Radiation Impact of Very Low Level Radioactive Steel Reused in Building Industry with Emphasis on External Exposure Pathway - 12569

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ABSTRACT

Considerable quantities of various materials are accumulated during the decommissioning process of nuclear installations. Some of arising materials are activated or contaminated. However, many of them continue to have an economic value and exist in a form that can be recycled or reused for special purposes. Furthermore much of the material generated during decommissioning process will contain only small amounts of radionuclides. For these materials there exist environmental and economic incentives to maximize the use of the concept of clearance from further regulatory control. This impact analysis is devoted to mentioned incentives. The aim is to conditionally clear maximum amount of the scrap steel and consequently recycle and reuse it in form of reinforcing components in tunnel and bridge building scenarios.

INTRODUCTION

With the growing number of nuclear power plants approaching the end of their operational lifetime, also the emphasis on activities performing during the decommissioning of these facilities raises. Considerable amount of decommissioning materials falls into the very low level radioactive waste category. Increased attention is recently dedicated to this group of materials in order to optimize the process of waste management. One of considered concepts of such optimization is the conditional clearance of materials with their subsequent recycling and reuse.

The concept of conditional clearance of materials into the environment is based on the requirements and conditions that have to be met in order to ensure that the risk arising from the exposure of people to radioactive materials is at the trivial level [1]. These conditions and assumptions are described in more detail in following lines.

Conditionally cleared materials should be mostly solid metal radioactive waste. A significant number of these materials are usually contaminated only with relatively short-lived radionuclides. These materials could be used for specific industrial purposes where long-term fixing of short-lived radionuclides in one place is expected. This long-term fixing ensures a significant reduction of radionuclides concentration in the material due to the natural radioactive decay. A typical example of the reuse of conditionally cleared materials could be the construction of highway bridges, tunnels and rails or reuse in the construction of roads. There are international recommendations that come out from the International Atomic Energy Agency

(IAEA) documents [2], [3] derived from the principles that individual effective dose must not exceed some tens of μSv/yr and collective effective dose 1 manSv/yr.

In order to prove that mentioned dose limits will be met, the concept of conditional clearance requires development of complex impact analysis of cleared materials that would be reused in specific, formerly determined, industrial applications. Radiological impact analysis consists of identification of the critical individual and the calculation of individual effective dose received by this person from various considered exposure pathways as well. The impact of one of the considered exposure pathways, specifically external exposure of workers performing activities related to construction of concrete bridges and motorway tunnels and external exposure of inhabitants using mentioned structural engineering projects are described in more detail. The goal is to identify new clearance levels for materials applicable without exceeding legislatively given dose limits for critical individual.

METHOD

Basically, two types of materials for clearance were considered at international level and relevant assumptions, approaches and results were published in IAEA, European Commission (EC) or United States Nuclear Regulatory Commission (NRC) documents [3-6]. First group of considered materials are represented by very low level radioactive metal waste (steel, copper, aluminium). Second group of materials comprise of slightly contaminated concrete rubble. Within the scope of this analysis only clearance of steel scrap is taken into account.
It is assumed that all steel scrap from decommissioning would be melted in controlled area. Ingots obtained from this process would be transported to the facility where the steel reinforcement components would be produced. Then the process of production would take place and final products could be transported, stored and finally used during the realization of chosen application, which would assume the long-term fixing of conditionally cleared materials in one place.

Basically there are two options of production of such components:

- Small facility for the production of steel reinforcement components located in controlled area (this requires additional investments, operational cost…)
- Civil production facility (this requires agreement with industrial stakeholders and additional cost as consequence of using protective equipment, instructing of workers about ALARA principles, decontamination of contaminated furnace…)

It is important to point out that these two options differ also on the applicable dose limits relevant for workers performing related activities. Therefore within the scope of performed impact analysis, the first option is assumed. Issue of melting and production of steel reinforcement components in this option would be assessed as the specialized scenario and it is not included in calculations stated below. Applicable dose limit in this case is 20 mSv/yr because all activities are performed in controlled area.

The assessment method applied on the conditional clearance issue is schematically described in following Fig. 1.

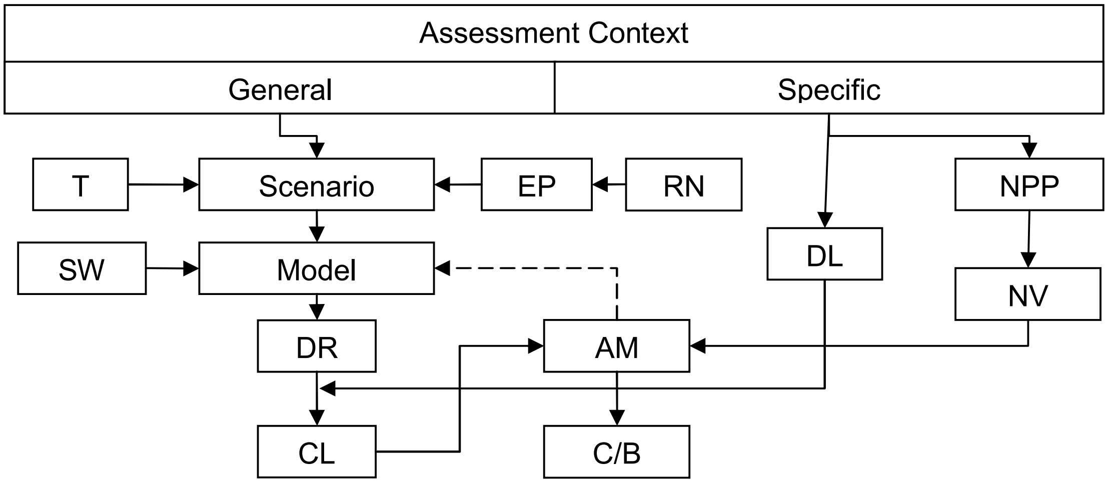

Fig. 1. Considered method applied for conditional clearance

Assessment context covers the framework and general boundary conditions for the performance of safety assessment. It provides information about key aspects of the safety assessment – the purpose, the radiological protection criteria, calculation end points, the assessment philosophy and the timeframes. The content of assessment context is divided to 2 basic parts, where first part comprises general elements and the second part consists of issues that are specific for the country or nuclear power plant [7].

Main element of general part of assessment context is the scenario. Scenarios cover all reasonable applications of conditionally cleared materials. Inputs needed for the creation of the scenario are technology (T) and exposure pathways (EP).Technology is always respective to the chosen application of conditionally cleared material e.g. bridge or tunnel building technology. Exposure pathways are always related to the physical nature of particular radionuclide (RN). Scenarios are processed to create computational models that are suitably adapted to be calculated using appropriate software (SW). Results of the calculations are in the form of absorbed doses (DR). Possible clearance levels (CL) of conditionally cleared material are derived from the comparison of calculated dose with the legislation dose limit (DL). Legislation dose limits parameter falls into the specific group of assessment context because the dose limits are country specific.

After the calculation of whole general model has been done, it is possible to adapt the model to the real application. Real application takes into account the amount of material (AM) from the decommissioning of real nuclear power plant (NPP). Most important characteristic of this decommissioning material is its radionuclide vector (NV) that defines the presence and the proportion between constituent radionuclides. The amount of real decommissioning material can be one of the inputs of computational model. Adding this input into the model changes the resulting clearance levels what could again change amount of material on the input. This process can iterate until the results of cost/benefit analysis (C/B) are satisfactory.

Identification, analysis and description of all possible exposure pathways of all models are very important procedures. Each exposure pathway requires different calculation tool. External exposure pathway, particularly gamma irradiation is the most important contributor to the resulting dose in case of scenarios dealing with the utilization of conditionally cleared very low level radioactive steel used as part of reinforcement of concrete bridges and tunnels. Number of software can be used for the calculation of the external exposure. Software that was chosen for calculations in this case is VISIPLAN 3D ALARA planning tool.

VISIPLAN 3D ALARA software allows the calculation of the absorbed individual effective dose in complex environments. It enables a creation of the simplified geometry model of working environment based on the technical documentation. Radiation sources, identified by the measurement, are placed in this geometry. Dimensions, material and radionuclide composition of radiation sources are also taken into account. After creating geometry with radiation sources, it is possible to create a grid of points, in which the program calculates dose parameters. The output in this case is a dose map that can be displayed as a coloured field or contours connecting the places with the same dose. A useful option of the program is a creation of "trajectory". Trajectories describe the movement of the person in an environment with radiation sources. They consist of several points. Each point contains the information about the movement of the person in the environment, the duration and the type of its activity. The calculated trajectory contains a record of the dose absorbed by the person summarily or individually at each trajectory point and also allows the recognition of the contribution of individual radiation sources to the resulting dose [8].

The potential for the utilization of very low level radioactive steel as part of the reinforcement of concrete bridge or tunnel constructions was identified after considering the basic characteristics of these structures that are suitable for this issue. The location of many bridges and tunnels in non-occupied territory, using of high quality concrete with low permeability, relatively thick reinforcement cover or the required service life of these structures that enable the natural decline of the radioactivity represent decision-making characteristics.

Concrete Bridge Scenario

Two types of concrete bridges were chosen as the base for modelling. Both bridges are widespread and very common and they are built using different building technologies. Thus these bridges can be considered representative. First bridge comprises prefabricated components that are produced in specialized facilities. Second bridge is \`monolithic\` and it is almost completely built on the construction site. Both bridges have the same length to be comparable. Chosen bridges can be divided into 3 parts depending on the placement of radioactive reinforcement steel:

- Utilization for piles construction
- Utilization for piers construction
- Utilization for superstructure construction

This division allows splitting the dose absorbed during the construction of each part and then to assess if different parts of the bridge are suitable for the incorporation of conditionally cleared steel. It is possible to determine the value of the mass activities for each part separately. Working procedures needed for building of both bridges were grouped according to 3 basic parts of the bridge and the calculation results were summarized for these parts.

The concrete bridge made of prefabricated components chosen as the basis of the model reaches the length of 1650 m. The foundations consist of large diameter piles 13 m long under the abutments and 14 m long under the piers. Piers of the bridge are cylinder shaped with the circular cross-cutting diameter of 1600 mm. The superstructure is composed of ten 1400 mm high I-96 type girders connected with a 200 mm thick concrete deck. Prefabricated girders are placed on prefabricated cross beams with a 500 mm thick bottom plate [8].

There are several technologies for the construction of monolithic bridges. The bridge constructed by the technology called `launching` was selected as a basis for modelling.
A bridge construction workplace is created in the initial point of the future bridge. A support structure installed inside this workplace also serves as moulding. Inside this structure workers bind the reinforcement of the sections of the superstructure. The section is then concreted and after hardening is hydraulically lifted and launched forward on pre-built piers. The entire length of the bridge superstructure is built following this process. `Launching` was chosen as a technology suitable for building a bridge that utilizes the very low level radioactive steel because this technology enables the determination of the type and the duration of the construction process precise enough. These findings are essential for modelling of the construction process. The monolithic concrete bridge chosen as the basis for creating the model reaches the length of 1650 m. Its foundation is identical to the foundation of prefabricated bridge. Bridge piers are rectangular with bevelled edges and the head on top [8].

Motorway Tunnel Scenario

The scenario is based on the real tunnel construction consisting of two tunnel tubes, which will carry the unidirectional traffic during a standard operation. The total lengths of the model tunnel tubes are 2 km and their radius is approximately 5 m. This length is chosen because it represents approximately the average length of tunnel constructions in the Slovak Republic and it is possible to bore a tunnel with this length during one year. The reinforcement of the model tunnel consists of primary (25 cm thick) and secondary lining (30 cm thick). As it was mentioned, it is assumed that the melted radioactive steel would be reused in form of reinforcing component assembled into primary or secondary lining, namely in form of two layers of steel reinforcing nets in primary lining and in form of re-bars bound together in reinforcement cage of the strip foundation in secondary lining [9].

The key to the external exposure impact assessment is to find a critical individual from the critical workers/population group. For this reason, it is necessary to create different groups of workers or members of the public for various activities carried out in motorway tunnel and concrete bridge construction and operation stage.
In both cases, the model designs should incorporate realistic modelling of current industrial practices in the Slovak Republic due to the minimization of the unnecessary or unduly

conservatism level, i.e. in order to avoid overestimating of dose rates. However, it could be difficult to obtain all the necessary data about current industrial practices or modelling of some applied techniques and procedures is overly complicated, so the engineering judgment is implemented as well.

RESULT AND DISCUSSION

Dose Assessment Results

The following tables includes summarized results containing the annual exposure time of workers or the population, average dose rates and received annual individual effective doses of workers or members of the public performing assigned activities related to the particular scenario. Calculations were performed for the specific mass activity 300 Bq/kg contained in the conditionally cleared steel.

Table I. Dose assessment results for the radionuclide Co-60 in bridge scenario

		Performed activity	Average dose rates (µSv/hour)	Annual exposure time (hours)	Annual received individual effective dose (µSv)
Monolithic bridge	**Construct-ion stage**	Building of piles	6.6E-03	1250	8.25
		Building of piers	8.3E-02	2000	166.63
		Building of superstructure	5.3E-02	2000	106.63
	Operation stage	Driver*	6.7E-03	12	8.03E-02
Prefabricated bridge	**Construct-ion stage**	Building of piles	6.6E-03	1250	8.25
		Building of piers	1.9E-02	2000	37.83
		Building of superstructure	1.9E-02	2000	37.93
	Operation stage	Driver*	3.5E-03	12	4.17E-02

* Driver uses bridge twice every day.

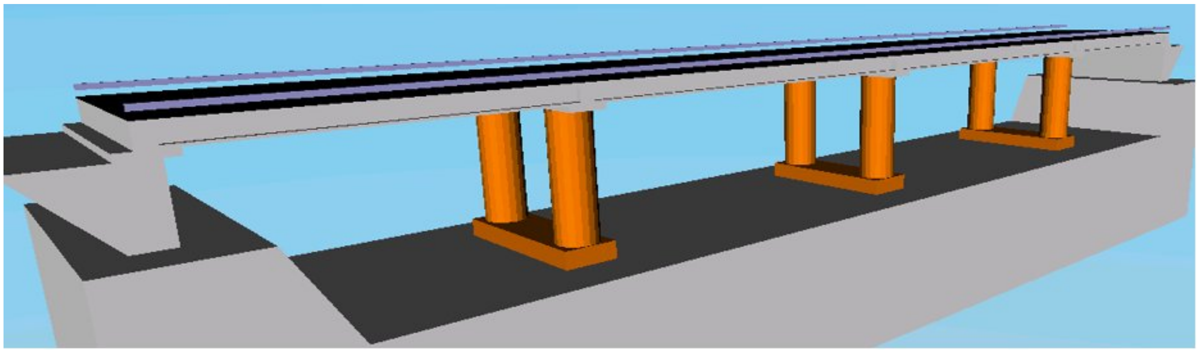

Fig. 2. Prefabricated bridge modelled in VISIPLAN environment

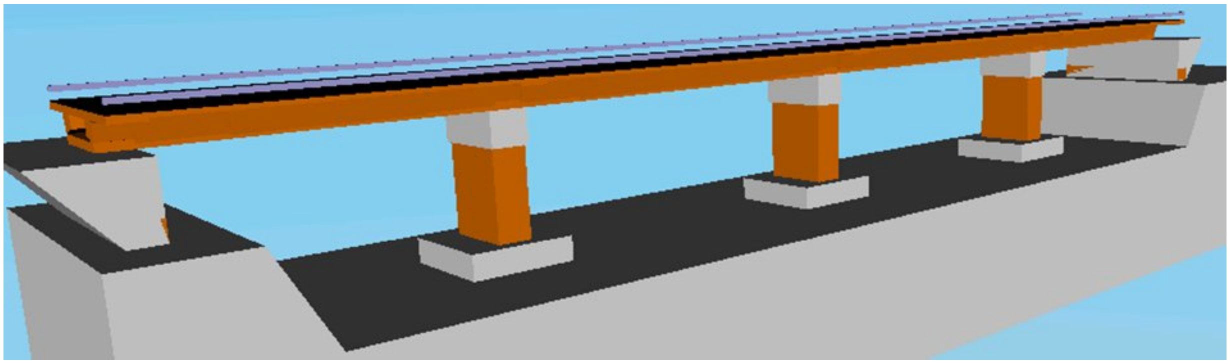

Fig. 3. Monolithic bridge modelled in VISIPLAN environment

Table II. Dose assessment results for the radionuclide Co-60 in tunnel scenario

	Performed activity	**Average dose rates (μSv/hour)**	**Annual exposure time (hours)**	**Annual received individual effective dose (μSv)**
Construction stage	Assembly of primary lining	3.19E-03 / 3.91E-03 *	1 848	6.22
	Assembly of strip foundation	4.64E-03	550	2.55
	Realization of secondary lining	2.75E-03	840	2.31
	Storage of steel nets and re-bars	5.10E-02	28	1.43
Operation stage	Maintenance of already built tunnel	7.33E-05	130	9.53E-03
	Professional driver	9.20E-05 / 1.04E-04 **	50	4.60E-03 / 5.20E-03 **
	Driver or passenger	9.20E-05 / 1.04E-04 **	10	9.20E-04 / 1.04E-03 **

[*] Activities are performed at two different vertical levels (calotte / bench level).

[**] Left values represent obtained results for driver who drives in the left traffic lane and right values are obtained for right traffic lane (professional driver drives through tunnel 10 times a day; driver or passenger commutes to work and back home daily)

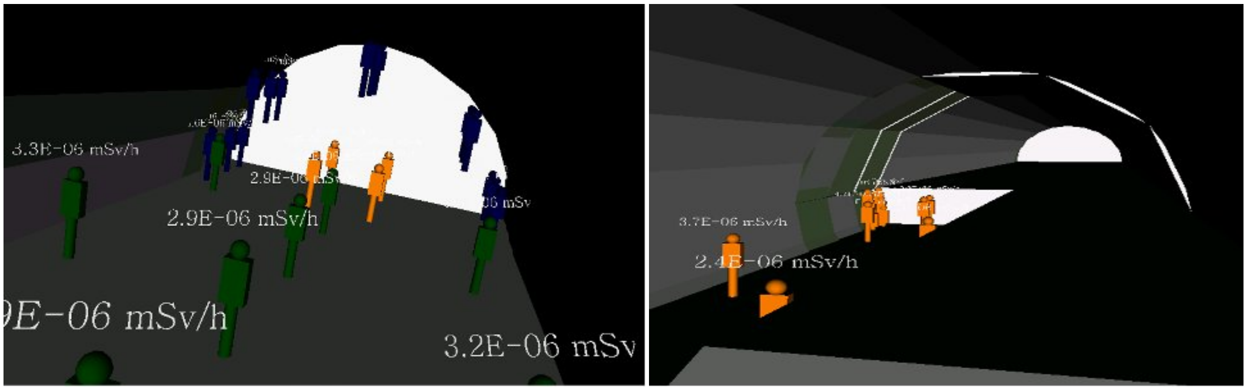

Fig. 4. 3D results for assembly of primary lining at different vertical levels obtained from VISIPLAN environment

New Clearance Levels

The derivation of the clearance level of particular radionuclide is performed by using following formula:

$$a = \frac{D_L}{IED} a_u \tag{Eq. 1}$$

Where: a – derived clearance level,
D_L – dose limit (10 μSv/yr or 50 μSv/yr),
IED – calculated annual individual effective dose received by critical individual,
a_u – reference value of specific mass activity (300 Bq/kg).

Table III. includes derived clearance levels for three selected radionuclides (Co-60, Nb-94 and Cs-137). Justifications of radionuclide selection are summarized in following few points:

- Co-60 is chosen due to its dominant share in real nuclide vector after melting process and due to its emitting of relative high energy gamma photons.
- Nb-94 is chosen due to its long-lived nature (half-life is over 20 000 years).
- Cs-137 represents fission products and it emits relative high energy gamma photons.

Other radionuclides are excluded from further consideration due to emitting of low energy or even no gamma photons, due to the their very short-lived nature (half-life under 1 year) or real nuclide vector from radiological characterization of Slovak NPPs does not include them.

Table III. Derived new clearance levels for considered scenarios

	Considered radionuclide	**Limiting sub-scenario (external exposure pathway)**	**Clearance levels value related to 10 μSv dose limit (Bq/kg)**	**Clearance levels value related to 50 μSv dose limit (Bq/kg)**	**Limits for unconditional clearance in Slovak Republic (Bq/kg)**
Tunnel scenario	Co-60	Assembly of primary lining	480	2 400	300
	Nb-94	Assembly of primary lining	660	3 300	300
	Cs-137	Assembly of primary lining	1 800	9 000	300
Prefabricated bridge scenario	Co-60	Assembly of piles reinfor.	360	1 800	300
		Assembly of piers reinfor.	-	390	300
		Assembly of transoms reinfor.	-	390	300
	Nb-94	Assembly of piles reinfor.	460	2 300	300
		Assembly of piers reinfor.	-	500	300
		Assembly of transoms reinfor.	-	350	300
	Cs-137	Assembly of piles reinfor.	1 250	6 200	300
		Assembly of piers reinfor.	-	1 300	300
		Assembly of transoms reinfor.	-	1 200	300

[*] The empty fields with the dash (-) represent the fact that in relevant case is not possible to increase the legislatively given mass activity of cleared steel because results of the calculations exceed annual individual dose limit.

Generally it is possible to say that the utilization of very low level radioactive steel in bridges construction is more appropriate in case of concrete bridges built using prefabricated components. 10 μSv/yr dose limit seems to be too strict for the utilization of the conditionally cleared steel as reinforcement of piers or the superstructure of the prefabricated bridge.
50 μSv/yr dose limit enables to use the radioactive steel with increased specific activity even in piers or superstructure of the prefabricated bridge. Building of monolithic bridge from this material would require making modifications in design of the reinforcement or incorporating some restrictions into working procedures. Design and construction of monolithic bridge foundation is identical to prefabricated bridge, thus the clearance levels relevant to assembly of piles reinforcement reach the same level as it is in case of prefabricated bridge. Application of very low level radioactive steel as reinforcement of other basic parts of monolithic bridge (piers, superstructure) does not enable to increase the clearance levels without modification of reinforcement design or working procedures, therefore the results related to monolithic bridge are missing in Table III.

I case of utilization of very low level radioactive steel during building of motorway tunnel construction both stated dose limits leads to an opportunity of the reuse of radioactive steels with increased specific mass activity. In case of 50 μSv/yr dose limit, it is even possible to conditionally clear steel with approximately one order of magnitude higher specific mass activity than it is defined in legislation of the Slovak Republic.

Derived clearance levels related to both selected scenarios could be increased even higher depending on available amount of decommissioning materials. Also other special measures (additional shielding, restrictions on working procedures or decrease of workers exposure time) may lead to increase of clearance level values; however cost-benefit analysis of conduct of such specific measures is highly desirable.
Prior to real application of the concept of conditional clearance, it is essential to discuss this issue with stakeholders (industry, government, members of the public) and to involve them into the process of implementation.

CONCLUSION

Recent calculations relevant for external exposure pathway indicate that concept of conditional clearance represent a feasible option for the management of radioactive materials. Even in chosen specific industrial applications it is possible to justify new, approximately one order of magnitude higher, clearance levels. However analysis of other possible exposure pathways relevant for particular scenario of reuse of conditionally cleared materials has to be performed in order to confirm indications from partially obtained results.
Basically, the concept of conditional clearance can bring two basic benefits. Firstly it is saving of considerable funds, which would be otherwise used for treatment, conditioning and disposal of materials at appropriate radioactive waste repository. Moreover materials with intrinsic value (particularly metals) can be recycled and reused in industrial applications instead of investing resources on mining and production process in order to obtain new, “fresh” materials.

REFERENCES

[1] International Atomic Energy Agency: Managing Low Radioactivity Material from the Decommissioning of Nuclear Facilities. IAEA, Vienna, 2008.

[2] International Atomic Energy Agency: Application of the Concepts of Exclusion, Exemption and Clearance. IAEA, Vienna, 2004.

[3] International Atomic Energy Agency: Derivation of Activity Concentrations Values for Exclusion, Exemption and Clearance, IAEA Safety Reports Series No. 44. Vienna: IAEA, 2005.

[4] European Commission: Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations, Radiation Protection No. 89. Luxemburg: EC, 1998.

[5] European Commission: Recommended Radiological Protection Criteria for the Clearance of Buildings and Building Rubble from the Dismantling of Nuclear Installations, Radiation Protection No. 113. Luxemburg: EC, 2000.

[6] U.S. Nuclear Regulatory Commission: Radiological Assessments for Clearance of Materials from Nuclear Facilities, Main Report, NUREG-1640. Washington D.C.: US NRC, 2003.

[7] International Atomic Energy Agency: Derivation of Activity Limits for the Disposal of Radioactive Waste in Near Surface Disposal Facilities, IAEA-TECDOC-1380. Vienna: IAEA, 2003.

[8] Panik, M., Necas, V.: Evaluation Of External Exposure During Building And Operation Of Concrete Bridges Constructions That Reuse The Conditionally Released Steels. ICEM 2011: 14th International Conference on Environmental Remediation and Radioactive Waste Management. Reims, France. New York: ASME, 2011.

[9] Hrncir, T., Necas, V.: Impact of Nuclide Vector Composition Contained in Conditionally Released Steel Reused in Motorway Tunnels Scenario on Calculated Individual Effective Doses. ICEM 2011: 14th International Conference on Environmental Remediation and Radioactive Waste Management. Reims, France. ASME, New York, 2011.

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