN 3D ALARA code, which was used to calculate external exposure of workers and members of the public.

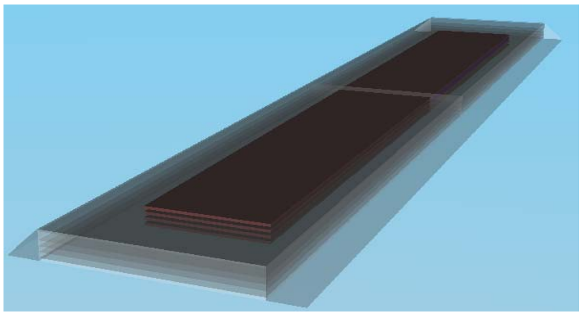

Figure 2. View of the road in VISIPLAN 3D ALARA

Table 1 shows list of materials considered during modeling of the road construction, where:

- Concrete – foundation material and radiation source
- Iron – shielding material in calculations for workers in machines

Table 1. List of used materials

Material	Density [g/cm^3]
concrete	2.35
asphalt- final road surface	1.29
iron	7.86

4. Modelling of construction activities by VISIPLAN

Calculations of external exposure were made for 6 employees performing 3 activities. Three workers are moving on a first section of the road, other three are moving on the second section following the same trajectories as the first three. Time they spent on a workplace and exposure time is 10 hours/day. **Figure 3** describes workers during construction activities. Staff working on the road was divided among three typical groups:

a) Worker (red figure) – works with contaminated material by means of manual tools, has a direct contact with the contaminated material.
b) Construction supervisor (yellow figure) – sits in a truck approximately 1 m away from the contaminated material for the entire duration of

construction, with a 1 cm thick layer of iron as shielding from irradiation in the model, in reality representing a chassis of the vehicles.

c) Heavy equipment worker (blue figure) – moves on the contaminated material in one of the heavy machines (roller, sprinkler truck, dozer). Same as before, with 1 cm layer of iron was used as a shielding in the model, representing vehicle chassis.

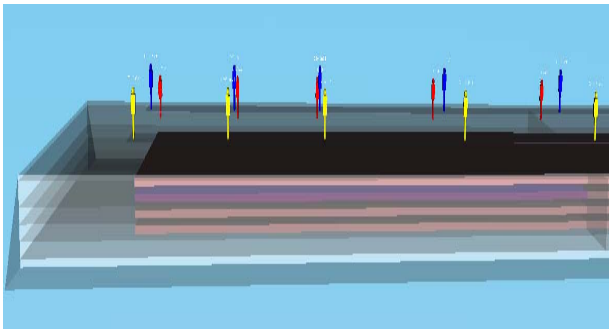

Figure 3. Side view of the workers trajectories.

5. External exposure calculation

This model considered a 100 m long road section. Calculations were transformed to 2 km long section with construction time 200 days, that means working time 800 hours. **Table 2** comprises values of received individual effective doses.

Table 2. Values of received doses per year

	Dose [μSv/y]					
	1st part			2nd part		
Employee	^{60}Co	^{137}Cs	^{54}Mn	^{60}Co	^{137}Cs	^{54}Mn
Operator	353	90.8	132	357	91	128
Worker	388	97.7	141	378	100.5	136
Supervisor	116	31	43	115	30.2	42

Received individual effective dose for a member of public (a car driver) per annum was calculated and is given in **Table 3** and **Table 4**. Assuming 200 working days a year, 400 travels a year by a single driver in a car is conservatively considered.

Table 3. Received dose of a car driver

Dose [μSv]				
Section length [m]	Time [s]	Received dose [μSv]		
		^{60}Co	^{137}Cs	^{54}Mn
100	4	4.20 E-08	2.70 E-10	1.40 E-09
2000	80	8.40 E-07	5.40 E-09	2.80 E-08

Table 4. Dose of a car driver per year

Dose [μSv/y]		
^{60}Co	^{137}Cs	^{54}Mn
3.36 E-04	2.16 E-06	1.12 E-05

Clearance levels for the motorway scenario were derived as ratio between a dose reference level for exposure management of a public and calculated annually received effective dose. **Table 5** shows calculated values of clearance levels for legislatively defined reference doses [1].

Table 5. Values of clearance levels without optimization

Reference dose [μSv/y]	Derived clearance levels [Bq/kg]		
	^{60}Co	^{137}Cs	^{54}Mn
50	130	500	355
10	25	100	70

6. Optimization

The following measures were suggested in order to optimize derived clearance levels:

Option No. 1.

Conditionally cleared material was applied in 2 layers instead of original 4 layers.

Option No. 2.

Conditionally cleared material was applied in 1 layer instead of original 4 layers.

During the calculations, scenario identical with as in the original model was used. Both optimization measures result in decrease of annual individual effective doses received by critical individual. Based on the calculation results, new clearance levels considering above mentioned optimization measures were derived. Clearance levels calculated for each considered variant are given in **Table 6** (below).

Table 6. Clearance levels of specific activity

Evaluation variants	Derived clearance levels [Bq/kg]					
	Reference dose 10 μSv/y			Reference dose 50 μSv/y		
	^{60}Co	^{137}Cs	^{54}Mn	^{60}Co	^{137}Cs	^{54}Mn
No optimi-zation	25	100	70	130	500	355
Option No.1	55	200	145	260	1000	715
Option No.2	100	415	290	500	2065	1430

7. Inhalation exposure pathway

Dose to a worker and public due to dust inhalation is given by:

- the dust concentration the air
- the time spent in the dust plume
- the breathing rate
- the dose factor for inhalation [8]

Our conservative assumptions were that the worker spent working time 2000 h/y in the dust plume for variant without optimization (800 h/y with optimization variant), rubble initial activity 1000 Bq for all radionuclides, assumed dust concentration was 1E-06 kg/m^3 and breathing rate 1.2 m^3/h. Derived clearance levels for inhalation exposure pathway are given in **Table 7** and **Table 8**.

Table 7. Derived clearance levels for inhalation exposure pathway and reference dose 10 µSv/y

Evaluation variants	Derived clearance levels [Bq/kg]			
	^{54}Mn	^{60}Co	^{137}Cs	^{239}Pu
Without optimization	2,78 E+06	1,34 E+05	1,07 E+05	3,47 E+01
Option 2	6,94 E+06	3,36 E+05	2,67 E+05	8,68 E+01

Table 8. Derived clearance levels for inhalation exposure pathway and reference dose 50 µSv/y

Evaluation variants	Derived clearance levels [Bq/kg]			
	^{54}Mn	^{60}Co	^{137}Cs	^{239}Pu
Without optimization	1,39 E+07	6,72 E+05	5,34 E+05	1,74 E+02
Option 2	3,47 E+07	1,68 E+06	1,34 E+06	4,34 E+02

8. Results

Based on the calculated doses, which was received by critical workers during individual phases of construction, we derived clearance level of specific activity. **Table 9** includes individual values of clearance levels for effective doses 10 and 50 µSv (optimized variant).

Table 9. Derived clearance levels for optimized variant

Evaluation variants	Derived clearance levels [Bq/kg]			
	^{54}Mn	^{60}Co	^{137}Cs	^{239}Pu
Reference dose 10 µSv	290	100	415	86,8
Reference dose 50 µSv	1430	500	2065	434
Critical exposure pathway	External exposure			Inhala-tion

9. Conclusion

We concluded, based on the results of calculations and optimization, that conditional clearance of radioactive demolition wastes and subsequent reuse in motorway scenario is feasible from the radiation safety point of view. Concept of conditional clearance is able to save considerable financial resources, which would be otherwise used for treatment, conditioning and disposal of very low level radioactive demolition waste (e.g. treatment and disposal of 1 m^3 of radioactive waste costs EUR 30 000 in Slovak conditions).

In practice, many other factors and requirements will influence viability of real application of conditional clearance of VLLW, including safety, regulatory, technological, economic, social, administrative factors and necessary public acceptance.

Acknowledgement

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