Preliminary Study on Recycling and Reuse of Metals from Decommissioning in Construction of Disposal Vaults in Slovakia – 17217

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ABSTRACT

The decommissioning of nuclear installations represents a complex process resulting in the generation of large amounts of various waste materials. Majority of them are non-contaminated, however some of them may be hazardous as well (e.g. chemicals, asbestos, oil products, etc.). During decommissioning of NPP, significant quantities of materials with various levels of radionuclides concentration arise as well. All of these materials should be managed appropriately keeping in mind safety principles, legislative requirements, lessons learned and other relevant factors. Therefore, selection of an appropriate strategy for management of the materials arising from decommissioning is crucial and strongly influences the overall effectiveness of decommissioning process. In line with international incentives for optimization of radioactive material management, concepts of recycling and reuse of slightly radioactive materials are widely discussed and applications of these concepts are analyzed.

Therefore, the paper is devoted to the preliminary study of potential for recycling of re-melted metals from decommissioning in form of reinforcement bars or mesh used in the construction of ferro-concrete disposal vaults within the near surface repository. The paper presents the preliminary results and discusses the technical and non-technical aspects related to the recycling scenario. Moreover, comparison of various scenarios related to the scrap metal clearance and recycling within nuclear industry is included. Key findings and lessons learned from study may be useful for the international community dealing with waste management optimization and in particular with recycling of materials within nuclear industry.

INTRODUCTION

Currently, decommissioning of two NPPs in Slovakia takes place resulting in the increase of generated waste materials. In parallel, the implementation of Council directive 2013/59/EURATOM [1] into the Slovak legislation has to be done at the latest by February 2018. Council directive comprises the new clearance levels valid for unrestricted clearance that are stricter for several radionuclides of concern than currently defined values in Slovak legislation. Moreover, there are plans for construction of melting facility and putting it in operation in the next few years. Besides aforementioned activities, the projects for increasing the disposal capacity of the near surface repository (construction of new double row of disposal boxes for LLW), construction of VLLW repository and analysis of new type of disposal containers recently began. Therefore identification of potential waste streams, modification and the optimization of waste management system is one of the top priorities in the next few years in Slovakia.

Following the waste hierarchy principles, attention in the paper is given to the application of the clearance and recycling concepts. Melting of scrap metal and subsequent recycling of some portion of this metals containing low concentration of radionuclides within the nuclear sector seems to be interesting from economical point of view and may save some disposal capacity.

The following chapters discussed the method and the preliminary results valid for the recycling of metals within nuclear industry in more detail.

METHODS

Safety assessment method follows the international recommendations for derivation of clearance levels based on dose constraint approach. Several rigorous documents describing the procedure for the development of clearance scenarios, related safety assessment and derivation of clearance levels are available [2-6].

Method for the overall assessment including safety and economical aspects was developed within the research project called CONRELMAT devoted to derivation of clearance levels and evaluation of possible scenarios for reuse and recycling of decommissioning materials both within and outside of nuclear sector [7]. Analysis of economic aspects implements the lessons learned from numerous decommissioning costing calculation cases including simulation of material flow. Principal scheme of this research project funded by the Slovak government is depicted in Fig. 1[8].

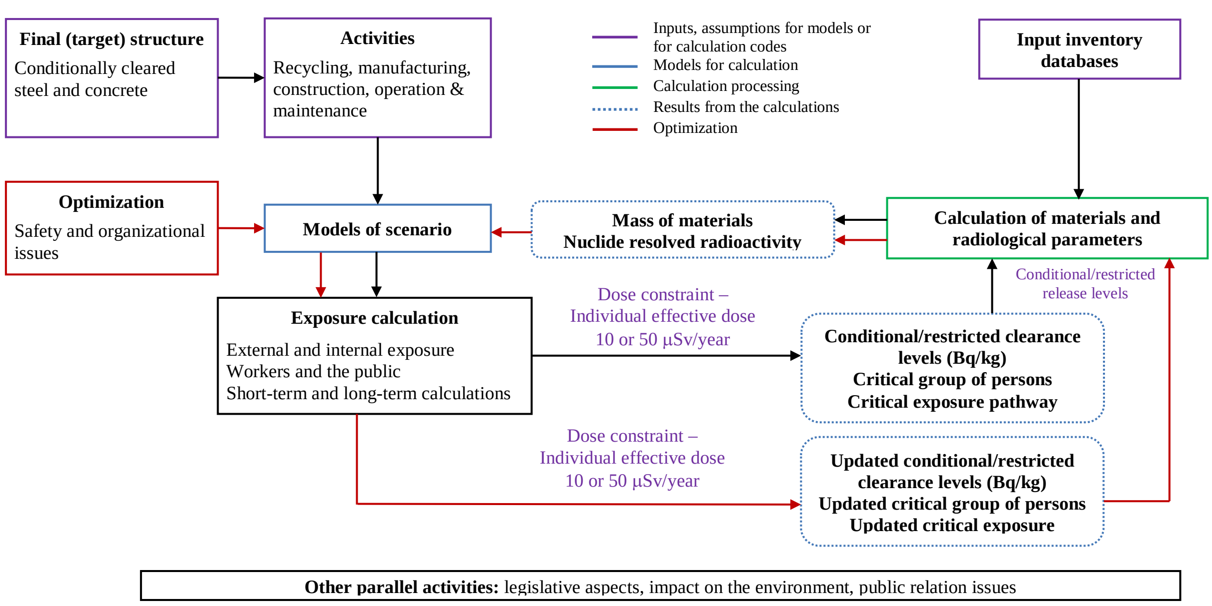

Fig. 1 Principal scheme of CONRELMAT research project devoted to the analysis of conditional/restricted clearance and recycling scenario [8]

Aforementioned method for overall assessment of clearance scenarios was adopted, adjusted and applied for the purpose of recycling of materials within nuclear industry.

Safety criteria

Based on international recommendations, the following safety criteria should be applied for the professional workers and the public:

- Application of clearance concept (both unrestricted and restricted): Unrestricted clearance allows any possible further use of cleared material. On the other hand, specific further use of material is defined in case of restricted release. Both unrestricted and restricted clearance concepts follow the international recommendations for the protection of the people and the environment. The dose constraint of the order of 10 μSv per year is defined for the public, i.e. in case of clearance of materials effective dose incurred by any individual owing to the cleared material relevant to the reasonably expected scenarios is of the order of 10 μSv or less in a year [1, 9].

- Application of the concept of recycling within the nuclear industry (without application of clearance concept): This option stands for the recycling of equipment or materials within the nuclear industry, therefore higher dose constraint may be applied. Based on the Basic Safety Standards, the annual limit for the occupational exposure of workers over the age of 18 years is 20 mSv per year averaged over 5 consecutive years [1, 9]. These workers are often classified as “Category A” workers. Besides these classified workers, non-classified workers, i.e. “Category B” workers, are defined within European Union legislation with relevant dose limit value of 6 mSv per year [1].

Based on the above mentioned criteria, the following dose criteria were taken into account in the preliminary analysis of recycling scenario presented in the paper:

- 20 mSv for the classified workers within the nuclear industry (e.g. workers at the melting facility for radioactive metals);
- 0.5 mSv for non-classified workers (e.g. construction workers – see scenario description) – preliminary assumption taking into account value conservatively lowered from aforementioned 6 mSv dose limit; relevant dose constraint shall be subject for the discussion with the regulatory body.

Scenario description

Presented scenario is relevant for the recycling of slightly radioactive metals from decommissioning of NPP within nuclear industry. The assumed procedure is as follows:

1. Melting of fragmented pieces of radioactive metal in the melting facility located at NPP site (it is assumed that melting facility will be put in operation in 2018).

2. Manufacture of reinforcing mesh from re-melted metal at NPP site. Since the project for the construction of melting facility is ongoing, it is assumed that small modification or extension of the facility may enable manufacture of different end products such as ingots with various dimensions (based on the mold) or specialized products such as metal bars or sheets (in case of adequate facility extension is installed).
3. Storage of reinforcing mesh at NPP site.
4. Transport of reinforcing mesh to the repository site.
5. Storage of reinforcing mesh at repository site.
6. Use of reinforcing mesh during construction of disposal boxes (see Fig.2). Reinforcement of walls and basement of disposal box by reinforcing meshed manufactured from recycled radioactive metal is assumed.
7. Regular operation of repository.
8. Closure and post-closure period.

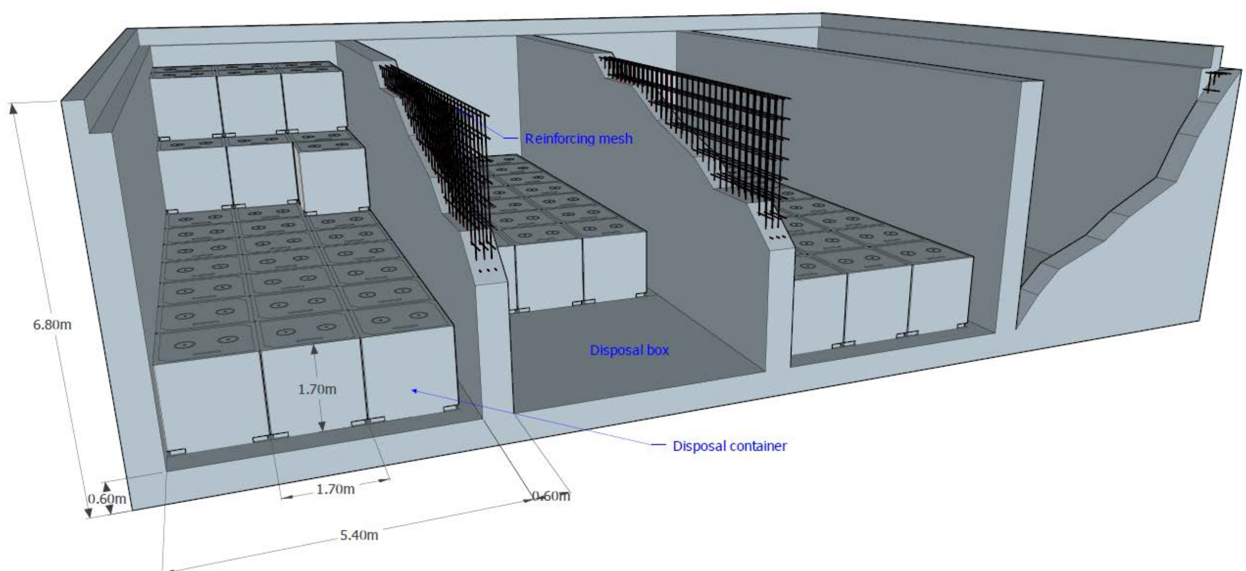

Fig. 2. Illustration and dimensions of disposal boxes at the near surface repository

Source term

The basis for the safety assessment is to define the source term, i.e. to create the list of the radionuclides of concern and their concentrations contained in material. The following list was set in case of V1 NPP (WWER-440 reactor type in the decommissioning stage) located in Slovakia based on the radiological characterization (see TABLE I).

TABLE I: Radionuclides of concern in the case of V1 NPP decommissioning

Exposure pathway	Radionuclides
External Exposure	^{60}Co, ^{137}Cs
Inhalation, Ingestion, Skin contamination	^{55}Fe, ^{59}Ni, ^{60}Co, ^{63}Ni, ^{90}Sr, ^{93}Mo, ^{135}Cs, ^{137}Cs, ^{151}Sm, ^{241}Pu

Preliminary safety assessment

Since complete relevant input data was not available, preliminary assessment is mainly based on the assumptions and analogy of input data and detailed analysis from similar case analyzed within CONRELMAT project –motorway tunnel construction scenario. This scenario assumed use of the slightly radioactive metal in form of reinforcing mesh as reinforcement for the primary lining of the tunnel tube.

Moreover, simple radiological models (see Fig. 3) were created to verify the similarity of radiological situation during construction of disposal box (recycling scenario) with the situation during construction of motorway tunnel (CONRELMAT project).

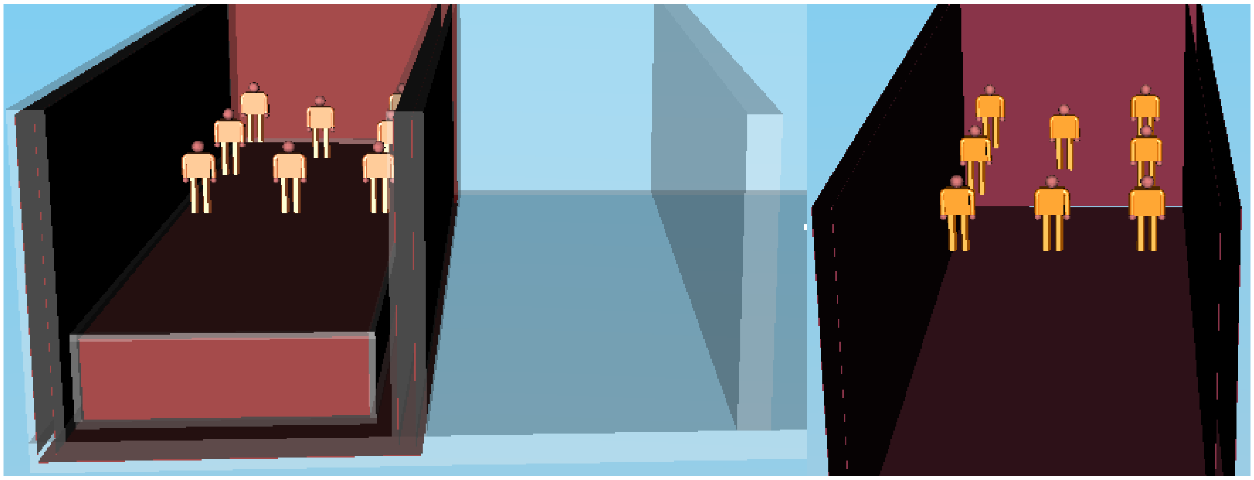

Fig. 3. Visualization of radiological models (left part – operation stage with disposal containers; right part- building stage of disposal box)

Based on lessons learned from the CONRELMAT project, construction would be the critical stage from the perspective of derivation of recycling levels. Therefore, gathering the all relevant parameters and conducting the detailed safety assessment are identified as vital for further detailed investigations.

Since recycled metal will be incorporated into the disposal box structure, activity concentrations of radionuclides should be added to the source term of the disposed waste. The same engineered barriers would be in place for recycled metals as for the waste besides the barrier represented by disposal container (e.g. disposal box structure, clay layers, etc.).

It should be highlighted, that activity of the recycled metal are well below the activity of waste regularly disposed in the disposal container. Therefore, impact of the use of recycled metal on the overall safety will be rather minor.

Moreover, based on the operational history, activity concentrations of radionuclides contained in the disposed waste is well below the waste acceptance criteria valid for the radionuclides of concern. There were several measures taken towards the optimization of the use of disposal capacity, however, there is still potential for enhancing the effectives of use of disposal capacity.

Nevertheless, the impact of use of recycled radioactive metal as reinforcement for construction of disposal box shall be addressed and evaluated in the revision of the safety report or the Limits and Conditions, if necessary.

Derivation of recycling levels

Principle for derivation of recycling levels was adopted from international guides relevant for the derivation of clearance levels [2]. The following formula was used ensuring that the dose constraint will be met.

$$A_{RL} = \frac{DC}{IED} RA \qquad \text{(Eq.1)}$$

Where A_{RL} is specific activity concentration of radionuclide - recycling level (Bq/kg), *DC* is given dose constraints, *IED* represents calculated individual effective dose received by individual in recycling scenario (mSv/yr) and *RA* is the reference value of specific mass activity (Bq/kg).

In case of mixture of radionuclides contained in the material, sum of quotients principle shall be applied.

Economic and material flow aspects

Using the robust decommissioning inventory database and derived clearance/recycling levels, it was possible to determine the amount of recyclable or clearable materials valid for particular scenario. OMEGA costing calculation tool was used for this purpose. OMEGA was in-house developed by DECOM company and is widely used for decommissioning costing purposes related to preliminary or the final decommissioning plan for nuclear installations in Slovakia and abroad (e.g. Hungary or Romania).

The new version of the OMEGA tool called eOMEGA is currently being deployed. International Structure for Decommissioning (ISDC) jointly recommended by IAEA, NEA/OECD and European Commission [10] is fully implemented in these codes. New eOMEGA code utilizes the lessons learned from OMEGA code development and use. Idea is to merge the ISDC itself, costing methodologies based on the ISDC, recent trends in decommissioning costing and funding along with principles of transparency, modern software design and user-friendliness into one compact and flexible working package [11].

Estimation of waste management costs including disposal costs relevant for various scenarios may be performed using the related economic data such as investment and operational costs, unit factors and manpower needed for the waste management.

Moreover a unique feature for simulation of material and radioactivity flow is implemented as well. This feature allows tracking the particular material piece along with relevant physical and radiological characteristics through the whole decommissioning process and thus calculating the quantities of materials that may be cleared and/or recycled or on the other hand that have to be disposed of at appropriate repository.

DISCUSSION

Presented recycling scenario was compared with selected scenarios of unrestricted and restricted clearance of metals taken into account the economic and material flow aspects. Results of the analysis are provided below.

Comparison of various scenarios

The following table illustrates various clearance and recycling levels derived based on the safety assessment and given dose constraints for clearance and recycling scenario (see TABLE II).

TABLE II: Comparison of various clearance and recycling levels for selected radionuclides

Radionuclides of concern	**Clearance levels (Bq/g)** dose constraint at the level of tens of μSv per year is applied				**Recycling levels (Bq/g)** dose constraint at the level of 0,5 mSv per year is applied
	IAEA – new BSS (IAEA) [9]	**Current state in Slovakia**	**Clearance after melting [4]**	**CONRELMAT project – motorway tunnel**	**Recycling of metals within nuclear sector – scenario presented in the paper**
^{60}Co	0.1	0.3	1	2.4	24
^{90}Sr	1	3	10	144	144
^{135}Cs	100	30	10	248	248
^{137}Cs	0.1	0.3	1	2.1	2.1
^{241}Pu	10	30	10	54	54

As it was mentioned above, preliminary safety assessment of presented recycling scenario was based on the analogy with the clearance scenario analyzed in the CONRELMAT project (motorway tunnel scenario). Since assumed dose constraint for the recycling scenario is 10 times higher than for the clearance scenario (0.5 mSv vs. 50 µSv), the recycling levels for several radionuclides are 10 times higher as well (e.g. ^{60}Co). The derived levels valid for the rest of radionuclides, which are equal (e.g. ^{90}Sr, ^{137}Cs, ^{241}Pu), are limited by the melting process performed within the controlled area at NPP site.

Figures below provide the comparison of scenarios from both economical (relative waste management costs, reference scenario equal to 100 % is the current state in Slovakia) and material flow point of view.

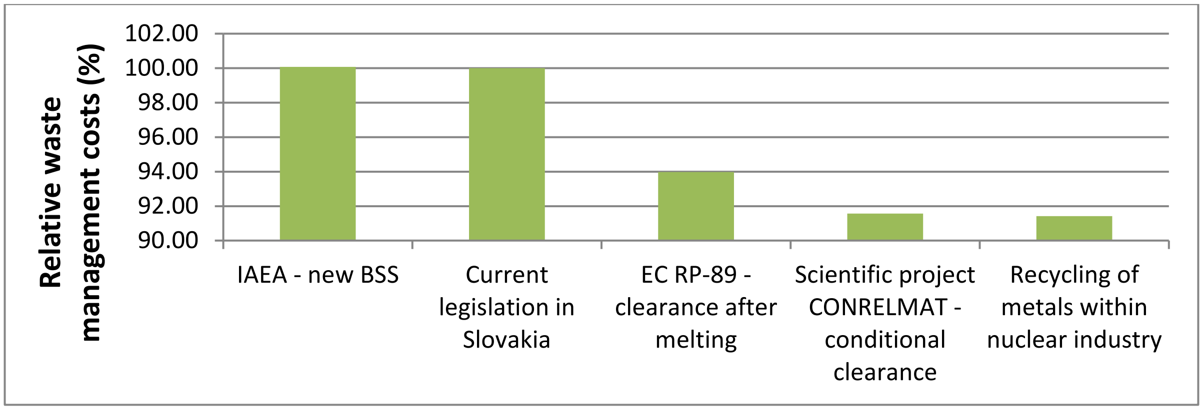

Fig. 4. Comparison of economic aspects of various clearance and recycling scenarios

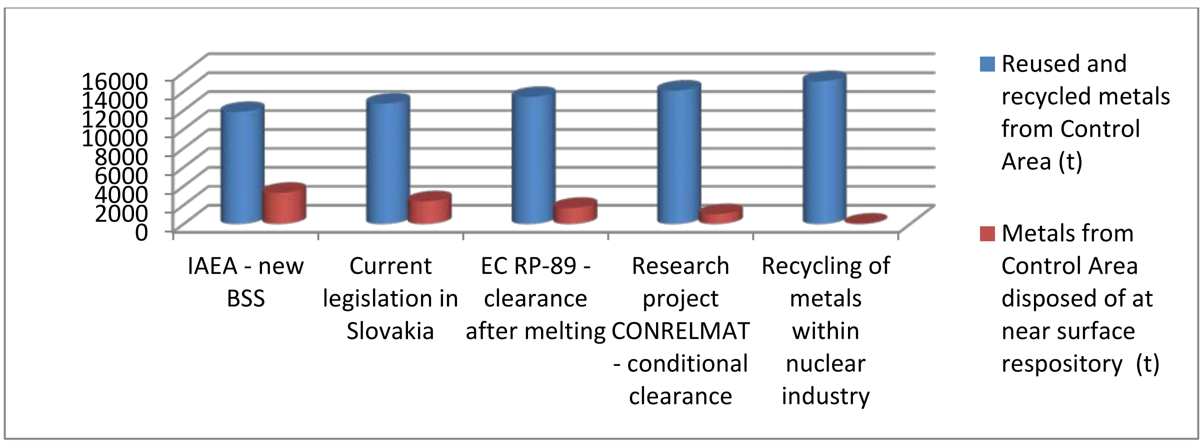

Fig. 5. Comparison of material flow relevant for various clearance and recycling scenarios

Needs for further detailed analysis

As it was mentioned, above presented results are based on preliminary analysis and related assumptions and simplifications. In order to perform the detailed and robust analysis, the following topics, inter alia, should be addressed:

- Discussions towards establishing the regulatory framework for the recycling and restricted clearance should be made to define clearly the rules and responsibilities;

- Input data, parameters and assumptions related to the safety assessment should be acquired in more detail and rationale for their selection should be provided;
- Impact of implementation of recycling scenario on current Limits and Conditions as well as on the safety assessment of near surface repository should be analyzed;
- Process of reinforcing mesh manufacture after the melting process within nuclear site should be investigated in more detail and other activities related to the scenario in the preparatory phase (e.g. storage of mesh at the NPP site, transport to the repository site) should be addressed;
- Measures for radiation protection during the construction of disposal vaults should be defined and approved;
- Detailed feasibility study including costing aspects should be elaborated, especially the costs relevant for small scale manufacture within the nuclear site.
- Aspects concerning the involvement of stakeholders should be addressed.

CONCLUSIONS

Method for overall assessment of clearance scenarios was developed within CONRELMAT project using the internationally accepted procedures for the development of clearance scenarios, identification of relevant exposure pathways, the dose assessment and derivation of clearance levels. This method was adopted and fit for purpose for recycling of slightly radioactive metals after melting within nuclear industry.

Based on the preliminary results, both concepts of recycling within nuclear industry and clearance appear to be feasible and may save some financial resources. Moreover, application of these concepts may optimize the use of disposal capacity and thus increase the overall effectiveness of the waste management process. This may be useful especially in the current worldwide situation, in which the disposal capacities available for radioactive waste are decreasing faster than expected and adding new capacity or siting and construction of new repositories is becoming more difficult from the societal and the economic point of view.

However, detailed analysis of recycling scenario is inevitable, particularly the detailed safety assessment, in order to select the optimal way for management of various waste streams. Development of detailed safety case for recycling scenario requires the qualified personnel, adequate period of time and, last but not least, the additional costs. Therefore, adequate feasibility study should be done to provide the cost-benefit analysis and determine whether the scenario is viable or not.

Moreover, involvement of the stakeholders represents a crucial part as well, particularly, the constructive discussion with the regulatory body on the safety aspects and the basic framework for the recycling option is vital.

As it was mentioned above, performed analysis is at conceptual stage, i.e. no detailed results as well as validation data are available yet. Nevertheless, preliminary quantification of presented scenario may establish the basis for the discussion of viable alternatives and enhance the decision making process within radioactive waste management.

REFERENCES

[1] Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. http://eur-lex.europa.eu/eli/dir/2013/59/oj

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

[3] International Atomic Energy Agency: Derivation of Activity Concentrations Values for Exclusion, Exemption and Clearance, IAEA Safety Reports Series No. 44. Vienna, Austria, 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., USA, US NRC (2003).

[7] T. HRNCIR, et al., “The impact of radioactive steel recycling on the public and professionals”, *J. Hazard. Mater.* 254/255 (2013), pp. 98-106.

[8] T. HRNCIR, et al., “Potential for recycling of metals within nuclear sector in Slovakia”. International Conference on Advancing the Global Implementation of Decommissioning and Environmental Remediation Programmes, Madrid, Spain, 23–27 May 2016, IAEA (2016).

[9] International Atomic Energy Agency, Radiation protection and safety of radiation sources: International Basic Safety Standards, IAEA General Safety Requirements No. GSR Part 3, Vienna, Austria, IAEA (2014).

[10] Nuclear Energy Agency, International Structure for Decommissioning Costing (ISDC) of Nuclear Installations, Paris, France, NEA/OECD (2012).

[11] M. ZACHAR, et al., “eOMEGA - ISDC Decommissioning Costing Platform”, 3rd Canadian Conference on Nuclear Waste Management, Decommissioning and

Environmental Restoration, Ottawa, ON, Canada, 11 – 14 September 2016, Canadian Nuclear Society (2016).

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