# CLEARANCE STANDARDS RECOMMENDED IN THE EUROPEAN UNION

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## ABSTRACT

Following a revision of the EURATOM Basic Safety Standards two new sets of recommendations pertaining to the clearance of materials and buildings from nuclear dismantling have been issued recently. They provide practical guidance in the form of nuclide specific clearance levels a) for metal scrap recycling (by melting) for the direct reuse of metal component, equipment and tools, and b) for the conventional recycling and disposal of building rubble and for the reuse of buildings.

The yardstick applied in deriving these clearance levels are the requirements for exemption laid down in IAEA Safety Series 98, ie individual effective dose<10µSv/y and collective dose <1manSv/y. The clearance levels and procedures recommended by the European experts have been tested on an industrial scale.


## INTRODUCTION

In the European Union (EU) national legislation on radiation protection is bound by the EURATOM Treaty to comply with the EU's general "Basic Safety Standards for the Health Protection of the General Public and Workers against the Dangers of Ionizing Radiation"(BSS)[1]. The latest Basic Safety Standards Directive of 1996 must be adopted in national legislation and regulatory practice by May 2000. One of the requirements of the new Directive is that the disposal, recycling and reuse of material containing radioactive substances is subject to prior authorization by the competent national authorities. This requirement concerns the control of practices as defined in ICRP-60. As guidance for the application of clearance practices, a group of experts acting under the terms of Article 31 of the Euratom Treaty has issued recommendations on radiological protection criteria for the recycling of metals [2] and the clearance of buildings and building rubble [3] from the dismantling of nuclear installations which presents nuclide specific clearance levels.In the case of metals once regulatory control has been removed from decommissioned material, there can be no guaranty that the material or component, having a significant economic value, will remain in the country where it was cleared. It is highly undesirable that this would give rise to further controls at the frontier or at the final destination of the metal, as such controls would be contrary to the concept of a single European market. It is therefore considered absolutely necessary to apply uniform criteria and standards within the EU. For non-metallic building materials such considerations are less important.

## QUANTITY OF CLEARABLE MATERIAL

Clearable metal scrap from nuclear installations primarily consists of materials like steel, aluminium, aluminium alloys, copper and copper alloys. The estimated annual quantity of clearable metal in the EU used for the calculation of the clearance criteria is:

| | |
|---|---|
| Steel and stainless steel | 10 000 Mg/y |
| Copper and copper alloys | 200 Mg/y |
| Aluminium and aluminium alloys (97% from enrichment plants) | 1 500 Mg/y |

According to present forecasts these figures will not be exceeded during the next ten years, but will rise by a factor of four in the years 2010 - 2020, when many more of the larger plants will be dismantled.

The quantity of metal used to build a typical 1000 MW PWR is about 37 000 metric tonnes. Roughly 75% of this mass is installed outside the controlled area and therefore does not require clearance. Of the remaining 25%, some 5000-8000 tonnes can be cleared after dismantling and decontamination. A considerable fraction of this material however will be reused by the nuclear industry, where it can be recycled without clearance procedures eg as shielding. This option is widely used in Germany where special High Integrity Containers for radwaste cast from slightly active steel were develloped

The total impact of ferrous scrap from dismantled nuclear facilities on the overall production of steel in Europe is insignificant. In 1992 Western Europe produced approximately 140 million metric tonnes of iron and steel, of which 64 million tonnes came from ferrous scrap. This compares with the projected amounts of 10 - 40 thousand metric tonnes of clearable steel.

Estimations of the total amount of building rubble resulting from completely dismantling all presently existing nuclear plants forecast that only some 700 000 metric tons will be produced in Europe during the next 25 years. Due to the wide range of safe enclosure periods envisaged in the various national strategies, dismantling of the remaining nuclear buildings thereby generating another 20 million tons of rubble will spread out until 2180.

## SCOPE OF THE EU CLEARANCE GUIDELINE

The recommendations reflect the limitations of the Basic Safety Standards. As in ICRP Publication 60 the concepts of *exemption* and *clearance* pertain to the regulatory control of *practices*. Materials contaminated as a result of military applications or as a consequence of accidents are subject to the distictly different requirements for *intervention.*

The BSS also introduces a third category of actions: *work activities* in presence of natural radiation sources. The Basic Standards distinguishes:

- the use of material processed in view of their radioactive, fissile or fertile properties is considered a *practice*
- *work activities* in which the presence of natural radiation sources leads to a significant increase in the exposure of workers or the public. The BSS apply to such cases.

For NORM guidance on specific reference levels are under preparation; these materials are not subject to the clearance levels recommended for decommissioning scrap.

## BASIC RADIOLOGICAL PROTECTION CRITERIA

The IAEA recommendation in Safety Series 89 [4] refers to an individual dose of "some tens of microsieverts per year (µSv/y)" as being trivial and therefore a basis for exemption from regulatory control. Furthermore, the IAEA suggests that in order to account for exposures from more than one exempt practice, the exposure to the critical group from one such practice should be in the order of 10 µSv/y. In addition the IAEA recommends a maximum collective dose commitment of 1 manSv per year for each such practice. These basic exemption criteria are included in the Basic Safety Standards of both IAEA and Euratom. The values for individual (whole body effective) doses for the annual collective dose commitment and an additional criteria, a limiting skin dose of 50 mSv/y were used by the Euratom group of experts to establish the recommended clearance levels. Distinct nuclide specific clearance levels were determined for the most relevant pathways, for landfill disposal, recycling and for direct reuse. It is presumed that if the above mentioned limits for the effective dose incurred by any individual member of the public are observed, the basic criteria are fulfilled without further consideration.

## RECYCLING OF MATERIALS FROM DISMANTLED NUCLEAR FACILITIES

Materials and components from dismantling (and repair) in the controlled area of nuclear facilities will either be kept under regulatory control or released under a supervised clearance procedure. The first option: reuse or recycling and disposal under regulatory control will avoid exposure of the public. A number of studies [5,6,7] have shown that recycling within the industry reduces the collective dose as well as the number of individuals receiving doses. Even if clearance according to the above mentioned radiological criteria is possible, recycling within the industry should be preferable, whenever it is economically sound. In many countries the industry is capable of recycling a large fraction of the dismantled ferrous material as shielding and as waste containers. Reuse of structural beams, larger diameter piping as well as some carbon-steel vessels by the nuclear industry is also common practice. Stainless steel is mainly used in core components and in the primary circuit of water reactors. Neutron activation prohibits the reuse or recycling of most core components, but many of the stainless fittings and circuit components of the primary loop and its direct ancillaries could be reused in other nuclear installations.

Very low active steel not reused in the nuclear industry and scrap consisting of aluminium, copper and their respective alloys can be considered for clearance. Recycling or reusing this material saves valuable natural resources and avoids unjustified cost for controlled disposal. The sequence of actions leading to the clearance can be outlined as follows: the nature and level of activity of all components inside the controlled area are assessed prior to dismantling. The decommissioning strategy and the plans for the management of the dismantled materials are then laid down and submitted to the authorities. These plans also outline, to what extent the components and structural materials of the controlled area can be recycled or reused within the nuclear industry, cleared for release to the public domain or prepared for licensed disposal. Components and materials earmarked for clearance will be monitored carefully and if necessary decontaminated before being submitted to the clearance assay. After scrap is cleared from regulatory control it is normally sold to a scrap dealer who will process and sort it before delivering it to a mill or foundry for remelting.

## DERIVATION OF CLEARANCE LEVELS

The radiological criteria for clearance are expressed in terms of doses, which are impractical for making clearance decisions. Therefore the dose criteria are converted into mass- and surface-specific activity limits below which clearance can only produce trivial doses, ie individual doses below 10 μSv/y. The determination of clearance levels requires a thorough examination of the reasonably possible routes by which humans can be exposed to cleared material. The scientific and technical basis [8,9] for the derivation of the recommended clearance levels presented in Table I and Table II is constituted by four studies commissioned by the EU.

## Table I: Nuclide specific clearance levels for metal scrap recycling

| Nuclide | Clearance levels | |
|---|---|---|
| | Mass-specific [Bq/g] | Surface-spec. [Bq/cm²] |
| H 3 | 1000 | 100 000 |
| C 4 | 100 | 1000 |
| Na 22 | 1* | 10 |
| S 35 | 1000 | 1000 |
| Cl 36 | 10 | 100 |
| K 40 | 1 | 100 |
| Ca 45 | 1000 | 100 |
| Sc 46 | 1* | 10 |
| Mn 53 | 10 000 | 100 000 |
| Mn 54 | 1 | 10 |
| Fe 55 | 10 000 | 100 000 |
| Co 56 | 1 | 10 |
| Co 57 | 10 | 100 |
| Co 58 | 1 | 10 |
| Co 60 | 1 | 10 |
| Ni 59 | 10 000 | 10 000 |
| Ni 63 | 10 000 | 10 000 |
| Zn 65 | 1 | 100 |
| As 73 | 100 | 1000 |
| Se 75 | 1 | 100 |
| Sr 85 | 1 | 100 |
| Sr 90 | 10 | 10 |
| Y 91 | 10 | 100 |
| Zr 93 | 10 | 100 |
| Zr 95 | 1 | 10 |
| Nb 93m | 1000 | 10 000 |
| Nb 94 | 1 | 10 |
| Mo 93 | 100 | 1000 |
| Tc 97 | 1000 | 1000 |
| Tc 97m | 1000 | 1000 |
| Tc 99 | 100 | 1000 |
| Ru 106 | 1 | 10 |
| Ag 108m | 1 | 10 |
| Ag 110m | 1 | 10 |
| Cd 109 | 10 | 100 |
| Sn 113 | 1 | 100 |
| Sb 124 | 1 | 10 |
| Sb 125 | 10 | 100 |
| Te 123m | 10 | 100 |
| Te 127m | 100 | 100 |
| I 125 | 1 | 100 |
| I 129 | 1 | 10 |
| Cs 134 | 1* | 110 |
| Cs 135 | 10 | 1000 |
| Cs 137 | 1 | 100 |
| Ce 139 | 10 | 100 |
| Ce 144 | 10 | 10 |
| Pm 147 | 10 000 | 1000 |
| Sm 151 | 10 000 | 1000 |
| Eu 152 | 1 | 10 |
| Eu 154 | 1 | 10 |
| Eu 155 | 10 | 1000 |

| Nuclide | Clearance levels | |
|---|---|---|
| | Mass-specific [Bq/g] | Surface-spec. [Bq/cm²] |
| Gd 153 | 10 | 100 |
| Tb 160 | 1 | 10 |
| Tm 170 | 100 | 1000 |
| Tm 171 | 1000 | 10 000 |
| Ta 182 | 1 | 10 |
| W 181 | 100 | 1000 |
| W 185 | 1000 | 1000 |
| Os 185 | 1 | 10 |
| Ir 192 | 1 | 10 |
| Tl 204 | 1000 | 1000 |
| Pb 210 | 1* | 1 |
| Bi 207 | 1 | 10 |
| Po 210 | 1 | 0.1 |
| Ra 226 | 1 | 0.1 |
| Ra 228 | 1 | 0.1 |
| Th 228 | 1 | 0.1 |
| Th 229 | 1* | 0.1 |
| Th 230 | 1* | 0.1 |
| Th 232 | 1* | 0.1 |
| Pa 231 | 1* | 0.1 |
| U 232 | 1 | 0.1 |
| U 233 | 1 | 1 |
| U 234 | 1 | 1 |
| U 235 | 1 | 1 |
| U 236 | 110 | 1 |
| U 238 | 1 | 1 |
| Np 237 | 1 | 0.1 |
| Pu 236 | 1 | 0.1 |
| Pu 238 | 1* | 0.1 |
| Pu 239 | 1* | 0.1 |
| Pu 240 | 1* | 0.1 |
| Pu 241 | 10 | 10 |
| Pu 242 | 1* | 0.1 |
| Pu 244 | 1* | 0.1 |
| Am 241 | 1* | 0.1 |
| Am 242m | 1 | 0.1 |
| Am 243 | 1* | 0.1 |
| Cm 242 | 10 | 1 |
| Cm 243 | 1 | 0.1 |
| Cm 244 | 1 | 0.1 |
| Cm 245 | 1* | 0.1 |
| Cm 246 | 1* | 0.1 |
| Cm 247 | 1 | 0.1 |
| Cm 248 | 1* | 0.1 |
| Bk 249 | 100 | 100 |
| Cf 248 | 10 | 1 |
| Cf 249 | 1 | 0.1 |
| Cf 250 | 1 | 0.1 |
| Cf 251 | 1 | 0.1 |
| Cf 252 | 1 | 0.1 |
| Cf 254 | 1 | 0.1 |
| Es 254 | 10 | 1* |

## Table II: Nuclide specific clearance levels for direct reuse of metal items

| Nuclides | Clearance levels Surface-specif.[Bq/cm²] |
|---|---|
| H 3 | 10 000 |
| C 4 | 1000 |
| Na 22 | 1 |
| S 35 | 1000 |
| Cl 36 | 100 |
| K 40 | 10 |
| Ca 45 | 100 |
| Sc 46 | 10 |
| Mn 53 | 10 000 |
| Mn 54 | 10 |
| Fe 55 | 1000 |
| Co 56 | 1 |
| Co 57 | 10 |
| Co 58 | 10 |
| Co 60 | 1 |
| Ni 59 | 10 000 |
| Ni 63 | 1000 |
| Zn 65 | 10 |
| As 73 | 1000 |
| Se 75 | 10 |
| Sr 85 | 10 |
| Sr 90 | 10 |
| Y 91 | 100 |
| Zr 93 | 100 |
| Zr 95 | 10 |
| Nb 93m | 1000 |
| Nb 94 | 1 |
| Mo 93 | 100 |
| Tc 97 | 100 |
| Tc 97m | 1000 |
| Tc 99 | 1000 |
| Ru 106 | 10 |
| Ag 108m | 1 |
| Ag 110m | 1 |
| Cd 109 | 100 |
| Sn 113 | 10 |
| Sb 124 | 10 |
| Sb 125 | 10 |
| Te 123m | 100 |
| Te 127m | 100 |
| I 125 | 100 |
| I 129 | 10 |
| Cs 134 | 1 |
| Cs 135 | 100 |
| Cs 137 | 10 |
| Ce 139 | 10 |
| Ce 144 | 10 |
| Pm 147 | 1000 |
| Sm 151 | 1000 |
| Eu 152 | 1 |
| Eu 154 | 1 |

| Nuclides | Clearance levels Surface-specif.[Bq/cm²] |
|---|---|
| Gd 153 | 10 |
| Tb 160 | 10 |
| Tm 170 | 1000 |
| Tm 171 | 10 000 |
| Ta 182 | 10 |
| W 181 | 100 |
| W 185 | 1000 |
| Os 185 | 10 |
| Ir 192 | 10 |
| Tl 204 | 100 |
| Pb 210 | 1 |
| Bi 207 | 1 |
| Po 210 | 0.1 |
| Ra 226 | 0.1 |
| Ra 228 | 1 |
| Th 228 | 0.1 |
| Th 229 | 0.1 |
| Th 230 | 0.1 |
| Th 232 | 0.1 |
| Pa 231 | 0.1 |
| U 232 | 0.1 |
| U 233 | 1 |
| U 234 | 1 |
| U 235 | 1 |
| U 236 | 1 |
| U 238 | 1 |
| Np 237 | 0.1 |
| Pu 236 | 0.1 |
| Pu 238 | 0.1 |
| Pu 239 | 0.1 |
| Pu 240 | 0.1 |
| Pu 241 | 10 |
| Pu 242 | 0.1 |
| Pu 244 | 0.1 |
| Am 241 | 0.1 |
| Am 242m | 0.1 |
| Am 243 | 0.1 |
| Cm 242 | 1 |
| Cm 243 | 0.1 |
| Cm 244 | 0.1 |
| Cm 245 | 0.1 |
| Cm 246 | 0.1 |
| Cm 247 | 0.1 |
| Cm 248 | 0.1 |
| Bk 249 | 100 |
| Cf 248 | 1 |
| Cf 249 | 0.1 |
| Cf 250 | 0.1 |
| Cf 251 | 0.1 |
| Cf 252 | 0.1 |
| Cf 254 | 0.1 |

These studies investigated the possible routes of the metals after clearance and established scenarios presentative of the critical exposure situations to workers and the general public. Examples of these scenarios and results of the dose calculations are briefly summarized in the following chapters.

**Dose Calculations**

The entire sequence of calculations proceeds along the following lines:

- choice of scenarios
- pathways of exposure
- choice of parameters
- calculation of individual doses per unit activity concentration (per unit surface concentration for direct reuse)
- identification of the limiting scenario and pathway
- reciprocal individual doses yield activity concentrations corresponding to 10 μSv, rounded to a power of ten.

The rounding[i] to powers of ten is consistent with the approach followed for the exemption levels. It implies that in reality the individual doses are not exactly 10 μSv but can in theory be up to 33 μSv. The rounding factors were examined so as not to be too large for the most important radionuclides. For a few radionuclides it was judged inappropriate to round down to 0.1 Bq/g, the doses corresponding to 1 Bq/g being judged acceptable.

In nearly all practical cases more than one radionuclide is involved. To determine if a mixture of radionuclides is below the clearance level a simple summation formula can be used:

$$\sum_{i=1}^{n} \frac{c_i}{c_{Li}} < 1.0 \qquad \text{Eq.1}$$

where:

$c_i$ is the level of activity of radionuclide $i$ in the structure,

$c_{Li}$ is the clearance level of radionuclide $i$,

$n$ is the number of radionuclides in the mixture.

It is worth noting that the sum-rule is conservative since the pathways of exposure or the reference group of exposed individuals are not necessarily the same. In many cases it will be useful to identify a measurable indicator nuclide within the spectrum and apply correspondingly a sum-index as defined above to the clearance level for that nuclide.

**Nuclide inventory for steel scrap**

To define a realistic source inventory, the list of radionuclides taken into account is composed of all the isotopes with half-lives longer than 60 days, quoted in the BSS. Short lived progeny are assumed to be in secular equilibrium with the parent nuclide eg Y 90 with it's parent Sr 90 and U 240, Np 240m and Np 240 with Pu 244.

Based on a study of the steel industry the maximum annual quantity of steel scrap from nuclear installations available for recyling is 10 000Mg. About 2000 Mg are assumed to be stainless steel to be recycled in an induction furnace. The remaining amount, predominantly carbon steel, will be shared equally between foundries with arc furnaces and steel mills with blast furnaces. The fraction of "nuclear"scrap included in each charge varies for the different type of furnaces. It is assumed to be 0.1 for carbon steel and 0.2 for stainless steel. After melting the radioactivity is homogeneously distributed in the product. The melting process has a strong effect of decontamination on certain radionuclides: uranium and plutonium isotopes are concentrated in the slag, whereas zinc and cesium gather in the dust fraction collected on the flue filters. If the dust is recycled, workers can be exposed to doses from Zn 65, Cs 134 and Cs 137. However as the evaluations have shown that the doses from recycling dust are lower than those expected from landfill disposal, the landfill scenarios cover the worst case.

**Flow of activity from cleared ferrous scrap and exposure scenarios**

The pathway of the activity contained in steel scrap has been divided into four sections:

1. Scrap processing at the scrapyard mainly causes exposure due to contact during handling, size reduction, transport and direct irradiation from scrap heaps; in this section the highest doses are expected from scrap contaminated with uranium and transuranic nuclides. These contaminants would become airborne due to thermal cutting of scrap.

2. Processing of the scrap at steel mills and foundries followed by a manufacturing process involves emission of active dust at the workplace and to the environment, as well as direct irradiation doses. The critical nuclides for the scenarios in this section are Cs 134, Cs 137 and Ru 106 inhaled as dust emitted from an arc furnace.

3. The use of the products manufactured with cleared steel scrap leads to a multitude of scenarios, which could give rise to direct irradiation eg work at a large machine, the use of steel kitchen utensils, the processing and storage of liquid food in steel vessels and the presence of rebar and steel radiators in buildings. The worst case scenario is that of the seaman living and working on board a ship constructed entirely with steel containing 10% cleared scrap.

4. The disposal and reuse of by-products of recycling steel scrap is also a main area of concern. Where dust from furnaces is deposited in landfills, the operators of these disposal facilities and the future inhabitants of the landfill site after it's closure risk direct irradiation, inhalation and ingestion doses. It is also common practice to use blast furnace slag as building material and as ground cover for sports fields and tracks. For athletes the latter use could lead to doses approaching the 10µSv/y, if the cleared scrap contained the maximum of TRU.

## Copper and aluminium based metals

The incentive for recycling copper scrap is it's high commodity value and the significant (80-92%) energy savings compared to refining primary copper ore. Aluminium is a widely available resource, but refining the original Bauxite consumes about 20 times the amount of (electric) energy required to recycle aluminium scrap. The economic incentives for recycling these metals are therefore quite important. The identification of scenarios follows the same scheme as for steel recycling.

- Copper is not used in the RPV, the primary circuit and the core internals of reactors. The activity of copper scrap therefore rarely stems from neutron activation. Metallic copper from electric motors and cables as well as brass or bronze condenser tubes are the main origins of clearable scrap. In the derivation of clearance levels it has been assumed, that for motors and for cables the separation of the copper from the other materials was carried out prior to clearance.

- For copper scrap processing, the critical scenario is the transportation of scrap occasioning direct irradiation and dust inhalation doses. During the refining and melting process inhalation doses from tritium, carbon 14, Fe 55 and Ni 63 will remain well below 10µSv/y; during the manufacture of copper ingots aerosols with TRU contaminants present the highest risk.

- Among the scenarios dealing with copper products, the highest doses were found for a musician playing a brass instrument. The disposal and reuse of dust and slag from copper processing leads to similar scenarios and results as for steel by-products.

- The scenarios for the recycling of aluminium scrap by and large are similar to those of the other metals investigated, except that the main by-product is salt slag, which is predominantly disposed in landfill.

As the handling and transport of scrap materials are similar regardless of the metal, surface contamination limits are largely independent of the type of metal. Comparing copper to steel scrap and to aluminium scrap the expected clearable quantity is much less and therefore copper and aluminium can be processed in a shorter time. This leads to shorter exposure times and lower doses. Since the radiological analysis for surface contamination is valid for all metals, the same surface specific clearance levels can be used. For bulk activity the doses depend on the type and density of the matrix metal; this was consequently considered in the scenario calculations.

## Direct reuse of equipment, components and tools

The clearance of equipment and tools for direct reuse is a common practice. The radiological criteria established for the recycling of slightly radioactive scrap may not be applied to the reuse of items because after clearance no further dilution or decontamination can be taken into consideration. The clearance levels for direct reuse are primarily surface contamination limits as in many cases non-destructive assaying of clearable material is not possible. Conventional measuring equipment however cannot distinguish the surface contamination from the bulk activity for strong $\gamma$-emitters like Co 60.

For weak $\gamma$-emitters and for ß- and $\alpha$-emitters the opposite occurs; these nuclides can escape detection if they are hidden under rust, corrosion or surface coatings. Nuclides in such surface layers must be considered surface activity, as they can be removed by sanding, stripping etc.

The clearance levels for direct reuse are derived on the assumption that the total surface activity, fixed and removable, is limited. The radiological assessment of the post-clearance scenarios included secondary ingestion after transfer by hands, skin doses from handling, direct irradiation and inhalation of aerosols from refurbishing or normal use. Using the clearance levels listed in Table II, the highest calculated exposure from Co 60 (clearance level= 1 Bq/cm²) would amount to 10µSv/y; the highest inhalation dose would be 3.84µSv/y calculated for the scenario of a Pu 239 (clearance level = 0.1Bq/cm²) contaminated item being sanded for eg rust removal.

### Collective dose from cleared metal scrap

The BSS states that a practice can be considered as optimized (ALARA) if the collective dose is below 1 manSV/y. The collective doses from recycling steel, copper and aluminium scrap were determined. The collective doses were calculated for one year of clearance and recycling and integrated over 100 years assuming that the products are recycled again after reaching the end of their useful lives and that contact with such product would become increasingly widespread. The collective doses are the sum of the individual doses from a subset of the most restrictive scenarios. For some radionuclides the collective dose at the clearance level is close to 1 manSv, but for a realistic radionuclide distribution the overall impact is well below this criterion. Moreover it is considered that, in the light of the benefit both in economic and ecological terms of recycling over landfill disposal, there is no doubt as to whether recycling is a sound option.

Thus in practice only the individual dose criteria (10 µSv/y effective dose, in a few cases 50 mSv/y skin dose) are of importance for the establishment of the clearance levels.

## RECOMMENDED CLEARANCE POLICY FOR BUILDINGS

The clearance criteria listed in Tables III, IV and V apply to buildings, rooms, sections of buildings and building structures in which practices requiring reporting or prior authorisation were carried out, and to building rubble resulting from the demolition of such structures. The decision to apply the clearance criteria remains the responsibility of the competent authorities and it is expected that the authorities will supervise the act of clearance to ensure that the criteria are met.

The radionuclides investigated here are those with half-lives longer than 60 days for which exemption values in the BSS exist, with the exception of the noble gases. This list of radionuclides is not exhaustive and therefore it is possible that an unlisted radionuclide could be relevant for clearance decisions. It is recommended that in such cases the authorities make a case by case decision. As an example the radionuclide Ba 133 which is an activation product in concrete and often used as a key nuclide for finger printing building rubble is not included in the BSS. Because of its importance, though, it has been included in the list of clearance levels. If the authorities find other radionuclides to be of importance it is suggested that they calculate their clearance levels using the scenarios described in [10] on a case by case basis.

Regarding the act of clearance, three main groups for buildings and building rubble, due to the further purpose of usage or handling, are derived:

clearance for buildings for any purpose (reuse or demolition);

clearance for buildings for demolition only;

clearance for building rubble.

Corresponding to these clearance options, three sets of clearance levels for buildings and building rubble are developed. The nuclide specific most restrictive scenarios presented in the following tables are described in detail in [10]. The possible exposure paths are due to external $\gamma$-dose ("external"), inhalation, ingestion ("water child", "water adult", "vegetable", "landfill") and $\beta$-skin-dose. If the criteria presented here are applied there is no radiological preference between demolition and continued non-nuclear use.

**Conventional Recycling and Disposal Options for Building Rubble and Reuse of Buildings**

After a building or building rubble has been cleared, many options are available which are shown schematically in Fig.1. Generally the rubble must first be processed (including crushing) and then sorted according to grain sizes depending on the later use. The material can be used in civil engineering for road construction or as an additive for manufacturing of new concrete. Rubble can also be used in foundations, to backfill holes or in recultivation and landscaping projects for which the rubble does not necessarily need to be processed. Recycling options with processing as well as without have been studied in detail [11,12,13]. For the assessment of individual doses and the derivation of clearance levels which have been performed in [10], conservative exposure scenarios corresponding to the diagram shown in Fig.1 were used. These scenarios have been based on large quantities (in the order of $10^5$ Mg).

Building rubble from nuclear installations could, however, also be used for other purposes where the contact to the general population is significantly reduced. Backfilling of underground mines, manufacturing of waste containers for waste disposal or in grouting of waste packs are examples of alternative management options. Such options must be reviewed in connection with the national regulations and could after a radiological impact study be implemented for material which has an activity level above the clearance level.

**Collective Dose from Cleared Buildings and Building Rubble**

When assessing collective doses, it is important to start from actual exposure situations. It is therefore meaningless to calculate collective doses for each nuclide. Instead, collective doses must be assessed for the most important exposure situations which are the reuse of large buildings and the recycling of building rubble from nuclear power plants. The latter provide the largest contribution to the total mass of building rubble from nuclear installations. This in turn makes Co 60 and Cs 137 the most important

nuclides as they dominate nuclide vectors in nuclear power plants, leading to external irradiation as the most important exposure pathway.

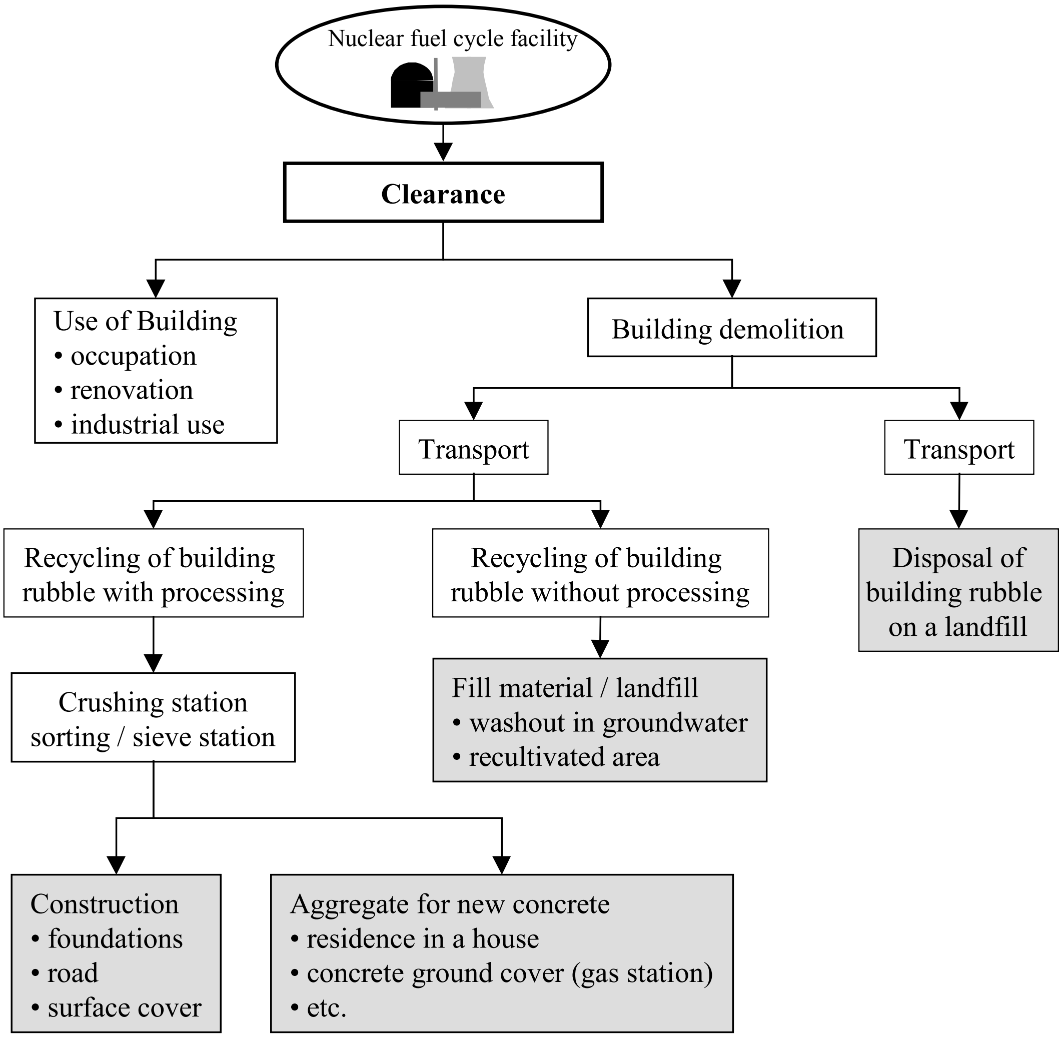


**Figure 1: Recycle, reuse and disposal options for cleared buildings and building rubble**

An estimation of collective doses based on these assumptions was performed in[10]. It has been shown there that collective doses from the reuse of buildings and collective doses from the cleared building rubble (cleared within one year) will remain below 1 manSv/a. For the reuse of buildings, a residency scenario has been used taking account of the number of people that could possibly inhabit the buildings; for the building rubble a recycling scenario has been used taking account of the number of people that might be affected by the recycled rubble. In both cases the collective dose resulting from clearance during one year is in the range of 0.1 manSv or less, taking into account the radiological consequences during all oncoming years.

## APPLICATION OF CLEARANCE PROCEDURES

### Regulatory Aspects

The BSS define clearance as a practice which requires reporting and prior authorization by national licensing bodies. National authorities can either permit clearance procedures on a case by case basis or in more general terms within national legislation. In either case clearance remains under the responsibility and control of the national authorities, who will also ensure compliance with the clearance criteria eg by appropriate audits.

**Table III: Radionuclide specific clearance levels for building reuse or demolition expressed as total activity in the structure per unit surface area**

| Radio nuclide | Most restrictive scenario | Clearance level (Bq/cm²) | Rounded cl. level (Bq/cm²) |
|---|---|---|---|
| H 3 | water child | 3.8E+3 | 10,000 |
| C 14 | ß-skin | 2.8E+3 | 1000 |
| Na 22 | external | 4.4E-1 | 1 |
| S 35 | ß-skin | 2.6E+3 | 1000 |
| Cl 36 | vegetable | 3.2E+1 | 100 |
| K 40 | external | 5.6E+0 | 10 |
| Ca 45 | ß-skin | 1.1E+3 | 1000 |
| Sc 46 | external | 1.3E+0 | 1 |
| Mn 53 | vegetable | 2.3E+4 | 10,000 |
| Mn 54 | external | 1.5E+0 | 1 |
| Fe 55 | inhalation | 1.0E+4 | 10,000 |
| Co 56 | external | 8.2E-1 | 1 |
| Co 57 | external | 1.2E+1 | 10 |
| Co 58 | external | 3.2E+0 | 10 |
| Co 60 | external | 3.6E-1 | 1 |
| Ni 59 | inhalation | 4.2E+4 | 100,000 |
| Ni 63 | inhalation | 1.8E+4 | 10,000 |
| Zn 65 | external | 2.3E+0 | 1 |
| As 73 | external | 4.0E+2 | 1000 |
| Se 75 | external | 5.2E+0 | 10 |
| Sr 85 | external | 6.2E+0 | 10 |
| Sr 90 | vegetable | 3.4E+1 | 100 |
| Y 91 | ß-skin | 4.1E+2 | 1000 |
| Zr 93 | inhalation | 3.1E+2 | 1000 |
| Zr 95 | external | 1.8E+0 | 1 |
| Nb 93m | external | 5.0E+2 | 1000 |
| Nb 94 | external | 5.3E-1 | 1 |
| Mo 93 | external | 7.5E+1 | 100 |
| Tc 97 | external | 8.0E+1 | 100 |
| Tc 97m | external | 2.9E+2 | 100 |
| Tc 99 | vegetable | 7.0E+1 | 100 |
| Ru 106 | external | 5.6E+0 | 10 |
| Ag 108m | external | 5.1E-1 | 1 |
| Ag 110m | external | 4.8E-1 | 1 |
| Cd 109 | external | 4.0E+1 | 100 |
| Sn 113 | external | 7.2E+0 | 10 |
| Sb 124 | external | 1.9E+0 | 1 |
| Sb 125 | external | 2.1E+0 | 1 |
| Te 123m | external | 1.4E+1 | 10 |
| Te 127m | external | 1.3E+2 | 100 |
| I 125 | external | 7.5E+1 | 100 |
| I 129 | water adult | 7.5E+0 | 10 |
| Cs 134 | external | 6.3E-1 | 1 |
| Cs 135 | ß-skin | 1.8E+3 | 1000 |
| Cs 137 | external | 1.5E+0 | 1 |
| Ce 139 | external | 1.2E+1 | 10 |
| Ce 144 | external | 2.6E+1 | 10 |
| Pm 147 | ß-skin | 1.5E+3 | 1000 |
| Sm 151 | inhalation | 3.6E+3 | 10,000 |
| Eu 152 | external | 7.7E-1 | 1 |
| Eu 154 | external | 6.9E-1 | 1 |
| Eu 155 | external | 1.5E+1 | 10 |
| Gd 153 | external | 1.2E+1 | 10 |
| Tb 160 | external | 2.9E+0 | 1 |
| Tm 170 | external | 3.7E+2 | 1000 |
| Tm 171 | external | 1.5E+3 | 1000 |
| Ta 182 | external | 1.7E+0 | 1 |
| W 181 | external | 5.1E+1 | 100 |

| Radio nuclide | Most restrictive scenario | Clearance level (Bq/cm²) | Rounded cl. level (Bq/cm²) |
|---|---|---|---|
| W 185 | ß-skin | 8.1E+2 | 1000 |
| Os 185 | external | 3.3E+0 | 10 |
| Ir 192 | external | 3.7E+0 | 10 |
| Tl 204 | ß-skin | 4.8E+2 | 1000 |
| Pb 210 | vegetable | 1.4E+0 | 1 |
| Bi 207 | external | 5.4E-1 | 1 |
| Po 210 | inhalation | 4.2E+0 | 10 |
| Ra 226 | external | 4.9E-1 | 1 |
| Ra 228 | inhalation | 4.4E-1 | 1 |
| Th 228 | inhalation | 2.7E-1 | 0.1 |
| Th 229 | inhalation | 1.2E-1 | 0.1 |
| Th 230 | inhalation | 3.3E-1 | 1 |
| Th 232 | inhalation | 1.4E-1 | 0.1 |
| Pa 231 | inhalation | 1.3E-2 | 0.1* |
| U 232 | inhalation | 1.7E-1 | 0.1 |
| U 233 | inhalation | 1.2E+0 | 1 |
| U 234 | inhalation | 1.4E+0 | 1 |
| U 235 | inhalation | 1.3E+0 | 1 |
| U 236 | inhalation | 1.5E+0 | 1 |
| U 238 | inhalation | 1.6E+0 | 1 |
| Np 237 | inhalation | 6.2E-1 | 1 |
| Pu 236 | inhalation | 7.1E-1 | 1 |
| Pu 238 | inhalation | 3.1E-1 | 1 |
| Pu 239 | inhalation | 2.9E-1 | 0.1 |
| Pu 240 | inhalation | 2.9E-1 | 0.1 |
| Pu 241 | inhalation | 1.1E+1 | 10 |
| Pu 242 | inhalation | 3.0E-1 | 1 |
| Pu 244 | inhalation | 3.1E-1 | 1 |
| Am 241 | inhalation | 3.4E-1 | 1 |
| Am 242m | inhalation | 3.2E-1 | 1 |
| Am 243 | inhalation | 3.4E-1 | 1 |
| Cm 242 | inhalation | 2.5E+0 | 1 |
| Cm 243 | inhalation | 4.6E-1 | 1 |
| Cm 244 | inhalation | 5.5E-1 | 1 |
| Cm 245 | inhalation | 3.0E-1 | 0.1 |
| Cm 246 | inhalation | 3.4E-1 | 1 |
| Cm 247 | inhalation | 3.7E-1 | 1 |
| Cm 248 | inhalation | 9.8E-2 | 0.1 |
| Bk 249 | inhalation | 8.4E+1 | 100 |
| Cf 248 | inhalation | 1.5E+0 | 1 |
| Cf 249 | inhalation | 2.1E-1 | 0.1 |
| Cf 250 | inhalation | 4.2E-1 | 1 |
| Cf 251 | inhalation | 2.0E-1 | 0.1 |
| Cf 252 | inhalation | 7.1E-1 | 1 |
| Cf 254 | inhalation | 4.2E-1 | 1 |
| Es 254 | external | 1.4E+0 | 1 |

*) if this nuclide is contributing more than 10% to the summation formula (p6), the unrounded value should be used.

**Table IV: Radionuclide specific clearance levels for building demolition expressed as total activity in the structure per unit surface area**

| Radio nuclide | Most restrictive scenario | Clearance level (Bq/cm²) | Rounded Cl. Level (Bq/cm²) |
|---|---|---|---|
| H 3 | water child | 3.8E+3 | 10,000 |
| C 14 | water child | 5.8E+3 | 10,000 |
| Na 22 | landfill | 3.5E+0 | 10 |
| S 35 | ing. worker | 2.0E+5 | 100,000 |
| Cl 36 | vegetable | 3.2E+1 | 100 |
| K 40 | vegetable | 2.4E+1 | 10 |
| Ca 45 | inhalation | 6.4E+4 | 100,000 |
| Sc 46 | landfill | 1.1E+1 | 10 |
| Mn 53 | vegetable | 2.3E+4 | 10,000 |
| Mn 54 | landfill | 1.2E+1 | 10 |
| Fe 55 | ing. child | 2.4E+4 | 10,000 |
| Co 56 | landfill | 6.1E+0 | 10 |
| Co 57 | landfill | 1.3E+2 | 100 |
| Co 58 | landfill | 2.6E+1 | 10 |
| Co 60 | landfill | 2.9E+0 | 1 |
| Ni 59 | ing. child | 8.9E+4 | 100,000 |
| Ni 63 | ing. child | 3.7E+4 | 100,000 |
| Zn 65 | landfill | 1.9E+1 | 10 |
| As 73 | landfill | 2.1E+4 | 10,000 |
| Se 75 | landfill | 4.9E+1 | 100 |
| Sr 85 | landfill | 5.2E+1 | 100 |
| Sr 90 | vegetable | 3.4E+1 | 100 |
| Y 91 | inhalation | 5.4E+4 | 100,000 |
| Zr 93 | inhalation | 2.5E+3 | 1000 |
| Zr 95 | landfill | 1.5E+1 | 10 |
| Nb 93m | ing. child | 3.8E+4 | 100,000 |
| Nb 94 | landfill | 4.3E+0 | 10 |
| Mo 93 | water adult | 2.3E+3 | 1000 |
| Tc 97 | vegetable | 6.9E+2 | 1000 |
| Tc 97m | water child | 5.2E+2 | 1000 |
| Tc 99 | vegetable | 7.0E+1 | 100 |
| Ru 106 | landfill | 4.5E+1 | 100 |
| Ag 108m | landfill | 4.2E+0 | 10 |
| Ag 110m | landfill | 3.9E+0 | 10 |
| Cd 109 | landfill | 4.1E+3 | 10,000 |
| Sn 113 | landfill | 6.7E+1 | 100 |
| Sb 124 | landfill | 1.5E+1 | 10 |
| Sb 125 | landfill | 1.8E+1 | 10 |
| Te 123m | landfill | 1.6E+2 | 100 |
| Te 127m | landfill | 3.3E+3 | 10,000 |
| I 125 | ing. worker | 1.4E+4 | 10,000 |
| I 129 | water adult | 7.5E+0 | 10 |
| Cs 134 | landfill | 5.1E+0 | 10 |
| Cs 135 | vegetable | 8.8E+3 | 10,000 |
| Cs 137 | landfill | 1.2E+1 | 10 |
| Ce 139 | landfill | 1.4E+2 | 100 |
| Ce 144 | landfill | 2.4E+2 | 100 |
| Pm 147 | inhalation | 2.4E+4 | 10,000 |
| Sm 151 | inhalation | 2.9E+4 | 10,000 |
| Eu 152 | landfill | 6.2E+0 | 10 |
| Eu 154 | landfill | 5.7E+0 | 10 |
| Eu 155 | landfill | 2.6E+2 | 100 |
| Gd 153 | landfill | 2.9E+2 | 100 |

| Radio nuclide | Most restrictive scenario | Clearance level (Bq/cm²) | Rounded Cl. Level (Bq/cm²) |
|---|---|---|---|
| Tb 160 | Landfill | 2.3E+1 | 10 |
| Tm 170 | Landfill | 9.0E+3 | 10,000 |
| Tm 171 | Landfill | 5.8E+4 | 100,000 |
| Ta 182 | Landfill | 1.4E+1 | 10 |
| W 181 | Landfill | 1.7E+3 | 1000 |
| W 185 | ing. worker | 3.9E+5 | 1000000 |
| Os 185 | Landfill | 2.9E+1 | 10 |
| Ir 192 | Landfill | 3.1E+1 | 100 |
| Tl 204 | vegetable | 2.5E+3 | 1000 |
| Pb 210 | vegetable | 1.4E+0 | 1 |
| Bi 207 | Landfill | 4.5E+0 | 10 |
| Po 210 | inhalation | 7.4E+1 | 100 |
| Ra 226 | vegetable | 9.4E-1 | 1 |
| Ra 228 | inhalation | 3.8E+0 | 10 |
| Th 228 | inhalation | 2.6E+0 | 1 |
| Th 229 | inhalation | 9.4E-1 | 1 |
| Th 230 | inhalation | 2.7E+0 | 1 |
| Th 232 | inhalation | 1.2E+0 | 1 |
| Pa 231 | inhalation | 1.1E-1 | 0.1 |
| U 232 | inhalation | 1.4E+0 | 1 |
| U 233 | inhalation | 9.7E+0 | 10 |
| U 234 | inhalation | 1.1E+1 | 10 |
| U 235 | inhalation | 1.0E+1 | 10 |
| U 236 | inhalation | 1.2E+1 | 10 |
| U 238 | inhalation | 1.3E+1 | 10 |
| Np 237 | inhalation | 5.0E+0 | 10 |
| Pu 236 | inhalation | 6.5E+0 | 10 |
| Pu 238 | inhalation | 2.5E+0 | 1 |
| Pu 239 | inhalation | 2.3E+0 | 1 |
| Pu 240 | inhalation | 2.3E+0 | 1 |
| Pu 241 | inhalation | 9.2E+1 | 100 |
| Pu 242 | inhalation | 2.4E+0 | 1 |
| Pu 244 | inhalation | 2.5E+0 | 1 |
| Am 241 | inhalation | 2.8E+0 | 1 |
| Am 242m | inhalation | 2.6E+0 | 1 |
| Am 243 | inhalation | 2.8E+0 | 1 |
| Cm 242 | inhalation | 4.0E+1 | 100 |
| Cm 243 | inhalation | 3.8E+0 | 10 |
| Cm 244 | inhalation | 4.5E+0 | 10 |
| Cm 245 | inhalation | 2.4E+0 | 1 |
| Cm 246 | inhalation | 2.8E+0 | 1 |
| Cm 247 | inhalation | 3.0E+0 | 1 |
| Cm 248 | inhalation | 7.9E-1 | 1 |
| Bk 249 | inhalation | 9.8E+2 | 1000 |
| Cf 248 | inhalation | 1.7E+1 | 10 |
| Cf 249 | inhalation | 1.7E+0 | 1 |
| Cf 250 | inhalation | 3.5E+0 | 10 |
| Cf 251 | inhalation | 1.6E+0 | 1 |
| Cf 252 | inhalation | 6.6E+0 | 10 |
| Cf 254 | inhalation | 1.4E+1 | 10 |
| Es 254 | landfill | 1.2E+1 | 10 |

**Table V: Radionuclide specific clearance levels for building rubble expressed as mass specific activity**

| Radio nuclide | Most restrictive scenario | Clearance level (Bq/g) | Rounded cl. level (Bq/g) |
|---|---|---|---|
| H 3 | water child | 6.2E+1 | 100 |
| C 14 | vegetable | 1.0E+1 | 10 |
| Na 22 | landfill | 1.0E-1 | 0.1 |
| S 35 | ß-skin | 1.0E+3 | 1000 |
| Cl 36 | vegetable | 1.1E+0 | 1 |
| K 40 | vegetable | 7.9E-1 | 1 |
| Ca 45 | ß-skin | 4.2E+2 | 1000 |
| Sc 46 | landfill | 1.1E-1 | 0.1 |
| Mn 53 | vegetable | 1.5E+3 | 1000 |
| Mn 54 | landfill | 2.6E-1 | 0.1 |
| Fe 55 | ing. child | 6.1E+2 | 1000 |
| Co 56 | landfill | 6.2E-2 | 0.1 |
| Co 57 | landfill | 2.7E+0 | 1 |
| Co 58 | landfill | 2.3E-1 | 0.1 |
| Co 60 | landfill | 8.9E-2 | 0.1 |
| Ni 59 | ing. child | 2.9E+3 | 1000 |
| Ni 63 | ing. child | 1.2E+3 | 1000 |
| Zn 65 | landfill | 3.8E-1 | 1 |
| As 73 | landfill | 2.1E+2 | 100 |
| Se 75 | landfill | 6.7E-1 | 1 |
| Sr 85 | landfill | 4.4E-1 | 1 |
| Sr 90 | vegetable | 1.5E+0 | 1 |
| Y 91 | ß-skin | 1.6E+2 | 100 |
| Zr 93 | inhalation | 8.2E+1 | 100 |
| Zr 95 | landfill | 1.2E-1 | 0.1 |
| Nb 93m | ing. child | 1.2E+3 | 1000 |
| Nb 94 | landfill | 1.4E-1 | 0.1 |
| Mo 93 | water adult | 3.8E+1 | 100 |
| Tc 97 | vegetable | 1.4E+1 | 10 |
| Tc 97m | water child | 8.6E+0 | 10 |
| Tc 99 | vegetable | 1.4E+0 | 1 |
| Ru 106 | landfill | 1.1E+0 | 1 |
| Ag 108m | landfill | 1.4E-1 | 0.1 |
| Ag 110m | landfill | 8.1E-2 | 0.1 |
| Cd 109 | landfill | 1.0E+2 | 100 |
| Sn 113 | landfill | 8.9E-1 | 1 |
| Sb 124 | ß-skin | 2.0E+2 | 100 |
| Sb 125 | landfill | 5.4E-1 | 1 |
| Te 123m | landfill | 2.1E+0 | 1 |
| Te 127m | landfill | 4.3E+1 | 100 |
| I 125 | ing. worker | 1.1E+2 | 100 |
| I 129 | water adult | 1.2E-1 | 0.1 |
| Cs 134 | landfill | 1.4E-1 | 0.1 |
| Cs 135 | ing. child | 4.3E+2 | 1000 |
| Cs 137 | landfill | 4.0E-1 | 1 |
| Ce 139 | landfill | 2.1E+0 | 1 |
| Ce 144 | landfill | 5.2E+0 | 10 |
| Pm 147 | ß-skin | 6.0E+2 | 1000 |
| Sm 151 | inhalation | 9.5E+2 | 1000 |
| Eu 152 | landfill | 2.0E-1 | 0.1 |
| Eu 154 | landfill | 1.8E-1 | 0.1 |
| Eu 155 | landfill | 8.1E+0 | 10 |
| Gd 153 | landfill | 6.0E+0 | 10 |
| Tb 160 | landfill | 2.1E-1 | 0.1 |
| Tm 170 | landfill | 1.3E+2 | 100 |
| Tm 171 | ß-skin | 1.5E+3 | 1000 |
| Ta 182 | landfill | 1.8E-1 | 0.1 |

| Radio nuclide | Most restrictive scenario | Clearance level (Bq/g) | Rounded cl. level (Bq/g) |
|---|---|---|---|
| W 181 | landfill | 2.4E+1 | 10 |
| W 185 | ß-skin | 3.2E+2 | 1000 |
| Os 185 | landfill | 3.3E-1 | 1 |
| Ir 192 | landfill | 2.9E-1 | 0.1 |
| Tl 204 | vegetable | 8.1E+1 | 100 |
| Pb 210 | ing. child | 8.7E-2 | 0.1 |
| Bi 207 | landfill | 1.5E-1 | 0.1 |
| Po 210 | inhalation | 1.1E+0 | 1 |
| Ra 226 | ing. child | 8.3E-2 | 0.1 |
| Ra 228 | inhalation | 1.2E-1 | 0.1 |
| Th 228 | inhalation | 7.3E-2 | 0.1 |
| Th 229 | inhalation | 3.1E-2 | 0.1 |
| Th 230 | inhalation | 8.8E-2 | 0.1 |
| Th 232 | inhalation | 3.8E-2 | 0.1 |
| Pa 231 | inhalation | 3.5E-3 | 0.1* |
| U 232 | inhalation | 4.5E-2 | 0.1 |
| U 233 | inhalation | 3.2E-1 | 1 |
| U 234 | inhalation | 3.6E-1 | 1 |
| U 235 | inhalation | 3.4E-1 | 1 |
| U 236 | inhalation | 3.9E-1 | 1 |
| U 238 | inhalation | 4.3E-1 | 1 |
| Np 237 | inhalation | 1.6E-1 | 0.1 |
| Pu 236 | inhalation | 1.9E-1 | 0.1 |
| Pu 238 | inhalation | 8.2E-2 | 0.1 |
| Pu 239 | inhalation | 7.7E-2 | 0.1 |
| Pu 240 | inhalation | 7.7E-2 | 0.1 |
| Pu 241 | inhalation | 3.0E+0 | 1 |
| Pu 242 | inhalation | 8.0E-2 | 0.1 |
| Pu 244 | inhalation | 8.2E-2 | 0.1 |
| Am 241 | inhalation | 9.1E-2 | 0.1 |
| Am 242m | inhalation | 8.5E-2 | 0.1 |
| Am 243 | inhalation | 9.1E-2 | 0.1 |
| Cm 242 | inhalation | 6.7E-1 | 1 |
| Cm 243 | inhalation | 1.2E-1 | 0.1 |
| Cm 244 | inhalation | 1.5E-1 | 0.1 |
| Cm 245 | inhalation | 8.0E-2 | 0.1 |
| Cm 246 | inhalation | 9.1E-2 | 0.1 |
| Cm 247 | inhalation | 9.9E-2 | 0.1 |
| Cm 248 | inhalation | 2.6E-2 | 0.1* |
| Bk 249 | inhalation | 2.2E+1 | 10 |
| Cf 248 | inhalation | 4.0E-1 | 1 |
| Cf 249 | inhalation | 5.5E-2 | 0.1 |
| Cf 250 | inhalation | 1.1E-1 | 0.1 |
| Cf 251 | inhalation | 5.4E-2 | 0.1 |
| Cf 252 | inhalation | 1.9E-1 | 0.1 |
| Cf 254 | inhalation | 1.1E-1 | 0.1 |
| Es 254 | landfill | 2.5E-1 | 0.1 |

*) if this nuclide is contributing more than 10% to the summation formula (p. 6), the unrounded value should be used

The authorization of dismantling operations will pertain to the entire sequence of operations, from characterization and segregation of the material up to the amounts that can be cleared at certain levels.

For metal recycling both the mass specific and the surface specific levels listed in Table I have to be observed. The total activity is averaged over measurements of a few hundred kilograms and a few hundred square centimeters. The intentional dilution of active scrap for the purpose of clearance is forbidden. The authorities must also verify, that the material can only be used for recycling after remelting; eg pumps, vessels or fittings should be rendered inoperable by sectioning.

Release of equipment for direct reuse can be authorized in compliance with the surface specific clearance levels in Table II. As in many cases some surface areas likely to be contaminated cannot be measured by non-destructive assay, such measurement can be replaced by a conservative assessment.

The surface specific criteria for reuse (or demolition) of buildings (Table III) are more severe than those applicable only for demolition (Table IV). Averaging on areas >1 $m^3$ is not permitted. The mass specific criteria for rubble allow averaging over 1 Mg. In any case demolition should not be practiced to obtain dilution of higher active material.

## Verification of clearance levels

Verification of the compliance with the clearance levels can be done by direct measurement on the metal to be cleared, by laboratory measurements on representative samples, by use of properly derived scaling factors or by other means which are accepted by the competent national authorities. The goal of keeping individual doses in the range of 10μSv/y and therefore within a small fraction of the natural background renders the use of extremely sensitive measurement techniques necessary. Many studies fully or partly devoted to measurements for clearance have been published [14,15,16,17,18]. It can be concluded, that the clearance levels for the most frequently occurring radionuclides typical for activation- and fission products can be directly measured. The activity level of many difficult to measure ß-emitters can be related to other radionuclides. For example Fe 55 and Ni 63 can be correlated to Co 60 and Sr 90 correlated to Cs 137. Both Co 60 and Cs 137 are strong γ-emitters and can therefore be measured easily.

In nearly all practical cases more than one radionuclide is involved. To determine if a mixture of radionuclides is below the clearance level, the summation formula (Eq.1) shall be used.

## Recycling in licensed facilities

The radiological assessments used to derive the clearance criteria for scrap metal recycling assume that the cleared active scrap will be mixed with a much larger fraction of inactive metal. Ingots produced in a licensed facility are made from 100% active scrap and could therefore lead to higher exposures. The clearance levels listed in Table I can therefore not be applied this situation. However, as melting in licensed facilities (generally the same foundries recycling uncleared active scrap for the nuclear industry) has some advantages ie the homogenization of activity and the decontamination effect of melting, national authorities can authorize clearance after melting after an appropriate investigation of the radiological consequences.

## CONCLUSION

The best way to manage materials and components removed from decommissioned nuclear facilities is to reuse them in other nuclear plants or to recycle them eg as waste containers or shielding slabs; but only a fraction of the items removed in the process of dismantling a nuclear plant can be usefully reemployed or recycled by the nuclear industry. The clearance of metals from the decommissioning of nuclear facilities is a radiologically and economically feasible alternative to the relatively expensive licensed disposal of low to very low active materials, in particular where shortlived nuclides like Co 60 are involved.

By May 2000 the new Basic Safety Standards will be introduced in national legislation and regulatory practice. In order to enable the use of these new standards in decommissioning of nuclear facilities, Community guidance has been produced for the application of the clearance concept for the reuse, recycling or disposal of materials arising from the dismantling of nuclear installations. This will facilitate the introduction of harmonized procedures and uniform clearance standards in the European Union.

The clearance criteria are based on internationally agreed radiological protection principles and should therefore find acceptance not only within the EU but also in the trade outside the Common Market. In this trade, scrap imports and exports are by far not as important as the trade with goods which may contain cleared metals. In order to avoid further trade conflicts the radiological approach and the resulting clearance criteria should be discussed and understood by the international scientific community. This paper may not contain all the details of the clearance policy and practice proposed by the European Commission but it should provide the elements for a broad understanding of it's scientific and technical rationale.

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## FOOTNOTES

* Rounded up to 1 Bq/g

[i] If the calculated value lies between 3 $10^{X}$ and 3 $10^{X+1}$, the rounded value is $10^{X+1}$.