MELTING OF CONTAMINATED METALS AS A SOURCE OF IRRADIATION TO THE WORKERS AND PUBLIC

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Abstract

The paper briefly describes the metal melting, suitable technology for reduction of metallic radioactive waste. Metal melting technology is advantageous in homogenising a number of radionuclides in the ingots and concentrating other radionuclides in the slag and dust filter resulting from the melting process, thus decontaminating the primary material. The main goal of the presented paper is the calculation of irradiation to the workers and the public living near the facility. The obtained results indicate that occupational dose to the workers and dose for inhabitants living near facility is much the below annual limits.

1. Introduction

As the number of nuclear power plants (NPP) approaching their end of operational lifetime is growing, also the emphasis on management of materials arisen during the decommissioning of these facilities rises. Relatively large amount of materials arisen from decommissioning can be classified as very low level and low level radioactive waste and have to be safely isolated from the environment in disposal facilities. In order to reduce the amount of radioactive waste, decontamination of such materials is required. At present many decontamination technologies exist and the first step is the selection of suitable technology. For decontamination of metallic materials suitable technologies such as melting, abrasive blasting or chemical decontamination are considered.

2. Description of metal melting technology

Metal melting is a thermal process, where the metallic component is heated to its melting temperature. During this process different elements and their radioactive isotopes are redistributed among[1] :

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

The distribution of radionuclides during metal melting is a complex that depends on elemental properties (chemical composition, solubility of an element in molten metal, density of oxides, composition and basicity of the slag former) as well as on furnace properties (melting temperature and furnace type). The more volatile elements such as cesium, iodine or hydrogen (tritium) leave the melt and are essentially transferred to the off-gases or, in some cases, to the slag. Some elements chemically similar to the iron such as cobalt, nickel, chromium, zinc and manganese mainly remain within the melt. Transuranic elements can be readily oxidized and will transfer to the slag.

Metal melting provides several advantages, for example particularly advantageous consequence of melting is its “decontamination” effect on Cs-137, a volatile element that has a half-life of 30 years. During melting, this nuclide accumulates in the dust collected by ventilation filters and is removed. The dominant remaining nuclide in the ingots (for most reactor scrap) is Co-60. This element has a half-life of only 5.27 years. Other remaining nuclides have even shorter half-lives (except nickel, Ni-59 has half-life of 76 000 years and Ni-63 100 years). Consequently, ingots with reasonably low-activity concentrations may be temporary stored for release in a near future[2] .

3. Irradiation to the workers

Melting of contaminated metals presents a complex process starting by delivery of radioactive scrap metal to the melting facility, ending by releasing of ingots to the environment for recycle and reuse. The main goal of the paper is the evaluation of an exposure of the workers during the melting and public living near the facility.

In the following chapters general assumptions and considered worker scenarios are described. The radiological impact assessment method is in detail described in [3] . For the calculation the VISIPLAN 3D ALARA calculation tool was used. This tool is appropriate for evaluation of external gamma and x-ray exposures and also allows modelling of real scenarios in a complex environment hence the 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 the volume source is divided into point sources. The photon fluency rate at a dose point is then determined by superposition of partial dose contributions from single point sources[4] .

3.1 General assumptions

In the calculation of radiation impacts of selected workers following considerations were taken into account:

- Melting facility comprises induction furnace of charge size of approx. 2 tonnes of scrap metal.
- The melting facility is able to melt two batches per one workday, i.e. approx. 4 tonnes of scrap metal.
- 250 workdays per year are considered, i.e. the annual capacity of melting facility is approx. 1 000 tonnes of scrap metal.
- Radiological limitation for the facility is 500 Bq/g for total β/γ activity (it is conservatively considered that workers melt entire year scrap metal with maximum allowed activity).
- Considered exposure pathways are external as well as internal.
- For the calculation two nuclide vectors are used. Nuclide vector characterizing radiological situation of NPP shut down after fuel accident (A1 NPP) and nuclide vector characterizing radiological situation of NPP shut down after standard operation (V1 NPP).
- During the melting radioactivity distribution coefficients for each radionuclide is considered. It is necessary to know the fraction of the activity originally present in radioactive scrap metal which may be transferred to the ingot, to the slag and to the dust after melting. These coefficients were adopted from the experiences obtained in the CARLA Plant, Germany [5] and from publication “NUREG-1640”[6] .

3.2 Description of worker scenarios during the melting

For dose assessment purposes, several representative worker scenarios for melting of contaminated metals were developed. In the following paragraphs the basic description of selected workers is given.

The furnace operator scenario models the potential dose to a worker who operates the furnace from the furnace control room. This worker operates the entire melting process from furnace loading (scrap metal is loaded into the furnace by crane) to ingot casting. During the whole melting process the worker is situated within the control room.

The slag worker scenario models the potential dose to a worker removing the slag and manipulating with the drum in which the slag is placed. Several different ways can be used to separate the slag from the molten metal or ingot. In the calculations it is considered that the slag is removed from the top of the furnace using a special customized manipulator operated by furnace the operator from the control room.

The ingot caster scenario models a worker casting metal ingots. The final ingot is a 400 kg cylindrical block. During casting the ingots the worker is situated in ingot moulds proximity.

The ingot handler scenario models the potential dose to a worker manipulating the ingots. This worker's activity includes pulling out the ingots of the ingot moulds and their replacement to 200 l drums. The ingots are then measured in a gamma scanner.

The transport and storage scenario models a worker transporting the ingots placed in the drums using a forklift into the storage facility. After the activity measurement, ingots are free released or transported to an interim storage facility if they do not meet requirements for free release.

The repairing of furnace lining scenario models the potential dose to a worker regularly repairing the furnace lining suffering from degradation by cyclical using. The worker is situated in the proximity of the slightly contaminated lining during this occupation.

The replacement of furnace lining scenario presents a worker replacing a furnace lining on a regular basis. The worker is situated in the proximity of the slightly contaminated lining during his occupation.

The dust manipulations model the dose to a worker manipulating the dust collected during the melting. The dust is absorbed on filters during the melting and continuously collected in drums. The scenario deals with replacement of the drum filled with dust by an empty one and its transport to the treatment and conditioning facility.

4. Irradiation to the environment and the public

The melting facility presents a source of discharges into the environment, therefore the ventilation and filter system is one of the most important safety elements of such facility. Air from the furnace area is transferred filtration and ventilation system with expected filtration efficiency 99,997%.

The general assumptions for the calculation of impacts on the environment and public are the same as for the irradiation to the workers. Irradiation to the public living near the facility was performed using ESTE AI code. ESTE AI (Annual Impacts) is a tool for calculation of radiation doses caused by discharges to the atmosphere and hydrosphere during standard operation of NPP. The tool calculates the doses to the members of critical groups of inhabitants in the proximity of NPP and, as a result, a critical group is determined. The method used in ESTE AI is based on the Lagrange trajectory model describing the movement of the centre of gravity of discrete clouds (puffs, PTM - puff trajectory model)[7] .

5. Results

The results presented in this paper are based on generic exposure scenarios and pathways analyses using two different nuclide vector compositions. One nuclide vector represents radiological situation of NPP shut down after standard operation and the other one represents NPP shut down after a fuel accident. Calculated individual effective doses of workers related to the melting of contaminated scrap metal from NPP shut down at different conditions are in Tab.1. As one can see from the results, the absorbed dose depends on several factors like dominant radionuclides in nuclide vector, radioactivity distribution during the melting, time of performed activity, etc.

Tab. 1. Irradiation to the workers

Worker scenario	**Annual individual effective dose [mSv]**	
	A1 nuclide vector	**V1 nuclide vector**
Furnace operator	0,71	0.77
Slag worker	0,80	0.23
Ingot caster	0,04	0.33
Ingot handler	0,07	0.64
Transport and storage of ingots	0,07	0.63
Repairing of furnace lining	0,04	0.01
Replacement of furnace lining	<0,01	<0,01
Dust manipulations	1,00	0.06

In general it can be said that the slag and dust manipulations leads to the highest received IED because the worker is manipulating the secondary RAW containing relatively high concentrations of several radionuclides (mainly from A1 NPP scrap metal). The lowest IEDs are received during activities after the slag is removed in the case of melting the scrap from A1 NPP because the decontamination effect (factor) is much higher for fission products as well as transuraniums. Mentioned IEDs are lower by approx. one order of magnitude than the IEDs received during melting of scrap from V1 NPP due to the low decontamination factor for dominant radionuclides in nuclide vector V1.

Tab.1.presentsthe calculated results of discharges to the environment during the melting of contaminated scrap metal with % of permitted annual limits stated in Slovak legislation [8] . It is obvious form the results that melting of contaminated scrap metal do not significantly impact the environment, because the annual discharges presents less than half percent of permitted annual limits.

Tab. 1. Annul discharges during the melting

Radionuclide	**Annual discharges**			
	A1 nuclide vector		**V1 nuclide vector**	
	[Bq]	**% of annual limits**	**[Bq]**	**% of annual limits**
Mixture of beta/gamma emitters	2,92E+06	0,45	1,09E+05	0,02
^{90}Sr	9,75E+04	0,50	6,65E+02	<0,01
Alpha emitters	6,25E+03	0,10	2,33E+03	0,04

The doses of inhabitants living near the Jaslovske Bohunice locality caused by atmospheric discharges during the melting were evaluated using ESTE AI software. The calculation of doses is based on the so-called sectors, i.e., the surroundings of NI locality are divided into sectors (parts) in which the doses are calculated. A critical individual dose was identified for the sector situated southeast of the locality. The calculated annual IED for adults living in this area is 5.70E-04μSv for melting the metal arisen from A1 NPP and approx. one order lower (5.30E-04 μSv) for melting the metal arisen from V1 NPP.

6. Conclusion

The main goal of the paper is to evaluate radiation impact on the workers as well as on the environment and public during the melting of contaminated scrap metal. As can be seen from the obtained results, the worker´s received dose depends on the performing activity as well as on radionuclide present in the scrap metal as contaminant and radioactivity distribution coefficients during melting.Discharges during the melting present only small fraction of permitted annual limits.

Individual effective doses of the workers meet legislatively given limits in Slovak Republic, in which value of 20 mSv[9] is defined as the maximum allowed dose received by a worker annually.It is also important to note that doses are calculated conservatively, because it is unlikely that the workers would be entire year melting the scrap metal with limit values (500 Bq/g). Irradiation of the public is on relative low level because the annual effective dosefor the critical individual living near the NI locality is a relatively low value comparing with the limit of 12 μSv annually stated in Slovak legislation [9] .

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References:

[1] International Atomic Energy Agency: Application of Thermal technologies for Processing of Radioactive Waste, IAEA-TECDOC-1572, Vienna: IEAE (2006).
[2] OECD/NEA: Decontamination Techniques Used in Decommissioning Activities, Paris: OECD/NEA (1999).
[3] A. Slimak, V. Necas: Decontamination of contaminated scrap metal by melting arisen from the decommissioning of nuclear power plant shut down after an accident. IAPGOS, ISSN: 2083-0157, Vol. 4, Number 4. p. 16 (2014).
[4] F. Vermeersch: VISIPLAN 3D ALARA Planning Tool, User´s manual, SCK-CEN, Mol, Belgium (2005).
[5] W. Quade, W. Muller: Recycling of radioactively contaminated scrap from the nuclear cycle and spin-off for other application. Revista de metalurga, Madrid Vol. Extr. (2005), pp. 23-28.
[6] U.S. Nuclear Regulatory Commission: Radiological Assessment for Clearance of Materials from Nuclear Facilities. Main Report, NUREG-1640, Washington D.C. (2003).
[7] P. Carny, et al. ESTE AI version 3.51, V-2, User´s manual, ABmerit nuclear science and software, Trnava, Slovakia, 2014.
[8] Statement of the Public Health Authority of the Slovak Republic no. OOZPŽ/7119/2011.
[9] Statutory Order No. 345/2006 on the Basic Safety Requirements on Personnel and Public Health Protection against Ionizing Radiation.