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# Application of Metal Melting Technology in Radioactive Materials Clearance Process During the Nuclear Installation Decommissioning

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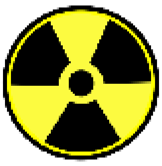

In the presented paper, the basic characterization of metal melting, described as a perspective decommissioning waste management method for radionuclides effective immobilizing and decontamination of metals up to clearance levels, is given. The materials with radioactivity below the clearance levels are releasable to the environment without any further restrictions. To evaluate the impact of metals melting application on the clearance process, it is necessary to monitor the physical and nuclide resolved radiological characteristics of the individual material items during the whole decommissioning.

These characteristics are implemented into the analytical calculation code OMEGA, especially into the integrated material flow tool that could be used for the evaluation of various options of melting application in the decommissioning waste management process. The possibilities of reaching the clearance levels, by applying the decontamination character of melting, are the main results discussed in the paper.

## 1 INTRODUCTION

One of the characteristic feature of nuclear installation (NI) decommissioning process is production of large amount of various radioactive and also non-radioactive waste that have to be managed and released from the former NI area, taking into account their physical, chemical, toxic and radiological properties. Therefore, the safe and economic implementation of the waste management plan is considered to be one of the key issues in the frame of the decommissioning. In the waste management process several methods and technologies are used to reach the two main goals:

- Release the materials to the environment (ENV) for further use and then minimize the volume of radioactive waste (RAW) – decontamination techniques;
- Safe isolation of the non-releasable materials from the environment within the radioactive waste repository barriers – waste treatment and conditioning techniques.

The melting technology, specified by international organizations as a promising method for metal waste (materials) processing (IAEA, 2008), could be included into both of two mentioned groups. In the paper the melting technology, applied as a decontamination method used for reducing the radioactivity of metals up to clearance levels, is analysed.

## 2 CHARACTERIZATION OF METAL MELTING

Melting is a high-temperature technology that completely destroys the metal components and redistributes the radioactivity among:

- **Ingots** as a primary product representing the main mass flow. Ingots are further managed according their characteristics.
- **Slag** as a secondary solid radioactive waste representing 1-4% of melted scrap weight. The slag has to be further treated and immobilized as a radioactive waste.
- **Dust** as a secondary radioactive waste is exhausted into the air conditioning system and before discharging to the ENV is absorbed on the high-efficiency filters.

The distribution of radionuclides during melting is a complex process that could be influenced by numerous chemical and physical factors, including the composition, solubility of an element in molten metal, density of the oxides, composition and basicity of the slag former, melting temperature and melting practices such as the furnace type and size or melting time.

Melting is considered to be the final and usually irreversible step in the metal radioactive waste treatment. The advantages of melting application in the decommissioning waste management process should be summarized as follows (IAEA, 2008; IAEA 2001; Min, et al., 2009):

- Decontamination of the melted metals reached by the effective separation of radionuclides from the metal waste and their redistribution to the slag and to the dust. The decontamination efficiency varies widely, depending on the radionuclides present. It is also possible to reach the clearance levels and release the ingots to the ENV for further use.
- Homogenous distribution and effective immobilizing of radionuclides in the ingots volume (no surface contamination), thus the possibility of contamination spreading is significantly reduced.
- Volume reduction, thereby the storage or disposal capacities are preserved.
- Precise determination of specific mass radioactivity and easier comparison with clearance levels by sampling each ingot.
- Simplified monitoring procedures for characterization of radioactive materials with complex geometry. The problem of inaccessible surfaces is eliminated.
- Suitable form and shape (ingots) for further use of metals e.g. re-melting and reuse outside or within nuclear industry, decay storage.

## 3 CLEARANCE PROCESS

Clearance is defined as the removal of radioactive materials within authorized practices from any further regulatory control applied for radiation protection purposes. The concept of clearance expects that once cleared materials are subject to no further radiological restriction, may be treated as a normal waste and recycled/reused in any other industrial area (OECD/NEA, 2008).

Clearance is based on the concept of triviality of exposure, generally taken to mean that radiation risks to individuals and collective radiological impact, caused by the cleared material, is sufficiently low. In quantitative terms, the mentioned state is related to the stipulation that the effective dose expected to be incurred by any member of the public due to the cleared materials is of the order of 10 $\mu$ Sv or less during the one year (OECD/NEA, 2008).

In the Slovak legislation – Statutory Order No. 345/2006 on the Basic Safety Requirements on Personnel and Public Health Protection against Ionizing Radiation, based on the 10 $\mu$ Sv principle, the surface contamination and mass radioactivity limits for unconditional release of radioactive materials to the ENV are defined. These limits could be understood as a clearance levels (Table 1.) defined for individual classes of radionuclides radiotoxicity (Table 2.).

*Table 1. The clearance levels for releasing the materials to the environment*

| | Radiotoxicity category | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| **Clearance level for mass radioactivity [kBq.kg-$^{1}$]** | 0,3 | 3 | 30 | 300 | 3000 |
| **Clearance level for surface contamination [kBq.m$^{-2}$]** | 3 | 30 | 300 | 3 000 | 30 000 |

*Table 2. Categories of radionuclides radiotoxicity*

| Category | Radionuclide |
|---|---|
| **1** | $^{22}$Na, $^{24}$Na, $^{54}$Mn, $^{60}$Co, $^{65}$Zn, $^{94}$Nb, $^{110}$Ag, $^{124}$Sb, $^{134}$Cs, $^{137}$Cs, $^{152}$Eu, $^{210}$Pb, $^{226}$Ra, $^{228}$Ra, $^{228}$Th, $^{232}$Th, $^{234}$U, $^{235}$U, $^{238}$U, $^{237}$Np, $^{239}$Pu, $^{240}$Pu, $^{241}$Am, $^{244}$Cm |
| **2** | $^{58}$Co, $^{59}$Fe, $^{90}$Sr, $^{106}$Ru, $^{111}$In, $^{131}$I, $^{192}$Ir, $^{198}$Au, $^{210}$Po |
| **3** | $^{51}$Cr, $^{57}$Co, $^{99}$Tc, $^{123}$I, $^{125}$I, $^{129}$I, $^{144}$Ce, $^{201}$Tl, $^{241}$Pu |
| **4** | $^{14}$C, $^{32}$P, $^{36}$Cl, $^{55}$Fe, $^{89}$Sr,$^{90}$Y, $^{99}$Tc, $^{109}$Cd |
| **5** | $^{3}$H, $^{35}$S, $^{45}$Ca, $^{63}$Ni, $^{147}$Pm |

## 4 EVALUATION OF A DECOMMISSIONING MATERIAL PARAMETERS USING OMEGA CODE

The analytical calculation code OMEGA (Oracle Multicriterial General Assessment of Decommissioning), developed in the DECOM Company, is characterized as a planning tool for evaluation of decommissioning parameters (costs, manpower, exposure, consumptions, duration of individual decommissioning tasks, effluents volume or radioactivity, amount of released or disposed materials etc.) and optimization of individual decommissioning options in the decision making process (Daniška and

Nečas, 2000).

Analysis and control of material and radioactivity streams during the whole decommissioning process (from dismantling up to release to the ENV or disposal within the radioactive waste repository barriers) is in the OMEGA code performed by using an integrated material flow tool where the material parameters are linked together with the nuclide resolved radiological characteristics of each material item. In the calculations, following attributes are taken into consideration (Daniška, et al., 2008; Zachar and Nečas, 2008):

- Physical parameters of material items from inventory database (mass, volume, surface, category etc.);
- Radiological parameters of materials (inner and outer surface contamination, induced or mass activity, dose rates);
- Nuclide vectors characterising the relative shares of individual radionuclides on the total contamination, induced activity or dose rate;
- Distribution coefficients characterizing the impact of all decommissioning activities on the materials and radioactivity distribution and on the secondary waste and effluents generation;
- Limits and conditions for waste treatment and conditioning facilities, for materials to be released to the environment, for radioactive waste disposal;
- Radioactive decay of nuclides.

## 5 MODEL CALCULATION ASSESSMENT OF MELTING APPLICATION IN THE CLEARANCE PROCESS

The OMEGA code and the database of the primary circuit technological equipment (without reactor and its internal parts) and the reactor building auxiliary systems of VVER-440 nuclear power plant (NPP) was used for the model calculation.

### 5.1 Input parameters of the calculation assessment

To evaluate the possibilities of melting application in the decommissioning materials clearance process various model scenarios were calculated. Following input parameters of decommissioning were changed:

- Surface contamination nuclide composition (nuclide vector) characterising the radiological situation of the primary systems at the end of NPP operation:
  - Nuclide vector characterising the NPP with standard ended operation without any serious accident that caused spreading of the fission product to the primary circuit. The dominant contaminant is activation product $^{60}Co$ (marked as “SO” – standard operation).
  - Nuclide vector characterising the NPP with fuel accident where the fuel elements were damaged and primary circuit systems was, except of activation products ($^{60}Co$), contaminated also with fission products as $^{137}Cs$, 90Sr and also alpha active nuclides e.g. $^{241}Am$, $^{238}Pu$, $^{239}Pu$ (marked as “AO” – operation with accident)
- Time period of melted ingots long term storage. To achieve the clearance levels, the time decontamination principle applied for following time periods were used in the calculation options:

- No storage period of ingots (marked as “0Y);
- 5 years storage period (marked as “5Y”);
- 10 years storage period (marked as “10Y”);
- 20 years storage period (marked as “20Y”);
- 30 years storage period (marked as “30Y”);
- 50 years storage period (marked as “50Y”).

In the calculation, the following initial assumptions were considered:

- No radioactivity or mass (volume) restrictions for metal melting technological facility.
- The 10 years long transition period after final NPP final shutdown (Fig. 1). During this time spent fuel have to be removed to interim storage facility, the parts of non-radioactive civil building should be decommissioned and the preparation activities before the radioactive systems dismantling are also done. Within the transition period (as for ingots long term storage) the radioactive decay of nuclides is considered.
- No radioactive decay of nuclides between dismantling and melting (Fig. 1). It means that all database items are dismantled, melted, released to ENV or disposed in the radioactive waste repositories in one day.
- Distribution coefficients for melting technology to ingots and secondary waste and ingots clearance levels (according to Slovak legislation as mentioned in chapter 3) for representative radionuclides as shown in Table 3.

*Table 3. Characteristics of dominant contaminants*

| Radio-nuclide | Nuclide vector | Distribution coefficients | | Clearance level [Bq.kg$^{-1}$] |
|---|---|---|---|---|
| | | Ingots | Secondary waste | |
| **$^{60}$Co** | SO,AO | 0,15 | 0,85 | 300 |
| **$^{63}$Ni** | AO | 0,1 | 0,9 | 3 000 000 |
| **$^{137}$Cs** | AO | 0,99 | 0,01 | 300 |
| **$^{90}$Sr** | AO | 0,99 | 0,01 | 3 000 |
| **Alpha nuclides** | AO | 0,99 | 0,01 | 300 |

5.2 Output parameters of the calculation assessment

For the melting application analysis, in terms of metals clearance process, the mass and radioactivity distribution of steel (carbon and stainless) items from the inventory database was evaluated. The total mass of steel was, based on the radiological parameters and subsistent limits, distributed into the following material flow streams (Fig. 1):

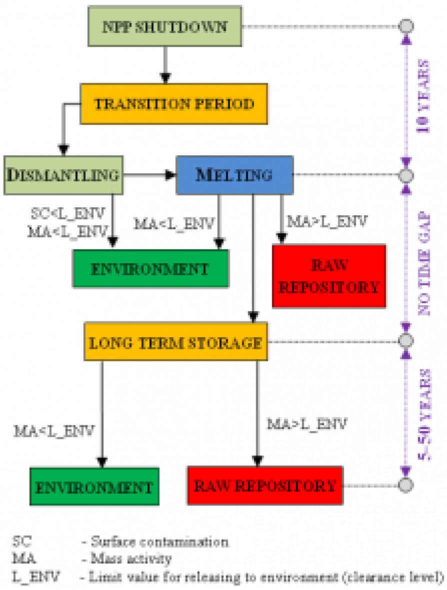


*Fig. 1 The materials flow streams and time aspects of model calculation*

Release of steel to the environment just after dismantling. The characterization applied after dismantling unambiguously demonstrates that the clearance levels for surface contamination and mass activity are fulfilled (SC