Brenk
Systemplanung
Ingenieurgesellschaft für wissenschaftlich
technischen Umweltschutz

Regulatory Aspects of Clearance and Recycling of Metallic Material forming Part of Buildings of Nuclear Facilities in Germany

S. Thierfeldt, S. Wörlen, P. Harding
Brenk Systemplanung GmbH, Aachen (Germany)

1. Introduction

Metallic materials as part of buildings of nuclear installations, like reinforcement in concrete, anchor slabs, pipework buried in concrete, but also steel liners of water basins or anchor rails that are welded to the reinforcement steel etc. require special considerations during decommissioning. It is the aim to release as much of this material as possible for recycling (either by melting in conventional foundries or by melting in a controlled recycling plant for reuse in the nuclear field). This poses problems as on the one hand these metallic materials cannot be removed (with reasonable effort) from the buildings prior to their demolition, while on the other hand they would in principle require a specific clearance procedure for which they should be available separately. Besides aspects of radiological characterisation and measurements, this is also a regulatory issue, as the competent authority has to grant clearance of materials that may not be fully characterised by measurements (as it is still attached to the building structure and cannot be measured separately), but for which a significant part of the information required for clearance is inferred from the operational history, from conclusions by analogy and from other sources.

In this paper, a possible solution for this problem is presented: Clearance of metals is referred to clearance criteria of the building structures. The clearance levels for buildings are applied to metals as well, for which they have to be suitably converted. Averaging criteria also play a role in this process. The benefit is that then only one clearance procedure for building structures and metal on these structures needs to be implemented, which significantly facilitates the measurement process.

2. Metals as part of Building Structures

This paper deals with the question how to clear metallic materials that form part of buildings and that cannot be removed prior to demolition of the building. In many cases, the materials are welded to the reinforcement steel inside the building structures or are embedded deep into the concrete so that the effort for removal prior to demolition would be totally incommensurate to the benefit from having the metal separated from the building structure for simplifying clearance.

Figures 1 to 3 show examples of metal on building surfaces which forms part of these surfaces or is intimately linked to the structure. Other examples are anchor slabs or pipework buried in concrete.

Figure 1: Reinforcement in a wall after removal of the outer concrete layer

Figure 2: Metal cladding on concrete surfaces in a nuclear power plant

Figure 3: Anchor rails in a conventional building showing the link to the reinforcement steel [4]

It is the objective of each clearance process to release as much material as possible with optimised provisions for clearance measurement without compromising the safety of demonstrating compliance with clearance levels. In buildings with some metallic material still being present during clearance measurements, it is of great advantage to use only one clearance procedure, i.e. to make no distinction between clearance procedure for building surfaces and clearance procedure for metals on these surfaces. This approach saves considerable effort as it is then possible to perform e.g. measurements with collimated in situ gamma spectrometry on building surface in the predetermined grid without measuring areas with metals separately or having to change from in situ gamma spectrometry to contamination monitors in between.

A further important consideration is that the metal forming part of buildings will be destroyed during the building demolition process, i.e. it cannot be reused directly again but has to be recycled (or disposed of) after it will have been separated from the rubble.

Furthermore, the following considerations only apply to contaminated metallic material, as activated materials require a different approach.

3. Clearance Regulations in Germany

3.1. Overview and Clearance Options

Clearance regulations in Germany are addressed here only briefly, as far as it is necessary to understand the issue of different clearance values and clearance regulations for building structures and metals.

In the German regulatory framework, clearance is regulated in the Radiation Protection Ordinance [1] (*Strahlenschutzverordnung*). General requirements are laid down in section 29, which also defines the different clearance options (see below), the clearance levels are listed for about 300 nuclides in Table 1 of Annex III, and further requirements for each clearance option are provided in Annex IV.

The Radiation Protection Ordinance contains the following clearance options:

1. Options for unconditional clearance:
    a. of materials for reuse, recycling or disposal including building rubble of less than 1000 Mg/a,
    b. of building rubble and soil of more than 1000 Mg/a,
    c. of nuclear sites,
    d. of buildings (for reuse or demolition).
2. Options for clearance for a specific purpose:
    a. of solid materials with up to 100 Mg/a and up to 1,000 Mg/a for disposal on landfills,
    b. of (solid and liquid) materials with up to 100 Mg/a and up to 1,000 Mg/a for disposal by incineration,
    c. of buildings for demolition,
    d. of metal scrap for melting.

An overview of clearance levels for these various clearance options are shown in Table 1.

Table 1: Extract from Table 1 Annex III of the German Radiation Protection Ordinance [1]

Radionuklid	Freigrenze			Freigabe											Halbwertszeit	
				uneingeschränkte Freigabe von					Freigabe von							
	Aktivität in Bq	spezifische Aktivität in Bq/g	Aktivität HRQ/1/100 A_1 in Bq	Oberflächenkontamination in Bq/cm²	festen und flüssigen Stoffen in Bq/g	Bauschutt, Bodenaushub von mehr als 1 000 t/a in Bq/g	Bodenflächen in Bq/g	Gebäuden zur Wieder-, Weiterverwendung in Bq/cm²	festen Stoffen bis zu 100 t/a zur Beseitigung auf Deponien in Bq/g	festen und flüssigen Stoffen bis zu 100 t/a zur Beseitigung in Verbrennungsanl. in Bq/g	festen Stoffen bis zu 1 000 t/a zur Beseitigung auf Deponien in Bq/g	festen und flüssigen Stoffen bis zu 1 000 t/a zur Beseitigung in Verbrennungsanl. in Bq/g	Gebäuden zum Abriss in Bq/cm²	Metallschrott zur Rezyklierung in Bq/g		
1	2	3	3a	4	5	6	7	8	9a	9b	9c	9d	10	10a	11	
Fe-52	1 E+6	1 E+1	3 E+9	1 E+2	1 E+1	7 E-2		1					2 E+3	1 E+1	8,3	h
Fe-55	1 E+6	1 E+4	4 E+11	1 E+2	2 E+2	2 E+2	6	1 E+3	1 E+4	1 E+4	7 E+3	1 E+4	2 E+4	1 E+4	2,7	a
Fe-59	1 E+6	1 E+1	9 E+9	1	1	2 E-1	6 E-2	1	1 E+1	1 E+1	4	4	3 E+1	1 E+1	45,1	d
Fe-60+	1 E+5	1 E+2													1,0 E+5	a
Co-55	1 E+6	1 E+1	5 E+9	1	1 E+1	1 E-1		1					1 E+3	1 E+1	17,5	h
Co-56	1 E+5	1 E+1		1	2 E-1	6 E-2	2 E-2	1	4	5	1	1	6	0,4	78,8	d
Co-57	1 E+6	1 E+2	1 E+11	1 E+1	2 E+1	3	8 E-1	1 E+1	1 E+2	1 E+2	5 E+1	5 E+1	1 E+2	2 E+1	271,3	d
Co-58	1 E+6	1 E+1	1 E+10	1	9 E-1	2 E-1	8 E-2	1	1 E+1	1 E+1	5	5	3 E+1	1	70,8	d
Co-58m	1 E+7	1 E+4	4 E+11	1 E+2	1 E+4	1 E+4		1 E+3					1 E+9	1 E+4	8,9	h
Co-60	1 E+5	1 E+1	4 E+9	1	1 E-1	9 E-2	3 E-2	4 E-1	6	7	2	2	3	0,6	5,3	a
Co-60m	1 E+6	1 E+3		1 E+2	1 E+3	6 E+1		1 E+3					7 E+7	1 E+3	10,5	m
Co-61	1 E+6	1 E+2		1 E+1	1 E+2	4		1 E+1					5 E+5	1 E+2	1,7	h
Co-62m	1 E+5	1 E+1		1	1 E+1	8 E-2		1					7 E+4	1 E+1	14,0	m
Ni-56	1 E+6	1 E+1													6,1	d
Ni-57	1 E+6	1 E+1													3,6 E+1	h
Ni-59	1 E+8	1 E+4		1 E+2	3 E+2 [1)]	3 E+2	8	1 E+3	3 E+3	1 E+4	3 E+2	3 E+3	9 E+4	1 E+4	7,5 E+4	a
Ni-63	1 E+8	1 E+5	4 E+11	1 E+2	3 E+2	3 E+2	3	1 E+3	1 E+4	6 E+4	1 E+3	6 E+3	4 E+4	1 E+4	100,0	a
Ni-65	1 E+6	1 E+1	4 E+9	1 E+1	1 E+1	4 E-1		1 E+1					3 E+4	1 E+1	2,5	h
Ni-66	1 E+7	1 E+4													54,6	h
Cu-60	1 E+5	1 E+1													23,0	m
Cu-61	1 E+6	1 E+1													3,4	h

In the current context, the last two clearance options (clearance for buildings for demolition and clearance of metal scrap for melting) are relevant. Columns 10 and 10a of Table 1 Annex III of the German Radiation Protection Ordinance contain the relevant clearance levels for these options. The following points should be noted with respect to these two clearance options:

3.2. Clearance of Buildings for Demolition

While there are two clearance options for buildings in the German Radiation Protection Ordinance (numbers 1.d and 2.c in section 3.1), only the latter one, i.e. clearance of buildings for demolition, shall be dealt with here, as this is the usual clearance option for buildings of nuclear installations.

The main requirements for this clearance option can be summarised as follows:

- Clearance is for dismantling only, i.e. there must be no reuse of the building between the clearance measurements and the dismantling.
- Contamination that has penetrated into the building structure is to be treated as if it was situated on the surface, i.e. the contamination in the volume shall be projected onto the surface [2]. In this way, surface specific clearance levels in Bq/cm² can be stipulated which effectively limit the contamination below the surface – see column 10 in Table 1 (the other possibility of stipulating mass specific clearance levels for building materials would have required to link these values to a penetration depth, which is much more complicated to apply in practice). The principle is shown in Figure 4.

- Although surface-related clearance levels are used, the penetration depth has to be determined. The measurement instruments have to be calibrated in such a way that the penetration depth is correctly accounted for, i.e. the absorption by surface layers of the material has to be taken into account.
- The averaging area for clearance measurements of buildings for demolition can be chosen larger than 1 m². Usually, 10 m² is used, as this harmonises well with measurements carried out with (collimated) in situ gamma spectrometry or with contamination monitors when using statistical approaches.

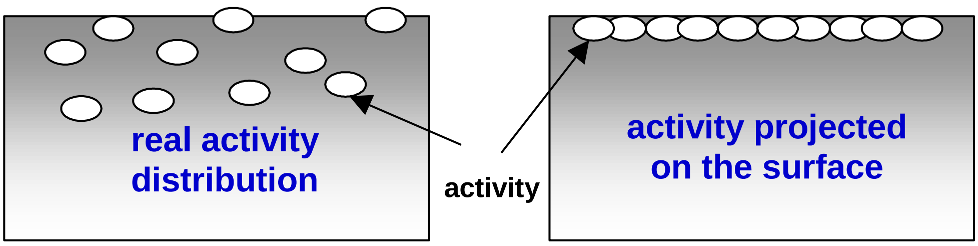

Figure 4: Projection of penetrated activity (real activity distribution, left) on the surface (idealised case, right) [2]

3.3. Clearance of Metals for Recycling

Metallic material can be cleared using one of three options:

- unconditional clearance, i.e. clearance for reuse, recycling (and disposal),
- clearance for recycling by melting only, i.e. the metal must not be reused before it reaches the smelter,
- clearance for disposal, i.e. the metal must be brought to a (conventional) landfill – this option is rarely used as recycling precedes disposal with respect to a resource like metal scrap.

These clearance options correspond to numbers 1.a, 2.d and 2.a of section 3.1, respectively, together with clearance levels of columns 5, 10a and 9a/9c in Table 1. As metal scrap that is salvaged from the rubble of a demolished building is no longer suitable for direct reuse, it can only be recycled by melting, so that the clearance levels of column 10a in Table 1 are relevant. They may be applied together with the averaging mass of several 100 kg (usually 300 kg).

4. <u>Strategy for Clearance of Metals as Part of Buildings</u>

4.1. How to Transform Clearance Levels for Buildings and Metals into each other

When metal is cleared together with the building, it will be dismantled together with the building structure. The dismantling process will destroy the metal structure and render it unsuitable for direct reuse, so that the only option remaining for the metal is recycling by melting (the other option of disposing of the metal in a landfill is usually discarded from considerations concerning the waste hierarchy, giving recycling precedence over disposal.

If the metal structures forming part of buildings are to be cleared with the same clearance process and hence with the same clearance levels as the building surfaces, then the question arises how to transform clearance regulations for buildings into those of metals, so that compliance of clearance levels according to column 10a in Table 1 can be demonstrated (see section 3.3). The following considerations have to be taken into account:

- Transformation of surface-related clearance levels (Bq/cm²) for building surfaces into mass-related clearance levels (Bq/g) for metals.
- There is no single (standard) conversion factor for such a transformation as the radiological scenarios on which they are based are different.
- There are different averaging criteria: e.g. 10 m² for buildings (surface) and several 100 kg for metals (volume).

The solution to this problem is to show that the application of clearance levels for buildings also for metals in buildings will not lead to violation of 10 µSv/a dose criterion. The approach is outlined in the section 4.2.

4.2. Calculation of mass-related Activities of Metals from surface-related Clearance Levels for Buildings

The first step is to calculate the mass-related activity of the metal (Bq/g) when the surface-related clearance levels for the building surface are completely exhausted. This is done in Table 2 for various thicknesses for a density $\rho = 7.8$ g/cm³. This table shows an example calculation for the three relevant nuclides Co-60, Cs-137 and Sr-90. The 2nd and 3rd column provide the clearance levels for buildings and metals, while to right part of the table shows the mass related activity of metal for various thicknesses if it was covered by a contamination of 100 % of the clearance levels for buildings. The part shaded in green shows compliance with the clearance levels for metals.

Table 2: Mass related activity on metal structures as a function of thickness

Nuclide	Clearance levels for		Activity in [Bq/g] for a thickness of					
	buildings, demolition [Bq/cm²]	metals, recycling [Bq/g]	0.5 cm	0.7 cm	1 cm	1.4 cm	2 cm	3 cm
Co-60	3	0.6	0.77	0.55	0.38	0.27	0.19	0.13
Cs-137	10	0.6	2.56	1.83	1.28	0.92	0.64	0.43
Sr-90	30	9	7.69	5.49	3.85	2.75	1.92	1.28

Table 2 demonstrates that if the nuclide vector is rich in Co-60 and the thickness of the metal exceeds 7 mm then the clearance levels for metals are complied with even if the clearance levels for buildings (3 Bq/cm² for Co-60) are fully exhausted. However, the question remains what to do if the metal is thinner than 7 mm or has a nuclide vector rich in Cs-137? In this case, obviously a more detailed line of argument is required.

4.3. Line of Argument for the General Case

1. The first step is to estimate the maximum total amount of activity remaining in the building of a nuclear power plant. A conservative estimate for the overall area covered with metal

structures in such a building is 1,000 m². It is further conservative to assume that the clearance levels for buildings are fully exhausted and that the nuclide vector is rich in Cs-137. The total activity would then be calculated on the order of 70 MBq together with a total mass of around 78 Mg (1 cm thickness, ρ = 7.8 g/cm³).

2. The real activity will be much smaller than 70 MBq would of course be much smaller than 70 MBq, as there are various reasons why clearance levels can never be fully exhausted in clearance measurements, mainly due to the calibration of the measurement instruments and due to the fact that nuclide vectors use conservative activity compositions (overestimation of real activity).
3. This will lead to an activity of a mass related activity on the metal of about 0.4 Bq/g related to a nuclide vector rich in Cs-137. This value is lower than a clearance level for metals with such a nuclide vector which would be on the order of 0.6 Bq/g.
4. The values for this mass-related activity as well as for the total activity on the metals are compatible with the scenarios that have led to the clearance levels for metals for recycling by melting in [3]. This means that the dose criterion 10 µSv/a will be complied with.
5. The last consideration applies to compliance with the averaging criterion for metals (several 100 kg). If it is assumed that clearance measurements are carried out on building surfaces using e.g. in situ gamma spectrometry with an averaging area of 10 m² on building surfaces (usual case) and that the thickness of a large wall cladding is 0.5 cm (conservative assumption), the one measurement covers 390 kg of metal, which is fully compatible with the assumptions of [3].
6. Surface related clearance levels play no role for clearance of metal scrap for recycling that has been salvaged from building rubble, as handling of this material takes place fully automatically (magnetic separator, loading by crane etc.).

A final consideration shall be given to cross contamination of metallic structures inside building structures by dust during demolition. When building rubble is crushed, reinforcement steel is removed. It may then become contaminated by the dust from building rubble which contains some residual activity. A simple calculation shows that the resulting mass-related activity of the scrap will not exceed 1 % of the mass-related activity in the building rubble, which is in any case far below the clearance levels for metals.

5. Conclusions

This paper has shown that clearance of metals as part of buildings can be significantly simplified if the same clearance procedure is used both for the building surfaces and for the metallic structures. In this case, no separate clearance procedure for metallic parts is required, making changes of instruments unnecessary and allowing continuation of measurements on building surfaces also on metallic objects with same device and the same set of clearance levels.

The radiological evaluation shows that compliance with clearance requirements for buildings will also guarantee compliance with clearance requirements for metal scrap for melting. Melting is the only option for such metal scrap (besides disposal, which is unfavourable for metal from the standpoint of waste hierarchy), as it is in no condition for direct reuse, so that unconditional clearance of metal scrap is not required.

The approach presented in this paper is pursued in various nuclear power plant decommissioning projects in Germany.

6. References

[1] Radiation Protection Ordinance (Verordnung über den Schutz vor Schäden durch ionisierende Strahlen, Strahlenschutzverordnung - StrlSchV) of 20 July Juli 2001 (BGBl. I 2001, Nr. 38, S. 1714, BGBl. I 2002, Nr. 27, S. 1459), amended on 4 October 2011 (BGBl. I 2011, Nr. 51, S. 2000)

[2] 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, 2000, ISBN 92-828-9172-0

[3] European Commission: Recommended radiological protection criteria for the recycling of metals from the dismantling of nuclear installations; Radiation Protection No. 89, Luxemburg, 1998, ISBN 92-828-3284-8

[4] HALFEN GmbH (Langenfeld, Germany): www.halfen.com