European Commission

Radiation protection 89

Recommended radiological protection criteria for the recycling of metals from the dismantling of nuclear installations

Recommendations of the
group of experts set up under the
terms of Article 31 of the
Euratom Treaty

1998

Directorate-General
Environment, Nuclear Safety
and Civil Protection

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FOREWORD

The present document lays down recommended radiological protection criteria for the recycling of metals arising from the dismantling of nuclear installations. With this document the Group of Experts set up under the terms of Article 31 of the Euratom Treaty, confirms and extends its recommendations made in 1988 on the recycling of steel (published as Radiation Protection No. 43). The Working Party set up for this purpose has examined radiation exposures related to the recycling of steel, copper and aluminium, in terms of nuclide specific mass activity concentration levels of these metals, and in terms of surface specific contamination levels for recycling or direct reuse. It has been demonstrated that below such clearance levels, materials can be released from regulatory control with negligible risk, from a radiation protection point of view, for the workers in the metal industry and for the population at large.

The definition of clearance levels is important in view of a harmonised implementation of the Basic Safety Standards[1]. It is also of interest with regard to the impact of the dismantling of nuclear installations on neighbouring Member States, which is assessed by the Commission under the terms of Article 37 of the Euratom Treaty.

While competent authorities of Member States are expected to benefit from the guidance offered by the Group of Experts, and this may ensure a harmonised approach within the European Community, it should be emphasised that the application of clearance levels by competent authorities is not prescribed by the Directive. It is clear that decisions whether or not to apply clearance levels will be taken not only on radiation protection grounds but will also take other factors into account.

Even though from a radiation protection point of view the impact of recycling at levels of radioactive contamination below the proposed clearance levels is trivial, the Commission is aware that there is a need for communication with the industry and with the general public in order to ensure acceptance of the recycling option. Otherwise the metal industry would understandably be reluctant to face a possible negative impact on the environmental image of metal recycling. The benefit of recycling is large in terms of saving energy and valuable raw materials. From a larger perspective it is reasonable to assume that metal recycling has a net positive impact on the health of workers and population compared to disposal as radioactive or ordinary waste and compared to the impact of metal ore mining to ensure replacement of spent metals. This net benefit should significantly outweigh the minor radiation detriment associated with the recycling of scrap with very low levels of radioactive contamination.

Within this broad environmental perspective the present document is a useful tool for the realistic assessment of the different options from a radiation protection point of view.

S. FRIGREN
Director

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1 Basic Safety Standards for the health protection of the general public and workers against the dangers of ionizing radiation (Council Directive 96/29/Euratom)

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1. INTRODUCTION

Radiation protection requirements pertaining to the operation of nuclear fuel cycle installations in the Member States of the European Union (EU) are established at a national level, whereby national legislation is bound by the Euratom Treaty to comply with the general EU standards: "The Basic Safety Standards for the Health Protection of the General Public and Workers against the Dangers of Ionizing Radiation" (BSS). A new Basic Safety Standards Directive was adopted in May 1996 and must be implemented in national legislation by the year 2000 [9]. One of the requirements in the new Standards is that the disposal, recycling and reuse of material containing radioactive substances is subject to prior authorization by national competent authorities. It is stated however that the authorities may specify clearance levels below which such materials are no longer subject to the requirements of the Standards. Clearance levels shall be established on the basis of the general criteria for exemption laid down in Annex 1 of the Directive, and take into account technical guidance provided by the Community. Thus upon decommissioning and dismantling of such installations, regulatory control may be relinquished for part of the premises or materials arising from dismantling. There are currently more than a hundred nuclear reactors operating in the EU and around 40, many of which are research reactors, which have been shut down and are being decommissioned. This represents a large potential of "waste" material under regulatory control. A considerable fraction of this material, of which metals are the economically most valuable, is not or is only very slightly radioactive. Recycling or reusing this material would avoid unjustified allocation of resources to the disposal of low activity waste and save valuable natural resources.

This recommendation gives guidance to the regulating authorities of the Member States of the EU concerning the conditions under which the removal of regulatory control from metal scrap, components and equipment from installations of the nuclear power industry is radiologically acceptable. Because of the economic value of metal, once regulatory controls have been removed it cannot be guaranteed that the metal will remain in the country in which regulatory control was lifted. In particular, in view of achieving a single European market, it is highly undesirable that this would give rise to further controls, either at the border or at the final destination of the metal. For this reason it is imperative that within the EU uniform criteria be applied for relinquishing regulatory control.

This need was identified already in the 1980s. At that time the BSS [8] had not yet introduced the concept of clearance, but release from regulatory control was possible on a case by case basis. Existing provisions for exemption from regulatory control were reviewed and it was felt that these provisions were not applicable to clearance in view of the very large quantities which are released upon dismantling. Thus specific guidance was required and in 1984 the Group of Experts, set up under the terms of Article 31 of the Euratom Treaty, convened a Working Party to establish radiological protection criteria appropriate to the recycling of materials from nuclear establishments. In 1988 the Article 31 Group of Experts recommended criteria which are directly applicable to the recycling of steel scrap from nuclear power stations [4]. The 1988 recommendation was based on information that was available in 1985 and the surface contamination criteria were based on the International Atomic Energy Agency's (IAEA) transport regulations [24] which were valid at the time of publication. Since then there have been a number of studies relating to recycling of slightly radioactive materials and there has also been new advice given on radiological protection criteria. In light of this the Article 31 Group of Experts decided in 1990 to reconvene the Working Party, which was asked to expand and update the 1988 recommendation. In particular the Working Party was instructed to consider criteria for

other metals (e.g. steel alloys, aluminium, aluminium alloys, copper and copper alloys), criteria for surface contamination specific to recycling of metal and to expand the scope of application to other installations of the nuclear fuel cycle, which includes uranium enrichment, fuel production, power generation and reprocessing (see figure 1-1). The present work does not include mining and milling operations or final repositories.

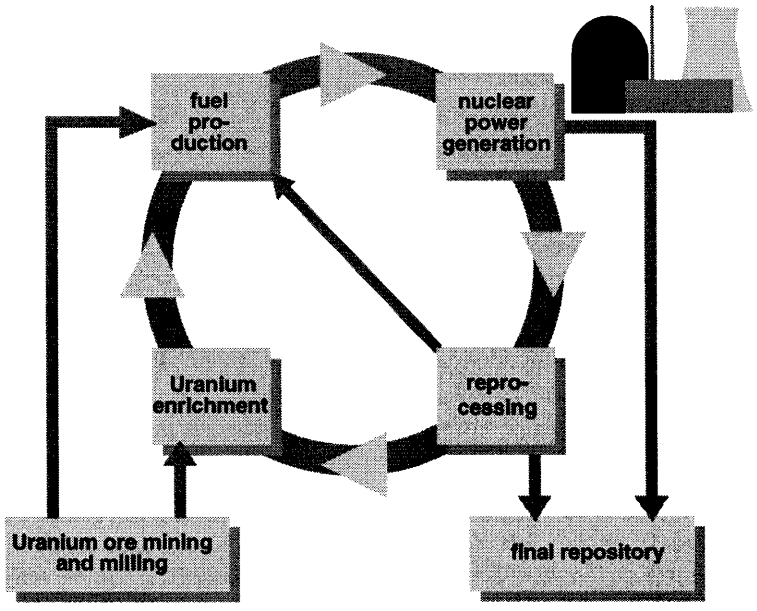

Figure 1-1: Diagram showing the nuclear fuel cycle, which starts with uranium enrichment then fuel production, power generation and completes the cycle with reprocessing.

The exposure scenarios have been investigated in technical work carried out on behalf of the European Commission (see acknowledgements) and examined by an expert group of the Article 31 Group of Experts. This work has subsequently been compiled in a comprehensive compilation to be published in parallel with the present report [6, 7]. The first document [6] gives the exposure scenarios in relation to mass activity concentrations of steel, copper and aluminium, both in terms of individual and collective dose, and also contains the underlying nuclide specific data. The second document [7] describes the exposure scenarios for surface contamination of metals.

2. UNDERLYING RADIATION PROTECTION PRINCIPLES

2.1 The European Union's Basic Safety Standards

The scheme in figure 2-1 illustrates the decision making process prescribed by the BSS. It should be noted that the scope of the BSS is defined in terms of practices [9] and only indirectly in terms of radioactive substances. Any practice involving radioactivity requires justification. If the use is deemed justifiable it must be decided if the practice should be put under the system of reporting and prior authorization as prescribed by the BSS. Practices which do not fall under this system are called exempt practices. Some practices are put without exception under the regulatory system due to their potential risks, for example all practices associated with the nuclear fuel cycle. Other practices can be exempt if the associated risks are sufficiently low. Nuclide quantities and activities per unit mass giving rise to trivial risks are called exemption levels and have been derived [5] for the BSS [9]. It is understood that practices, not a priori subject to regulation, involving

radioactive substances below either one of such levels are exempt from the regulatory requirements.

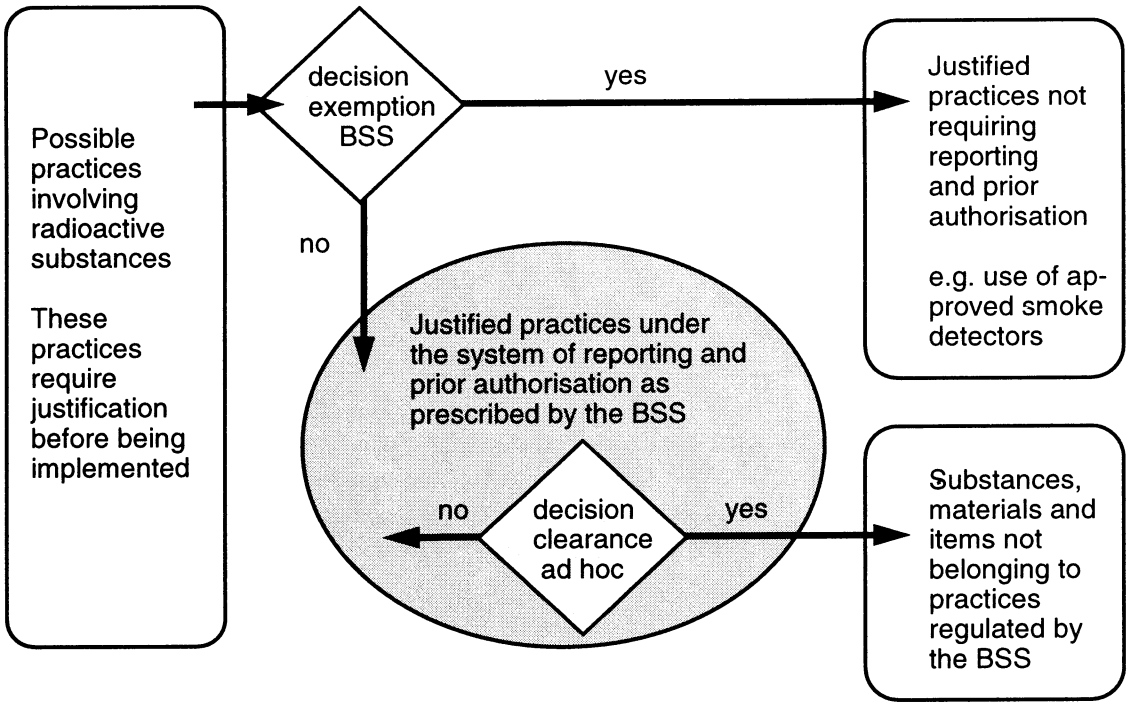

Figure 2-1: Schematic diagram illustrating the implementation of the European Union's Basic Safety Standards (BSS).

Once a practice is put within the regulatory system all the associated activities and material movements are regulated. Relinquishing regulatory control is a process which must be carried out within the system of reporting and prior authorization set out under the BSS. The release from regulatory control of materials for recycling, reuse and disposal is the responsibility of the competent national authorities and is generally carried out on an ad hoc case by case basis. The purpose of this recommendation is to propose radionuclide specific concentration limits for various metals below which the material could be released from regulatory control. The term clearance is used to describe the removal of control and clearance levels are the recommended nuclide specific limits below which authorities could authorize clearance. The scheme in figure 2-1 implies that substances, materials and items which are cleared do not re-enter the system of reporting and prior authorization. The BSS automatically exempts cleared substances from the requirements of reporting and authorization. However it is not in general possible to trace the origin of the material, which implies that criteria and decisions on clearance are not fully independent of the exemption criteria.

2.2 Radiological protection criteria

The IAEA recommendation, laid down in Safety Series 89 [21], refers to an individual dose[1] of "some tens of microsieverts per year" (μSv/y) as being trivial and therefore a basis for exemption. Furthermore, the IAEA suggests that in order to take account of exposures of individuals from more than one exempt practice, the exposure to

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[1] Individual dose is the individual whole body effective dose as defined by ICRP 60 [23].

the critical group from one such practice should be of the order of 10 μSv/y. For comparison 10 μSv/y corresponds roughly to around 0.5 % of the average natural background. In addition the IAEA recommends that for each practice a study of available options be made by the regulating authorities in order to optimise radiation protection. If the study "indicates that the collective dose commitment resulting from one year of the unregulated practice will be less than about 1 manSv . . . it may be concluded that the total detriment is low enough to permit exemption without a more detailed examination of other options." The general international consensus for the basic criteria for exemption is reflected by their inclusion in both the IAEA BSS and Euratom BSS.

In defining the radiation protection principles for clearance the Working Party adopted in 1984 the 10 μSv/y and 1 manSv per year of practice collective dose criteria. The work leading to the exemption values in the BSS [5] are also based on these criteria and in addition the skin dose was limited to 50 mSv/y. These criteria were used in the present work as well.

The International Commission on Radiological Protection's (ICRP) publication 60 [23] also devotes a paragraph to the concept of exemption from regulatory control. While referring to the advice issued by IAEA, ICRP points to the difficulty in establishing a basis for exemption on grounds of trivial dose, and to the underlying problem that exemption is a source-related practice while the triviality of dose is related to an individual (ICRP 60 par. 288).

Relating the dose received by individuals to a practice, and to the levels of radioactivity involved in a practice, is more difficult in the case of clearance than in the case of a fully regulated practice, since the clearance criteria must be defined for a largely hypothetical environment. This problem was dealt with by the Working Group in a practical manner for metals by constructing a set of exposure scenarios, which relates the activity content of the metals to an individual dose. The proposed clearance levels are derived radioactivity levels from the most critical scenario which lead to a derived dose of either 10 μSv/y or a skin dose of 50 mSv/y. The dose coefficients for intake were taken from the BSS, the skin dose coefficients were taken from [5] and the external dose rate was calculated using a point kernel integration.

2.3 Clearance of material

Clearance is carried out under the system of reporting and prior authorization, but once the material has been cleared no further control is possible. Placing conditions on the clearance of material, conditional clearance, means that the material is still under regulatory control until certain conditions are met. The application of conditions which apply after the act of clearing is not envisaged since no regulatory control can be exercised. The clearance criteria presented here are conditional only on the properties of the material itself, i.e. being metal suitable for either recycling or reuse. If the regulatory authorities decide to apply conditions to the destination of the material after release or require the traceability of the material it is recommended that the term "clearance" not be used in such cases.

An explicit example of the implications of the concept of conditional clearance is that if metal is treated as input for the production of new metal (scrap recycling), the possibility that it is used in an application not requiring smelting (direct reuse) must be ruled out. This condition could be fulfilled by requiring that all potentially reusable parts not be cleared, unless they are damaged beyond repair or the metal is directly delivered to a

smelting furnace. Inversely, material released for direct reuse could in reality go to a smelter. Hence, the surface clearance levels for direct reuse are either more restrictive than recycling or equal.

2.4 Recycling within the nuclear industry

Recycling or reusing metal within the nuclear industry will avoid exposure of the general public to this material. It has been shown that recycling within the nuclear industry reduces the collective dose as well as the number of individuals who receive doses [17,18,26]. Even if it has been demonstrated that clearance, consistent with the radiation protection criteria in 2.2, is possible, recycling within the nuclear industry might be preferable to clearance to the public domain, whenever it is economically sound to do so. This is consistent with the general principles outlined in the BSS [9]; "all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account" and ". . . the exposure of the whole population as a whole from practices is kept as low as reasonably achievable, economic and social factors being taken into account."

3. RECOMMENDED CLEARANCE POLICY

It was concluded from the studies underlying this report that criteria can be defined such that slightly radioactive metal scrap, components and equipment from nuclear fuel cycle installations can be authorized for clearance to the public domain whenever recycling within the nuclear industry is not appropriate. Recycling or reusing this material saves valuable natural resources and avoids unjustified allocation of resources for the controlled disposal of low activity waste.

The decision to apply the clearance criteria in 3.1 and 3.2 remains the responsibility of the competent authorities. The clearance criteria have been derived on the basis of the radiation protection principles defined in chapter 2 and as described in chapter 6. The calculated clearance levels have been rounded in the same way as the exemption levels [5]; if the calculated value lies between $3 \cdot 10^x$ and $3 \cdot 10^{x+1}$, then the rounded value is 10^{x+1}.

The radiological analysis has in general been based on the large amounts of metal coming from nuclear facilities, in particular nuclear power plants. A number of the radionuclides in the tables 3-1 and 3-2 are not present in any significant quantity in the typical radionuclide mixes coming from such facilities and hence the cleared quantities are over-estimated for such radionuclides. The authorities should be aware that these clearance levels may therefore be overly restrictive in particular for metal coming from small users of radioactivity like research laboratories. Hence, in practice the lower boundary to the mass specific clearance levels for recycling has been chosen to be equal 1 Bq/g. The radionuclides for which the clearance level has been raised to 1 Bq/g are marked with an asterisk in table 3-1. For the sake of completeness unrounded clearance levels for each type of metal are given in table 7-2, since the values in table 3-1 besides being rounded also make no distinction between different metal types.

As indicated in chapter 2.1 problems could occur if the clearance criteria would be such that the released metals would still require reporting upon receipt for further use or processing. In order to avoid legal and regulatory problems it is recommended that the

mass specific clearance level not exceed the corresponding exemption level in the BSS[2]. Under these circumstances the radionuclide concentration in cleared metal will be below the mass specific exemption level and therefore exempt from reporting. It should be noted however that certain nuclides concentrate during the melting process in the dusts and slags so that the activity concentration in these by-products may exceed the exemption levels. The radiological analysis has accounted for this phenomena in the scenarios so that the resulting doses would not exceed 10 μSv/y and the BSS automatically exempts such material, so that reporting and authorization in such cases would not be necessary.

3.1 Clearance criteria for metal scrap recycling

The nuclide specific clearance levels in table 3-1 are the lowest value from all the metals studied (compare table 7-2) and apply to metal scrap for which beyond any reasonable doubt its only use after clearance is as input for the production of new metal, i.e. recycling by melting is reasonably ensured. The recommended clearance levels are values below which regulatory control can be relinquished when applied as set out in paragraphs i through vi. The short-lived progeny are included with the parent nuclides (see table 6-1) and therefore require no extra limitation.

i The mass specific clearance levels apply to the total activity per unit mass of the metal being released and are intended as an average over moderate amounts of metal. The authorities should ensure that the averaging procedure is not used to intentionally clear metal above the clearance levels. In this context moderate is interpreted to mean masses of a few hundred kilograms.

ii The surface specific clearance levels apply to the total surface activity concentration, fixed plus non-fixed, and are intended as an average over moderate areas. In this context the authorities can authorize, depending on the type of material, contamination and homogeneity of the contamination, averaging areas of several hundred square centimetres up to 1 square meter. For non-accessible surfaces for which some degree of surface contamination can be reasonably expected, a conservative assessment of the surface activity for comparison with the clearance levels shall be made.

iii The mass specific and surface specific clearance criteria must both be met. Any exceptions to this should be investigated and authorized by the competent authorities.

iv 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:

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

where

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[2] None of the clearance levels in table 3-1 exceed the exemption levels but for the radionuclides ^{53}Mn, ^{55}Fe and ^{59}Ni the unrounded values (see table 7-2) are higher than the corresponding exemption levels.

c_i is the specific activity of radionuclide *i* in the material being considered (Bq/g and Bq/cm^2),

c_{Li} is the specific clearance level of radionuclide *i* in the material (Bq/g and Bq/cm^2),

n is the number of radionuclides in the mixture.

In the above expression, the ratio of the concentration of each radionuclide to the clearance level is summed over all radionuclides in the mixture. If this sum is less than one the material complies with the clearance requirements.

v The recommended clearance levels are not intended for composite materials like electrical cables. Such materials must be separated into their metal and non-metal fractions before the clearance criteria can be applied to the metal fraction. Any exceptions to this should be investigated and authorized by the competent authorities.

vi The recommended clearance levels do not apply to metal items or ingots from scrap which was melted before clearance.

Table 3-1: Nuclide specific clearance levels for metal scrap recycling

Nuclide	Mass specific (Bq/g)	Surface specific (Bq/cm^2)
H 3	1000	100000
C 14	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	10000	100000
Mn 54	1	10
Fe 55	10000	10000
Co 56	1	10
Co 57	10	100
Co 58	1	10
Co 60	1	10
Ni 59	10000	10000
Ni 63	10000	10000
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	10000
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*	10
Cs 135	10	1000
Cs 137	1	100
Ce 139	10	100
Ce 144	10	10
Pm 147	10000	1000
Sm 151	10000	1000
Eu 152	1	10
Eu 154	1	10
Eu 155	10	1000
Gd 153	10	100
Tb 160	1	10
Tm 170	100	1000
Tm 171	1000	10000
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	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	10	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

* Raised to 1 Bq/g (see table 7-2)

3.2 Clearance criteria for direct reuse

The nuclide specific clearance levels in table 3-2 apply to metal components, equipment or tools for which a post-clearance use in the same or modified form is foreseen, i.e. direct reuse. The recommended clearance levels are maximum allowable activities below which regulatory control can be relinquished when applied as set out in paragraphs i through iii. The values in table 3-2 are the lower of the recycling and reuse clearance levels (compare table 7-1) and are valid for all metals. The short-lived progeny are included with the parent nuclides (see table 6-1) and therefore require no extra limitation.

i The surface specific clearance levels apply to the total surface activity concentration, fixed plus non-fixed, and are intended as an average over moderate areas. In this context moderate is interpreted to mean areas of several hundred square centimetres. For non-accessible surfaces for which some degree of surface contamination can be reasonably expected, a conservative assessment of the surface activity for comparison with the clearance levels shall be made.

ii Mass specific clearance levels for direct reuse were not derived. In general the equipment will only be surface contaminated. The sole application of surface activity clearance levels is appropriate if for α- and β-emitters activity hidden under surface layers (for example under paint or rust) is included as surface activity and if for γ-emitters all counts are attributed to surface activity even if in reality they are emitted from deeper layers.

iii 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:

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

where

c_i is the specific activity of radionuclide i in the material being considered (Bq/cm^2),

c_{Li} is the specific clearance level of radionuclide i in the material (Bq/cm^2),

n is the number of radionuclides in the mixture.

In the above expression, the ratio of the concentration of each radionuclide to the clearance level is summed over all radionuclides in the mixture. If this sum is less than one the material complies with the clearance requirements.

Table 3-2: Nuclide specific clearance levels for direct reuse of metal items

Nuclides	Surface specific (Bq/cm^2)
H 3	10000
C 14	1000
Na 22	1
S 35	1000
Cl 36	100
K 40	10
Ca 45	100
Sc 46	10
Mn 53	10000
Mn 54	10
Fe 55	1000
Co 56	1
Co 57	10
Co 58	10
Co 60	1
Ni 59	10000
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
Eu 155	100
Gd 153	10
Tb 160	10
Tm 170	1000
Tm 171	10000
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
Es 254	1

4. VERIFICATION OF CLEARANCE LEVELS

From a regulatory viewpoint, it is necessary to be able to verify compliance with the clearance levels. This 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 authority. It is noted that the goal of keeping individual doses in the range of 10 μSv/y implies that dose rates have to be detected which are a small fraction of natural background and so it is necessary to operate at the lower bounds of detectability. Many studies fully or partially dedicated to measurement methods, devices and techniques as required to verify clearance levels have been published [2, 19, 20, 25, 38]. It can be concluded from the reports that the clearance levels for the most frequently occurring radionuclides typical for metal from the nuclear fuel cycle can be directly measured. Many radionuclides which are difficult to measure directly can be related to other radionuclides. For example ^{55}Fe and ^{63}Ni can often be correlated to ^{60}Co, and ^{90}Sr to ^{137}Cs, both of which are easy to measure. When using scaling factors to verify levels of radionuclides which can not directly be measured on the material, it is necessary to have a well founded base for the scaling factor and use the factor only on the metal components for which the scaling factor has been established. Depending on the radionuclides present it may be necessary to supplement direct measurement on the material with laboratory analysis of suitably selected samples.

Administrative measures can be used to justify that certain radionuclides need not be assessed in the analysis. For example, if it is known that a certain type or group of radionuclides is not present in the metal to be cleared, most competent authorities would accept that those radionuclides need not be investigated. In doing so the authorities will take into account the relative contribution of such nuclides to the weighted sum. While this sum should be less than or equal to unity, some flexibility is warranted in applying this rule, in the same way as the nuclide specific clearance levels have been rounded upwards or downwards by a factor 3. It may therefore be appropriate to verify compliance with the criteria on the basis of just one nuclide, the reference value being set equal to the clearance level for that nuclide. In this respect, the isotopes of caesium (^{134}Cs and ^{137}Cs) are of particular interest, since the clearance level for ^{134}Cs was raised to 1 Bq/g and the rounded value for ^{137}Cs is 1 Bq/g (mass specific clearance levels for recycling). Distinguishing between these isotopes would be justified only if metals are released soon after reactor shut-down, in view of the relatively short half-life of ^{134}Cs, and in such large quantities as assumed in the limiting scenario (dust disposal). In many cases it will be appropriate to disregard ^{134}Cs. In the same way it was considered unduly restrictive to require compliance with clearance levels below 1 Bq/g for some other radionuclides including ^{239}Pu. In particular for the α-emitting radionuclides the restrictive surface contamination clearance levels will lead to mass specific activities averaged over the total scrap to be cleared which will be significantly less than the 1 Bq/g value. Furthermore it should be noted that in general the large quantities of metal coming from nuclear fuel cycle facilities will contain a mix of radionuclides. Therefore it can be expected that for all practicable purposes the total activity limit calculated using the summation formula would never be smaller than 1 Bq/g. Finally for these radionuclides the theoretical doses of a few 10 μSv/y resulting from the scenarios and corresponding to a clearance level of 1 Bq/g were regarded to be within the range considered to be negligible.

Decommissioning projects in EU member states have successfully implemented clearance levels similar to those presented in tables 3-1 and 3-2 showing that their

implementation and verification by the national authorities is possible. Some examples include the nuclear power plants at Gundremmingen [38] and Niederaichbach [2], the enrichment installation at Capenhurst [3] and the Eurochemic reprocessing plant in Dessel [39].

5. REGULATORY ASPECTS

The structure of the BSS implies that clearance must be placed within the system of reporting and prior authorization since clearance endeavours to remove regulatory controls from material belonging to a regulated practice (see figure 2-1). Therefore it can be expected that the national authorities will authorize or license clearance either on a case by case basis or within national legislation. In either situation the process of clearance remains under the control of the authorities and therefore it is expected that they will carry out audits to ensure compliance with the clearance criteria. A means should also be established to verify that the operator continues to comply with the authorized clearance criteria, normally by a national programme of inspection and the requirement to maintain records. Once the act of clearance has been completed the metal is no longer under control and therefore no post-release restrictions can be applied.

Although dilution in the environment is recognised as an important factor in reducing doses to members of the public, competent authorities should ensure that dilution is not used to clear relatively high specific activity materials by deliberately diluting them in order to meet clearance levels. Records should be kept of the dismantling operations in order to demonstrate that such materials are kept separate. Clearance should be carried out as the metal arises.

The competent authorities may decide to impose further criteria, such as yearly total activity or mass release limits for a particular license holder. Authorities may even decide as a matter of principle to keep all material under control and require, for example, that contractual arrangements with the metal producing industry be made. Although such additional provisions are out of the scope of this recommendation, it would be possible for instance in this way for the competent authorities to guarantee that the accumulation of radioactivity in slags and dusts is controlled (see chapter 3).

6. DERIVATION OF THE CLEARANCE LEVELS

The radiological criteria guiding clearance are expressed in terms of dose which are impractical for making clearance decisions. Therefore the dose criteria are converted into mass specific and surface specific activity limits below which clearance leads to trivial doses. Within the recycling and reuse context 10 μSv/y is considered trivial (see chapter 2). The derivation of clearance levels requires a thorough examination of the reasonably possible routes by which humans can be exposed to cleared material. The European Commission contracted four studies which form the technical and scientific basis for the recommended clearance levels [6, 7]. In these studies the routes through which the metal passes were analysed and scenarios proposed which represent the critical exposures to workers and the general public from this material. In this chapter a brief overview is given and the critical exposures discussed.

6.1 Radioactivity content

Radioactivity in nuclear fuel cycle installations originates from the nuclear fuel, including fission products and neutron capture products (^{90}Sr, ^{137}Cs, ^{235}U, ^{238}U, ^{239}Pu, etc.) and from radionuclides created by neutron flux, activation products (^{55}Fe, ^{60}Co, ^{63}Ni, etc.). A differentiation is made between radioactivity that is transported for example by air or water to an item, contamination, and radioactivity within an item created by neutron flux, activation. Activation products are created in power reactors and are transported throughout the reactor as contamination. Fission products are also found in the contamination spectra of most nuclear fuel cycle facilities.

Table 6-1: List of radionuclides with short-lived progeny assumed to be in equilibrium

Parent	Progeny included in secular equilibrium
Sr 90	Y 90
Zr 95	Nb 95, Nb 95m
Ru 106	Rh 106
Pd 103	Rh 103m
Ag 108m	Ag 108
Ag 110m	Ag 110
Cd 109	Ag 109m
Sn 113	In 113m
Sb 125	Te 125m
Te 127m	Te 127
Cs 137	Ba 137m
Ce 144	Pr 144, Pr 144m
Pb 210	Bi 210
Ra 226	Rn 222, Po 218, Pb 214, Bi 214, Po 214
Ra 228	Ac 228
Th 228	Ra 224, Rn 220, Po 216, Pb 212, Bi 212, Tl 208, Po 212
Th 229	Ra 225, Ac 225, Fr 221, At 217, Bi 213, Tl 209, Po 213, Pb 209
U 235	Th 231
U 238	Th 234, Pa 234m, Pa 234
Np 237	Pa 233
Pu 244	U 240, Np 240m, Np 240
Am 242m	Np 238, Am 242
Am 243	Np 239
Cm 247	Pu 243
Es 254	Bk 250

It is not possible to give a standard radionuclide spectrum for each type of nuclear fuel cycle facility. The spectra depend on the type of fuel, if fuel was reprocessed, core geometry, building material, etc. A significant amount of literature exists which investigates spectra and how they change over time [37,11,17,26]. Such data is important for deciding on decommissioning strategies, but is less important within the context of nuclide specific clearance levels. The list of radionuclides investigated here (see tables 3-1 and 3-2) is composed of all the radionuclides with half-lives longer than 60 days for which exemption levels in the BSS exist, with the exception of the noble gases. Some of these nuclides have short lived progeny making it necessary to consider the progeny in secular equilibrium with the parent. Table 6-1 lists the nuclides for which the progeny are included with the parent nuclide.

6.2 Quantity of clearable metal scrap, components and equipment

Clearable scrap metal from nuclear fuel cycle installations consists primarily of ferrous metals like steel, aluminium, aluminium alloys, copper and copper alloys like brass. The estimated quantity of clearable metal from EU facilities is given in table 6-2. Lead is also used in nuclear installations, typically for shielding purposes. It is generally reused within the nuclear industry, although lead is cleared from nuclear installations [17]. A number of special alloys with base metals other than iron, copper or aluminium, such as nickel, zirconium or cobalt, are also used in the nuclear industry. These alloys are typically used in critical areas of reactors so that they are highly radioactive and therefore are not suitable for clearance.

Table 6-2: Quantities of metal used to make the radiological assessment for the EU

Clearable material	Quantity Mg/y
Steel and stainless steel	10,000
Copper and copper alloys	200
Aluminium and aluminium alloys*	1,500 (40)
Direct reuse (all metals)	1,000

* 40 Mg/y is for power plants and 1,500 Mg/y for enrichment facilities

Table 6-3: Metal inventory of a pressurised water reactor (PWR) [22].

Metal	Inventory of metal used for a 1971 vintage 1000 MWe PWR	Metallic radwaste from the decommissioning of a 1175 MWe PWR	
	1000 tonnes	1000 tonnes	
		Contaminated	Activated
Steel	33	3.9	0.4
Stainless Steel	2.1	--	0.4
Galvanised iron	1.3	--	--
Copper	0.7	--	--
Inconel	0.1	--	--
Lead	0.05	--	--
Bronze	0.03	--	--
Aluminium	0.02	--	--
Brass	0.01	--	--
Nickel	0.001	--	--
total	37	3.9	0.8

The quantity of metal used in a commercial power reactor is greater than in other facilities of the nuclear fuel cycle, with the exception of a large enrichment plant, but the number of commercial reactors vastly outnumbers all other nuclear fuel cycle facilities together, so that more than 90% of the potentially clearable metal scrap, components and equipment is expected to originate from power reactors. The quantity of metal used to build a 1000 MWe pressurised water reactor is given in table 6-3 not all of which is found in the controlled areas. Clearable scrap metal arises during normal operation (10 - 50 Mg/y) and during revision or backfitting of nuclear installations, an example is given in table 6-4, although the majority is generated when the installation reaches the end of its useful life and is dismantled. Roughly 8,000 to 13,000 tonnes of metal are used in the

controlled area of a commercial reactor of which during dismantling roughly 50% to 70% is potentially clearable. The exact quantity of potentially clearable scrap arising at any point in time is dependent on many factors including: decommissioning strategies, availability of a repository and its costs, decontamination techniques and their costs, scrap market, projects in progress, national energy needs as well as the clearance levels for scrap metal. An estimate for cleared steel scrap arising from the decommissioning of commercial power reactors in the EU is given in figure 6-1, and shows that up to about the year 2010 roughly 10,000 Mg/y can be expected.

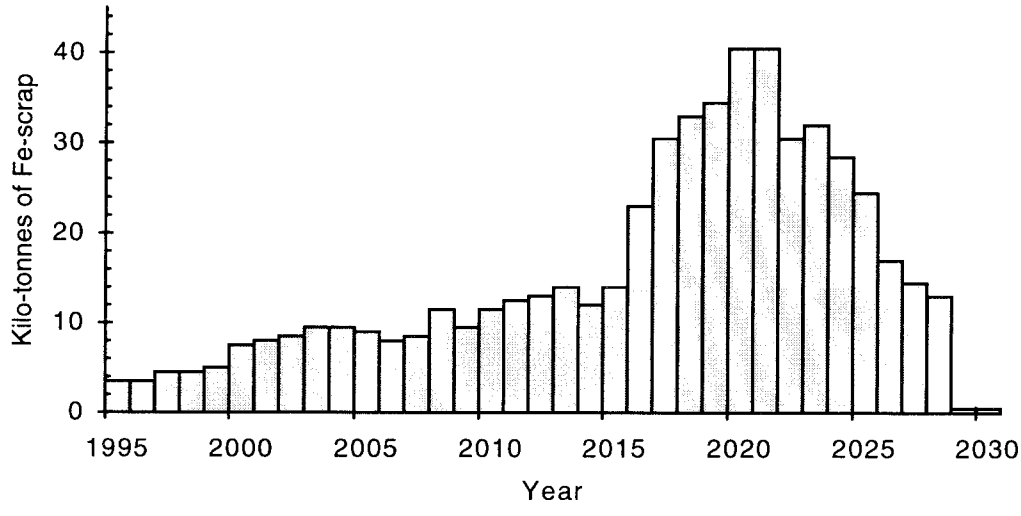

Figure 6-1: Projected amount of clearable steel scrap from decommissioning commercial power reactors in the EU under the assumption that no new reactors are built [28].

Table 6-4: Clearable metal scrap from the revision of the Würgassen boiling water reactor in Germany [31].

Dismantled equipment	Approximate quantity Mg	Metal type
Steam pipes including support structure	350	steel
Feed water pipes	100	steel
Turbine parts	100	steel
Condenser pipes	350	brass
Sheet metal	50	aluminium and steel

The amount of metal scrap expected from the decommissioning of other facilities from the nuclear fuel cycle is not as well known as for nuclear power plants. Nevertheless examples exist. One of the largest decommissioning projects in the EU was the gaseous diffusion plant at Capenhurst UK. It has been successfully dismantled resulting in approximately 40,000 Mg of cleared scrap metals of which 22,000 Mg were structural steel, 11,000 Mg were aluminium components, 3,500 Mg of electrical motors and the rest was made up of steel, stainless steel and brass components [3]. An estimate for the quantity of aluminium with a low activity level from the first French uranium isotope enrichment plant at Pierrelatte lies around 6,000 Mg [15]. Other facilities are considerably smaller, like fuel fabrication plants or reprocessing facilities resulting in significantly smaller amounts of clearable metal scrap, on the order of 1% to 10% of enrichment facilities. For example the decommissioning plans for the pilot reprocessing plant in Karlsruhe (WAK) estimates 800 Mg of metallic components of which around 250 to

300 Mg is projected to be clearable [26]. Metal scrap arises not only during decommissioning but also during normal operation. For example the fuel fabrication plant at Hanau in Germany with a capacity of 1000 Mg/y uranium produces about 50 Mg/y of potentially clearable steel scrap of which about 15% is stainless steel [26].

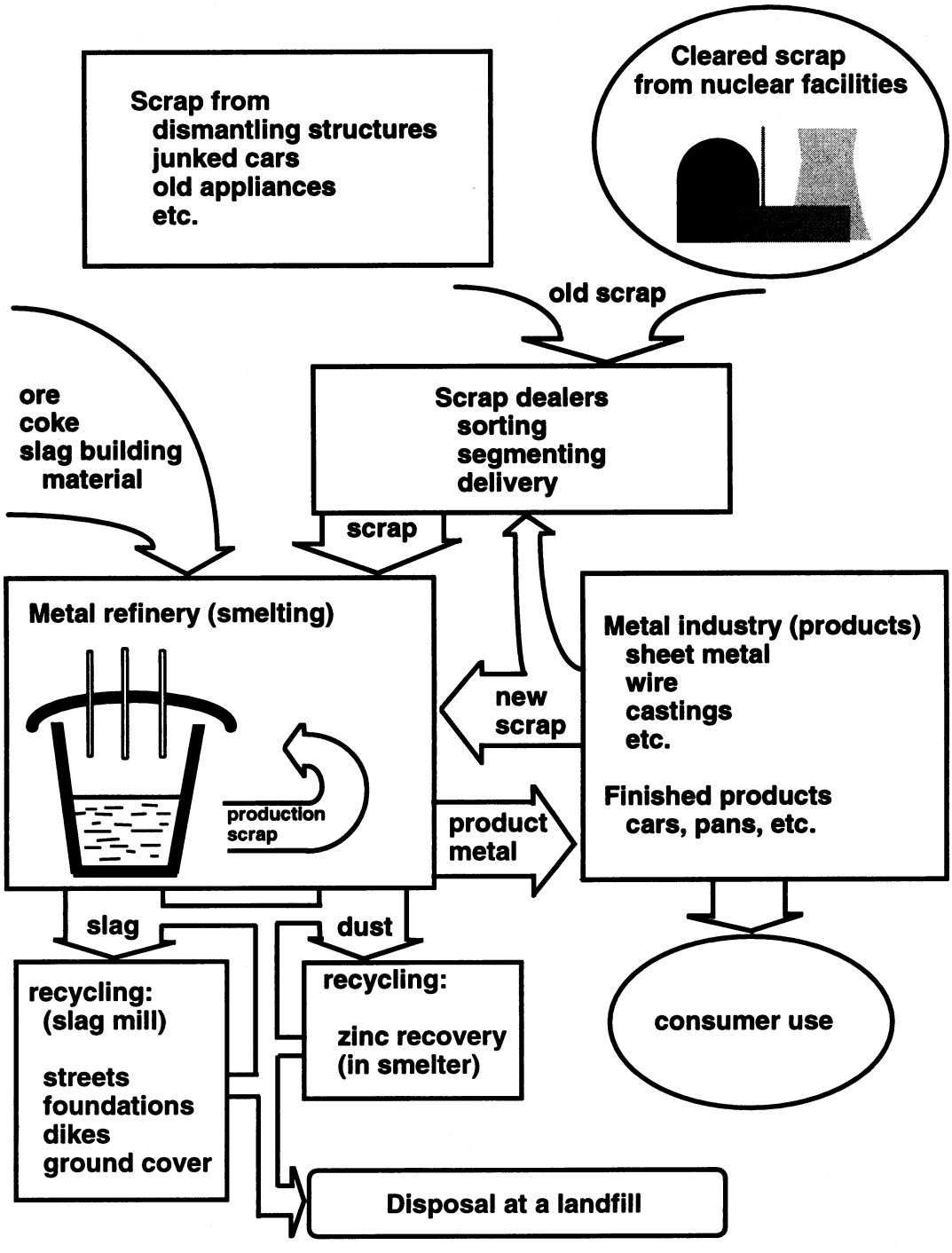

Figure 6-2: Schematic diagram of scrap metal recycling.

6.3 Ferrous scrap

Ferrous metals make up the largest fraction of metal scrap coming from nuclear installations (see table 6-2). In figure 6-2 a simplified schematic diagram shows the

production steps through which the scrap is expected to follow. The radiological assessment explicitly considers both carbon steel and stainless steel.

6.3.1 Ferrous scrap in the steel industry

Steel is world wide the number 1 raw material. With a production of 770 million tonnes it outstrips aluminium with 18 million tonnes and plastics with 98 million tonnes [33]. In 1992 western Europe produced approximately 140 million tonnes of iron and steel of which 64 million tonnes came from ferrous scrap [14]. Of this scrap roughly 33% was production scrap, 23% new scrap and 44% old scrap. The percent of old scrap used in steel production will continue to increase, as figure 6-3 demonstrates, since the average life expectancy for steel products is roughly 20 years and the explosive growth in the steel industry during 1950 to 1980 has levelled off and is not expected to show any growth in the industrialised nations. Scrap metal is actively traded world wide as a valuable resource, which is shown in figure 6-4. In December 1993 type 1 steel scrap was traded at around 90 - 100 ECU per tonne [32].

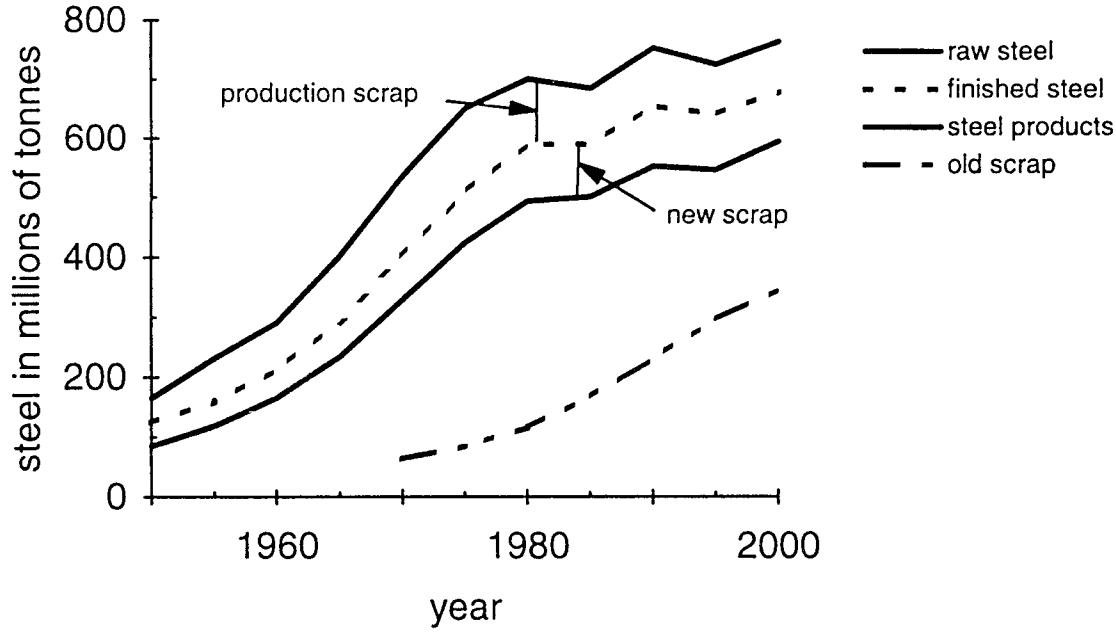

Figure 6-3: World steel and scrap production [40]. The difference between raw steel and finished steel is the production scrap and the difference between finished steel and steel products is new scrap. About 70% of the steel products are recycled (old scrap) after an average life expectancy of 20 years.

The availability of scrap and the energy savings (approximately 60%) from producing steel from scrap is changing the steel production strategy. More and more steel is being produced in mini-mills (a production capacity of less then 10^6 Mg/y) using electric arc furnaces which are capable of producing steel from 100% scrap. The Thomas and Siemens-Martin processes have been replaced by the more economic oxygen blast processes, although the trend is towards electro-steel. In the EU countries an increase from 23% of the steel production to 35% in electric arc furnaces before the turn of the century is expected [40]. The quality of electro-steel is hard to control due to the unknown scrap quality. At present technological as well as administrative procedures are being developed which will allow better control of the quality of electro-steel.

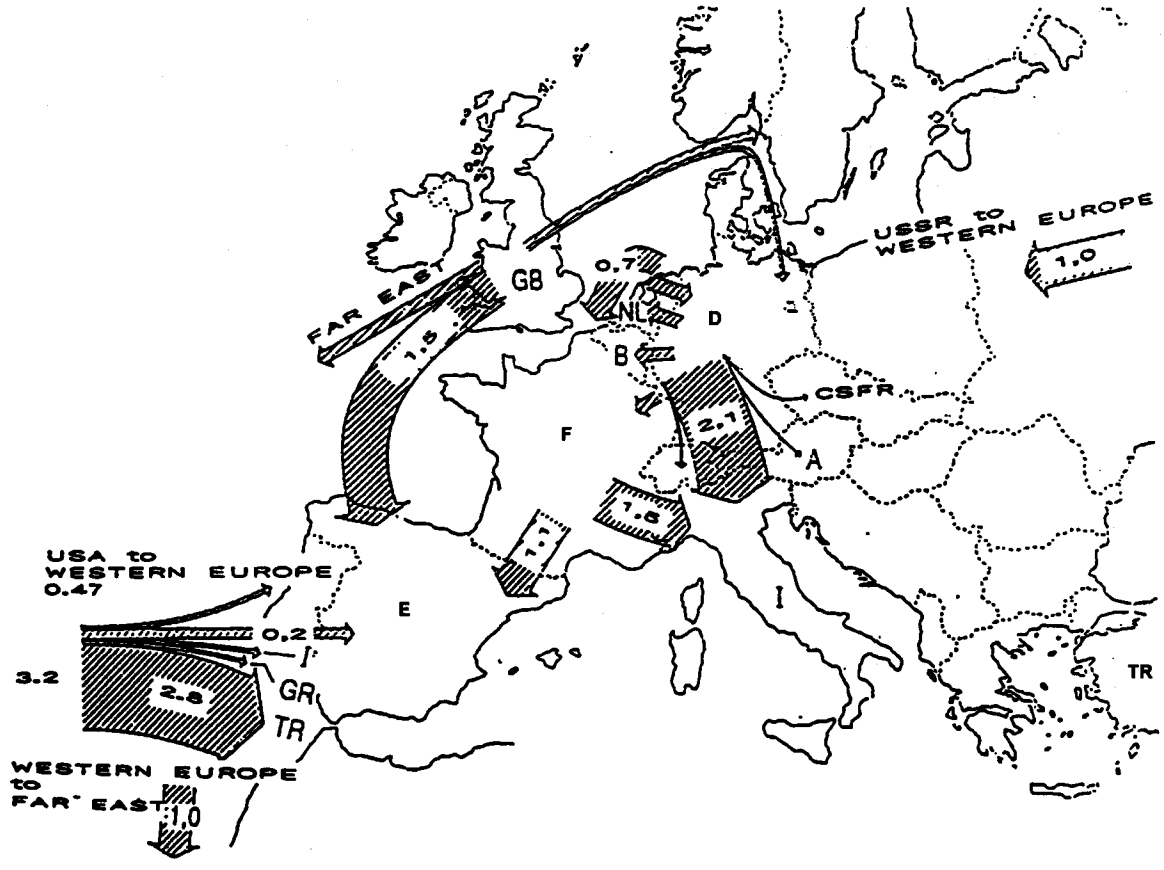

Figure 6-4: Scrap import and export to, from and within Europe in 1990 in millions of tonnes [27].

The typical scrap fraction used in oxygen furnaces is around 300 kg per tonne of steel produced. Due to the scrap market development this is expected to change and there are already reports from Japan that an oxygen-steel process has been developed and implemented which uses 100% scrap [14]. In both oxygen-steel as well as electro-steel a number of different scrap types are used in each melt to control the quality of the final product.

Table 6-5: Main consumers of steel in the EU. The values are averages for the years 1986-88 [13].

Steel consumers	in percent
Buildings, civil engineering and construction	28%
Transport, including: ship construction and automobile industry	20%
Metallic work	14%
Machine construction	13%
Electrical equipment	4% to 5%
Boiler construction	4% to 5%
Metal packaging	4% to 5%
Miscellaneous, e.g. mines, railway, steel industry, etc.	11.5%

Finished steel and iron is used to produce products in rolling mills, foundries or the like. Foundries also use well characterised scrap, about 19 million tonnes per year in western Europe, to directly manufacture products. Steel is used in all areas of civilisation, as the main consumers of steel in table 6-5 shows. Besides steel two main by-products,

slag and dust, arise during the production of steel. A rough estimate of the expected quantities as a function of the furnace type is shown in table 6-6. The slag from steel mills and foundries has always been a valuable building material. In table 6-7 the consumption of steel mill slag in Germany is given.

Table 6-6: By-product production from various furnaces [29].

Type of furnace	kg dust/tonne of steel	kg slag/tonne of steel
Electric arc furnace	15	140
Induction furnace	1.5	20
Oxygen blast furnace	15	90

Dust retention and reduction systems have been implemented in the EU as the controls on the worker environment have become progressively stricter. The 0.55 million tonnes of dust from electro-steel production in western Europe is typically disposed of at industrial landfills. As more restrictions on the disposal of wastes are passed and enforced in the EU the options for disposal of dust are becoming more and more expensive and therefore dust recycling is becoming more attractive. At present, only the recycling of the zinc oxide component of the dust (up to 30%) is practiced on an industrial scale at four plants in the EU (Lille, Duisburg, Freiberg and Bilbao) with a total dust capacity of 0.26 million tonnes annually [36].

Table 6-7: Consumption of steel mill slag in Germany (4.57 million tonnes per year) [16].

Slag consumers	in percent
Recycle within the steel mill	19.9%
Fertiliser	9.0%
Ground cover	19.2%
Dike construction	8.3%
Road construction	4.4%
Fill material	24.3%
Landfill	9.8%
Miscellaneous	5.1%

6.3.2 Radiological consequence of recycling radioactive ferrous scrap

After the scrap is cleared from regulatory control it is typically sold to a scrap dealer who processes, sorts and sells it. Before the scrap is melted the surface activity can be re-suspended and inhaled or transferred to the worker leading to an incorporation of the activity or an external contamination of the skin. Working near the scrap will lead to external irradiation from gamma emissions. The possible doses from processing scrap have been investigated. The derived individual doses from the most restrictive scenario for a mass specific activity of 1 Bq/g as well as a surface contamination of 1 Bq/cm^2 are presented in table 6-8 for a selected set of radionuclides. The doses from all the various scenarios and for all the nuclides can be found in the technical documentation, along with a detailed description of the scenarios and parameters [6, 7].

Table 6-8: Derived maximum individual dose and most restrictive scenario for ferrous metal recycling

Nuclide	Maximum dose (µSv/y) / (Bq/g)	Steel recycling scenarios	Maximum dose (µSv/y) / (Bq/cm^2)	Scrap processing scenarios
H 3	7.30E-03	Steel plant (Atmos)	2.69E-04	Inhalation (torch)
C 14	1.31E-01	Steel plant IF (ING)	8.67E-03	Inhalation (torch)
Mn 54	6.12E+00	Boat AF (EXT)	3.80E-01	External (scrap)
Fe 55	3.73E-04	Steel plant IF (ING)	2.75E-03	Inhalation (torch)
Co 60	1.74E+01	Boat AF (EXT)	1.10E+00	External (scrap)
Ni 59	2.60E-05	Boat AF (EXT)	6.57E-04	Inhalation (torch)
Ni 63	3.39E-05	Steel plant IF (ING)	1.55E-03	Inhalation (torch)
Zn 65	1.88E+01	Dust L. AF W (EXT)	2.50E-01	External (scrap)
Sr 90	6.94E-01	Steel plant IF (ING)	1.18E+00	Inhalation (torch)
Nb 94	2.48E+01	Slag L. IF W (EXT)	7.20E-01	External (scrap)
Tc 99	2.57E-01	Slag L. IF Child	9.56E-03	Inhalation (torch)
Ru 106	6.94E+00	Dust L. AF W (EXT)	5.23E-01	Inhalation (torch)
Ag 108m	1.22E+01	Boat AF (EXT)	7.60E-01	External (scrap)
Ag 110m	1.98E+01	Boat AF (EXT)	1.20E+00	External (scrap)
Sb 125	3.11E+00	Boat AF (EXT)	2.10E-01	External (scrap)
Cs 134	4.83E+01	Dust L. AF W (EXT)	7.20E-01	External (scrap)
Cs 137	1.74E+01	Dust L. AF W (EXT)	2.60E-01	External (scrap)
Pm 147	1.68E-03	Player IF (INH)	1.05E-02	Inhalation (torch)
Sm 151	1.35E-03	Player IF (INH)	7.77E-03	Inhalation (torch)
Eu 152	2.17E+01	Slag L. IF W (EXT)	5.10E-01	External (scrap)
Eu 154	1.92E+01	Slag L. IF W (EXT)	5.50E-01	External (scrap)
U 234	3.16E+00	Player IF (INH)	2.03E+01	Inhalation (torch)
U 235	2.86E+00	Player IF (INH)	1.82E+01	Inhalation (torch)
U 238	2.70E+00	Player IF (INH)	1.71E+01	Inhalation (torch)
Np 237	1.68E+01	Player IF (INH)	4.48E+01	Inhalation (torch)
Pu 238	3.70E+01	Player IF (INH)	8.97E+01	Inhalation (torch)
Pu 239	4.04E+01	Player IF (INH)	9.56E+01	Inhalation (torch)
Pu 240	4.04E+01	Player IF (INH)	9.56E+01	Inhalation (torch)
Pu 241	7.74E-01	Player IF (INH)	1.73E+00	Inhalation (torch)
Am 241	3.23E+01	Player IF (INH)	8.07E+01	Inhalation (torch)
Cm 244	1.92E+01	Player IF (INH)	5.08E+01	Inhalation (torch)

IF = Induction furnace, AF = Arc furnace, L = Landfill, W = Worker

In assessing the radiological consequences of recycling scrap metal from nuclear installations one of the most critical factors is the quantity of scrap with nuclear origin, for steel 10,000 Mg (see table 6-2). The assessment assumes that 4000 Mg of carbon steel are recycled in a plant using electric arc furnaces and 2000 Mg of stainless steel in a plant using induction furnaces. Besides the quantity processed in a single plant the fraction of nuclear origin scrap in a single melt is important. For oxygen steel a maximum scrap fraction of about 0.33 is possible with present technology. Since the quality of the steel depends on the scrap it is very probable that only a part of the scrap fraction will originate from a nuclear source, therefore in the radiological assessment the fraction of nuclear scrap in steel is assumed to be 0.1. Special alloys are produced in induction or electric arc furnaces. This can lead to a higher fraction of metal from a single source since foundries typically have small furnaces (around 0.5 to 7 tonnes for induction furnaces and 10 to 100 tonnes for electric arc furnaces) compared to steel mills (10 to 125 tonnes for electric arc

furnaces and 100 to 300 tonnes for oxygen blast furnaces) [30]. Not only this, but also a better characterisation of the steel alloys requires less mixing to achieve the desired quality. In the steel study a nuclear fraction of 0.2 for stainless steel is assumed.

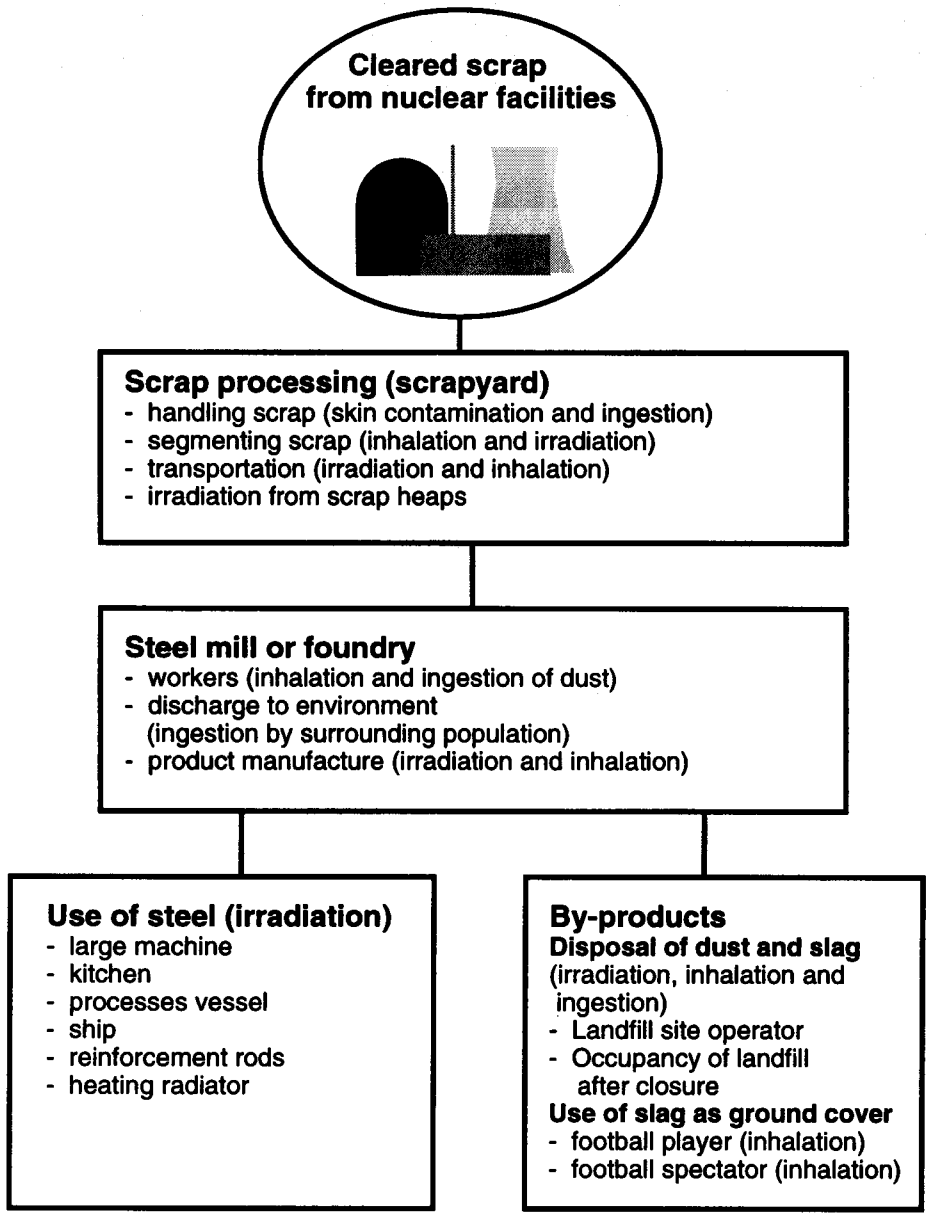

Figure 6-5: Schematic diagram of the flow of radioactivity and the exposure scenarios for ferrous metal scrap cleared from nuclear facilities.

After melting, the radioactivity is assumed to be homogeneously distributed throughout the product materials and the doses are calculated using the activity concentration in the substance. To calculate the concentration in the steel or the by-products another critical factor, the distribution of the radioactive isotopes, is needed. For example the cobalt, iron and nickel isotopes tend to be found in the steel after melting, while the uranium and plutonium isotopes are found in the slag and zinc and caesium in the dust fraction. The nuclide separation during melting has been taken into account. For a small number of the radionuclides considered here, in particular ^{65}Zn, ^{134}Cs and ^{137}Cs doses can occur if the dust is recycled. Evaluations have shown that the derived doses from recycling dust are smaller than from disposal at a landfill and therefore the landfill scenarios can be considered as enveloping scenarios for dust recycling.

The diagram in figure 6-5 demonstrates the basic flow of the radioactivity from release to the area of potential exposure. Since it is not possible to calculate every possible scenario, a set of scenarios was chosen (see figure 6-5) which represent a whole group of possible scenarios. For example the use of the kitchen sink represents any number of household appliances and utensils. The parameters for the scenarios were chosen realistically but on the conservative side. This means that higher doses are possible but unlikely.

6.4 Copper based metals

Copper scrap is significantly more valuable than steel scrap, which along with energy savings of between 80 and 92% compared to refining primary copper, leads to a recycling rate of roughly 80%. In nuclear installations copper metal comes primarily from electrical components like motors [15,18], although some power plants use brass in the heat exchangers which after decontamination may be clearable.

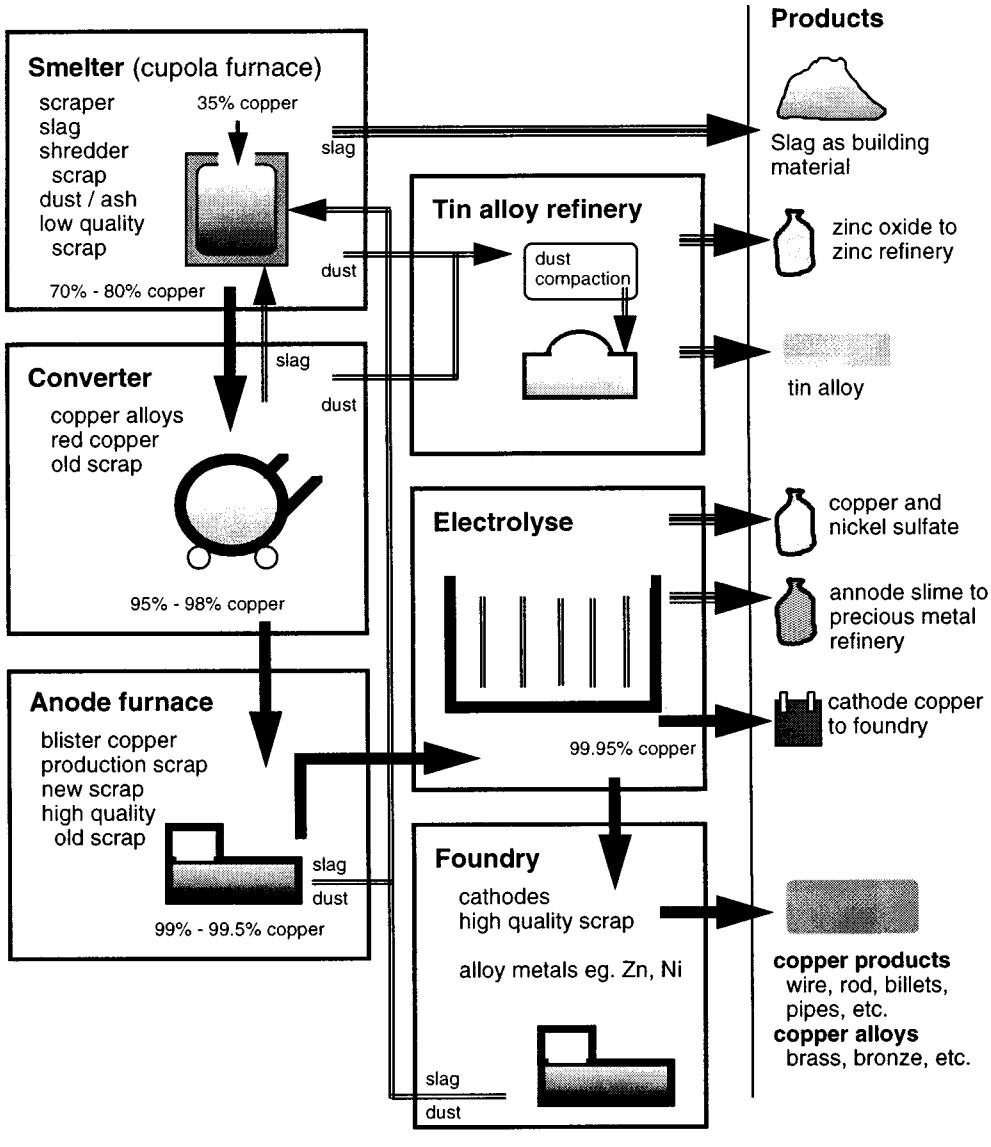

Figure 6-6: Schematic diagram of secondary copper production [12].

6.4.1 Recycling copper scrap

Refining copper scrap is significantly more complicated than recycling steel. The classic recycling process for copper scrap is shown in figure 6-6 and produces, after the electrolyses, a copper quality indistinguishable from grade A primary copper. Around 40% of the refined copper produced in the EU comes from old scrap. In table 6-9 the quantity of scrap used in copper refineries versus the quantity formed directly into products in foundries for the EU is shown. New and production scrap is ideally suited for direct use in foundries. It is not possible to use mixed scrap or unknown alloys in foundries so that such scrap is always passed through a refining works, the number of steps it passes through depends on the desired purity. It is possible, however to melt old copper and copper alloy components directly in foundries, given that the metal is well characterised.

Table 6-9: Copper scrap consumption in the EU [10].

Scrap consumption	1978	1980	1982	1984	1986	1988
in refineries (1000 Mg)	332.0	397.7	375.7	374.4	468.8	549.8
in foundries (1000 Mg)	604.7	718.6	605.3	649.4	698.1	891.7

During the refining of copper most of the accompanying metals are removed. In the first two steps (see figure 6-6) volatile metal oxides like tin, zinc and lead are separated out into the dust and ash fractions while less precious metals like iron, aluminium and cobalt are bound into the slag. These by-products are recycled within the refinery or sold as raw material, for example the slag as building material and the dust to tin alloy and zinc refineries. During the further processing, especially the electrolysis step, the precious metals are removed from the copper. From the production of 1 tonne of copper about 1 to 2 kg of silver can be recovered. Other metals of interest include, gold, selenium, tellurium, arsenic, antimony, nickel and bismuth. Most of the precious metals are in the copper ores and enter the process via black and red primary copper so that the content varies drastically depending on where the ore was mined. The purification and separation processes lead to a 1000 fold and more increase in the concentration of certain metals.

Table 6-10: Copper consumers in the EU (1993) [1].

Copper consumers	in percent
Electrical products	60%
Civil engineering (including buildings, e.g. copper façade)	14%
Mechanical engineering, machine construction and optics	10%
Transport	10%
Metal products	4%
Miscellaneous	2%

The consumption of the product copper and copper alloys from refined copper, roughly 2.5 million tonnes (copper) in the EU, is broken down by consumer in table 6-10. The EU is a net importer of copper and produces only about 50% of its refined copper need [15]. Because of its excellent electrical conductivity the major user of copper is the electrical industry. The use of copper and copper alloys in modern architecture is very visible, for example building façades. The corrosion resistance of copper alloys makes them ideal for plumbing and ship building (e.g. propellers). Copper also has a long historical tradition in art (sculpture) and music (instruments).

6.4.2 Radiological consequences of recycling radioactive copper scrap

Surface contamination limits for metal scrap are largely independent of the metal type since the transport and handling are similar regardless of the metal. Comparing copper to steel scrap the expected clearable quantity is significantly less and therefore can be processed in less time, leading to shorter exposure times and smaller doses. Since the radiological analysis for surface contamination is valid for all metals, the same surface specific clearance levels as steel are used for copper. For bulk activity the doses depend on the metal type so that these scenarios have been calculated for each metal type.

Table 6-11: Derived maximum individual dose and most restrictive scenario for copper and copper alloy recycling.

Nuclide	Maximum dose (µSv/y) / (Bq/g)	Copper recycling scenarios
H 3	1.17E-04	Refining (INH)
C 14	3.76E-03	Refining (INH)
Mn 54	2.49E+00	Transport Scrap (EXT)
Fe 55	2.98E-04	Refining (INH)
Co 60	8.66E+00	Transport Scrap (EXT)
Ni 59	2.52E+00	Musical instrument (SKIN)
Ni 63	6.74E-04	Refining (INH)
Zn 65	1.92E+00	Transport Scrap (EXT)
Sr 90	1.12E+00	Musical instrument (EXT effective)
Nb 94	1.11E+01	Musical instrument (EXT effective)
Tc 99	2.66E-02	Landfill Child
Ru 106	1.43E+00	Transport Scrap (EXT)
Ag 108m	1.17E+01	Musical instrument (EXT effective)
Ag 110m	1.89E+01	Musical instrument (EXT effective)
Sb 125	2.59E+00	Musical instrument (EXT effective)
Cs 134	4.31E+00	Transport Scrap (EXT)
Cs 137	1.50E+00	Transport Scrap (EXT)
Pm 147	6.64E-01	Musical instrument (SKIN)
Sm 151	6.19E-05	Football Player (INH)
Eu 152	3.76E+00	Musical instrument (EXT effective)
Eu 154	4.16E+00	Musical instrument (EXT effective)
U 234	1.47E+00	Manufacture of ingots (INH)
U 235	1.32E+00	Manufacture of ingots (INH)
U 238	1.23E+00	Manufacture of ingots (INH)
Np 237	3.24E+00	Manufacture of ingots (INH)
Pu 238	6.48E+00	Manufacture of ingots (INH)
Pu 239	6.91E+00	Manufacture of ingots (INH)
Pu 240	6.91E+00	Manufacture of ingots (INH)
Pu 241	1.25E-01	Manufacture of ingots (INH)
Am 241	5.83E+00	Manufacture of ingots (INH)
Cm 244	3.67E+00	Manufacture of ingots (INH)

The majority of copper which is potentially clearable comes from electrical equipment and is in the form of cables. Cables are usually coated with an insulating material, very often PVC, which must be separated from the copper before smelting. The remaining insulating material will most likely be disposed of at a landfill but recycling

options are being investigated and pilot projects already exist. Neither the radiological consequences of cable separation nor the further use or disposal of the insulating material are considered in the radiological assessment studies. Therefore the clearance criteria discussed in chapter 3 apply only to the copper fraction of the cables and it is assumed that separation is carried out before clearance and the insulation material treated as radioactive waste.

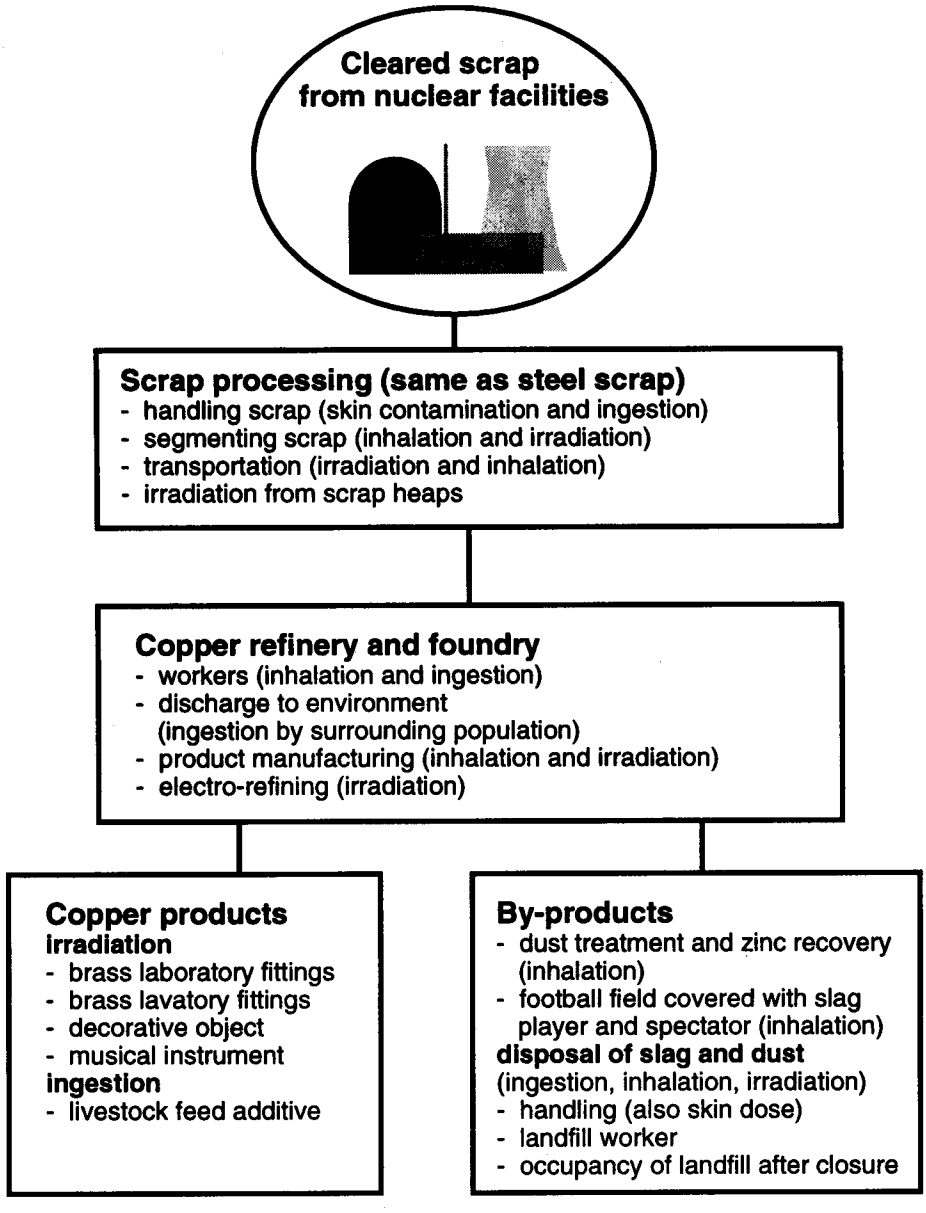

Figure 6-7: Schematic diagram of the flow of radioactivity and the exposure scenarios for recycling of copper scrap cleared from nuclear facilities.

After recovering the precious metals from the electrolysis slimes the radioactive isotopes will be found with the other isotopes of the same metal. An economic slime processing plant has a capacity of roughly 1000 tonnes per year, which represents the slime from around 140,000 tonnes of cathode copper. Therefore the fraction of slime from cleared nuclear scrap is nearly guaranteed to be less than 1%. Furthermore the leading nuclides from the nuclear fuel cycle (^{60}Co, ^{137}Cs, ^{235}U, ^{238}U, etc.) are found in the slag and dust and not the slimes. Therefore the scenarios covering the recycle and disposal of

waste products (see figure 6-7) lead to more restrictive clearance levels than scenarios covering precious metal recovery.

Besides the doses received during copper refining by the workers, doses from using copper products are considered (see figure 6-7). The fraction of cleared copper scrap in the products is assumed to be 0.3. If the scrap is directly sold to a foundry and used to make products this is a realistic but conservative assumption. On the other hand, for copper scrap which was processed in a refinery this estimate is overly conservative. Since no controls are possible after the scrap has been released, the conservative scrap fraction was used for all products. In table 6-11 the largest derived individual dose from scrap with 1 Bq/g activity is shown along with the scenario which lead to this dose for selected radionuclides. The parameters and scenarios are discussed and the doses from all the radionuclides are calculated in the technical documentation.

6.5 Aluminium based metals

An active policy of aluminium recycling is pursued since recycling uses up to 95% less energy than refining Bauxite. Aluminium and its alloys are used in nuclear power plants primarily for electrical components and in ventilation ducts. For security reasons the use of aluminium is restricted in power plants. Large amounts of aluminium are used in uranium enrichment facilities, especially in gaseous diffusion plants.

6.5.1 Recycling aluminium scrap

In western Europe around 5.23 million tonnes of aluminium were produced in 1990 of which 31.5% was secondary aluminium. Approximately 24% of the scrap used in the secondary production was new or production scrap. The EU demand for aluminium scrap is higher than the supply so that the EU is a net importer (110,000 tonnes in 1990). About 7% of the aluminium scrap need comes from outside the EU, with the largest portion, 33%, from the former east bloc countries [34,35].

Technological advances in the aluminium production have caused a continuous decrease in production costs in the last decades which in turn has lead to an ever increasing demand. Aluminium has found its way into all areas of daily life due to its versatility. In table 6-12 the major consumers of aluminium are shown for the EU.

Table 6-12: Aluminium consumers in the EU [15,18].

Aluminium consumers	in percent
Transport, including: ship construction and automobile industry	34%
Buildings, civil engineering and construction	13%
Electrical engineering (including electronics)	11%
Packaging industry	9%
Mechanical engineering	6%
Metallurgical industry	6%
Domestic products (including pots and pans)	5%
Miscellaneous	16%

The schematic diagram in figure 6-2 also applies to the recycling of aluminium scrap. In contrast to steel production, aluminium scrap is not used in the production of

primary aluminium from Bauxite. Three types of furnaces, rotary, reverberatory and induction, are used to produce secondary aluminium, the rotary being the most important. The furnace capacities vary from 0.5 to 20 tonnes and use as input aluminium scrap, which is sorted into about 25 categories. The product metal is typically composed of a number of different scrap types which are held in stock piles at the plant and mixed depending on the desired aluminium quality. With present technology it is possible to recycle aluminium without a loss in quality. Nevertheless secondary aluminium is used primarily for casting and primary aluminium for formable aluminium (e.g. cans, sheets, etc.) [18].

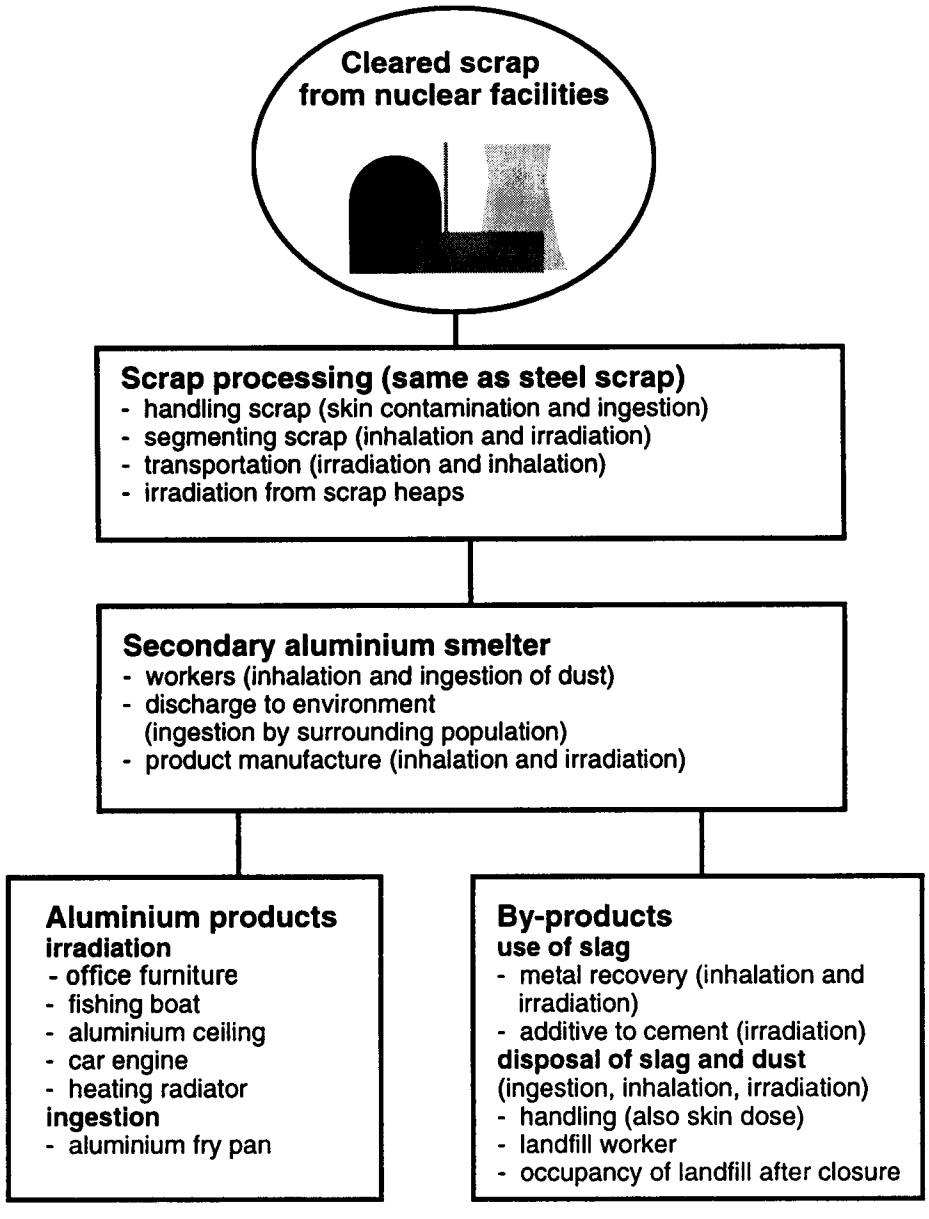

Figure 6-8: Schematic diagram of the flow of radioactivity and the exposure scenarios for recycling of aluminium scrap cleared from nuclear facilities.

The reactivity of aluminium with oxygen requires that it be melted under a liquid salt covering, which leads to a large amount of salt slag which is poured off and forms blocks. The boundary between the aluminium and salt cover (scraper) contains 20 to 50% aluminium and can be recycled after a separation process. Per tonne of aluminium about 300 kg of slag and 3 kg of dust are produced [15]. The possible uses for these by-

products are limited which means that the majority is disposed of at landfills, although the slag can be used as an additive in cement. Reprocessing the salt slag within the aluminium smelting works is increasing as disposal costs rise and environmental laws in the EU become stricter.

Table 6-13: Derived maximum individual dose and most restrictive scenario for aluminium and aluminium alloy recycling.

Nuclide	Maximum dose (µSv/y) / (Bq/g)	Aluminium recycling scenarios
H 3	5.60E-04	Refining (INH)
C 14	1.80E-02	Refining (INH)
Mn 54	2.61E+00	Transport Scrap (EXT)
Fe 55	1.43E-04	Refining (INH)
Co 60	8.53E+00	Transport Scrap (EXT)
Ni 59	1.14E-04	Refining (INH)
Ni 63	8.09E-05	Refining (INH)
Zn 65	1.93E+00	Transport Scrap (EXT)
Sr 90	2.47E-01	Fishing boat (EXT)
Nb 94	1.77E+01	Slag processing (EXT)
Tc 99	1.90E-02	Landfill Child
Ru 106	1.09E+00	Refining (INH)
Ag 108m	4.64E+00	Transport Scrap (EXT)
Ag 110m	8.67E+00	Transport Scrap (EXT)
Sb 125	2.96E+00	Slag processing (EXT)
Cs 134	1.72E+01	Slag processing (EXT)
Cs 137	6.19E+00	Slag processing (EXT)
Pm 147	3.33E-04	Slag processing (INH)
Sm 151	2.47E-04	Slag processing (INH)
Eu 152	1.26E+01	Slag processing (EXT)
Eu 154	1.38E+01	Slag processing (EXT)
U 234	6.46E+00	Slag processing (INH) (AG3)
U 235	1.24E+01	Slag processing (EXT) (AG3)
U 238	5.42E+00	Slag processing (INH) (AG3)
Np 237	1.43E+00	Slag processing (INH)
Pu 238	2.85E+00	Slag processing (INH)
Pu 239	3.04E+00	Slag processing (INH)
Pu 240	3.04E+00	Slag processing (INH)
Pu 241	5.51E-02	Slag processing (INH)
Am 241	2.57E+00	Slag processing (INH)
Cm 244	1.62E+00	Slag processing (INH)

6.5.2 Radiological consequence of recycling radioactive aluminium scrap

The reasoning applied to copper scrap in section 6.4.2 is also valid for aluminium scrap, therefore the surface contamination limits for aluminium scrap are taken equivalent to those for steel. Separate material dependent bulk activity calculations were carried out for aluminium scrap.

The secondary aluminium smelting process nearly guarantees that the scrap will be mixed with a number of other scrap types. Therefore the assumed fraction (0.2) of scrap with a nuclear origin is a reasonable and conservative estimate. During aluminium smelting a nuclide separation between the dust, slag and metal fractions occurs, which is accounted for in the radiological assessment. A list of the scenarios considered is given in figure 6-8, which shows the areas where radiation exposures are expected. In table 6-13 the largest derived individual doses and corresponding critical scenarios from the radiological assessment are presented for a selected set of radionuclides. For the uranium isotopes it is assumed that 1,500 Mg of aluminium is cleared. This accounts for the large amount of aluminium expected from gaseous diffusion plants. For all other nuclides it is assumed that only 40 Mg of aluminium is cleared which is in line with the quantities expected from nuclear power plants.

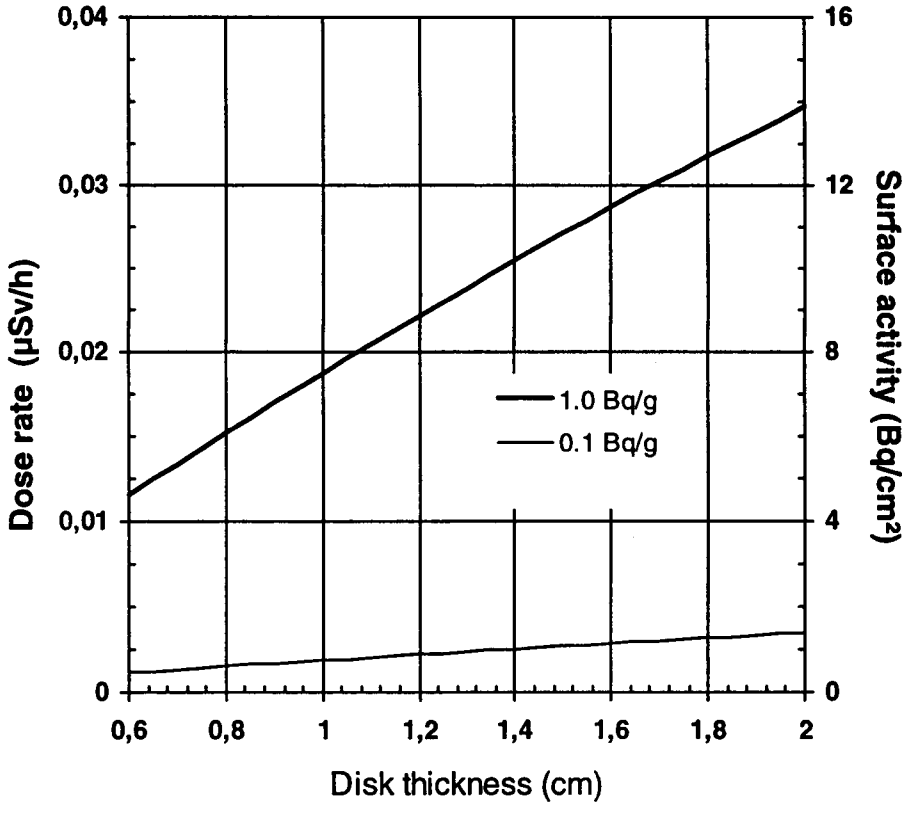

Figure 6-9: Dose rate at a distance of 1 m versus thickness for a 1 m^2 iron disk homogeneously radioactive with ^{60}Co. The right axis shows the surface activity of ^{60}Co resulting in the same dose rate (contamination on the surface facing the detector).

6.6 Direct reuse of equipment, components and tools

The clearance of equipment and tools from licensed sites for direct reuse is a common practice in the nuclear industry and is economically preferable to disposal or scrapping the equipment. The same radiological criteria applicable to recycling of slightly radioactive scrap cannot be applied to the reuse of items. Recycling scrap involves melting and reforming the scrap into new products, during which the scrap is mixed with scrap from non-nuclear sources and the radionuclides are partially separated out of the metal. Therefore the activity content of new products from recycled nuclear origin scrap is

significantly lower than the activity content of the cleared scrap. After clearing an item for direct reuse no reduction in the activity occurs.

Table 6-14: Derived maximum individual dose from the direct reuse of cleared equipment, components and tools.

Nuclide	Maximum dose (µSv/y) / (Bq/cm^2)	Direct reuse scenarios
H 3	3.94E-04	Ingestion (reuse)
C 14	1.30E-02	Ingestion (reuse)
Mn 54	2.70E+00	External (reuse)
Fe 55	6.55E-03	Ingestion (reuse)
Co 60	1.00E+01	External (reuse)
Ni 59	1.42E-03	Ingestion (reuse)
Ni 63	3.36E-03	Ingestion (reuse)
Zn 65	1.60E+00	External (reuse)
Sr 90	6.83E-01	Ingestion (reuse)
Nb 94	7.40E+00	External (reuse)
Tc 99	1.76E-02	Beta skin effective (reuse)
Ru 106	7.09E-01	External (reuse)
Ag 108m	7.70E+00	External (reuse)
Ag 110m	7.99E+00	External (reuse)
Sb 125	1.91E+00	External (reuse)
Cs 134	6.19E+00	External (reuse)
Cs 137	2.70E+00	External (reuse)
Pm 147	9.73E-03	Beta skin effective (reuse)
Sm 151	3.12E-03	Inhalation (sanding)
Eu 152	5.09E+00	External (reuse)
Eu 154	5.51E+00	External (reuse)
U 234	8.16E+00	Inhalation (sanding)
U 235	7.32E+00	Inhalation (sanding)
U 238	6.85E+00	Inhalation (sanding)
Np 237	1.80E+01	Inhalation (sanding)
Pu 238	3.60E+01	Inhalation (sanding)
Pu 239	3.84E+01	Inhalation (sanding)
Pu 240	3.84E+01	Inhalation (sanding)
Pu 241	6.96E-01	Inhalation (sanding)
Am 241	3.24E+01	Inhalation (sanding)
Cm 244	2.04E+01	Inhalation (sanding)

The clearance criteria for direct reuse are primarily surface contamination limits since measurement of the bulk activity would in many cases mean destroying the equipment's integrity. A problem arises when setting surface activity clearance levels for items which are contaminated by high energy γ-emitters like ^{60}Co. Here the detector cannot decide if the activity belongs to the surface or bulk. Setting restrictive surface clearance levels (fixed plus removable) will restrict the bulk activity by simply measuring the total γ-flux at the surface of the item. This is shown in figure 6-9 where the ^{60}Co dose rate is plotted as a function of the thickness. Here the dose rate was calculated at a perpendicular distance of 1 m from the 1 m^2 frontal area of a ferrous metal disk with a homogeneous constant activity. The right hand axis shows the total ^{60}Co surface activity

which results in the dose rate shown on the left hand axis. For radionuclides which emit low energy γ-rays or for β- and α-emitters the opposite problem occurs. These radionuclides can go undetected if they are located under rust, corrosion or surface coatings. Nuclides located in these surface layers must be categorised as surface activity since they will be released when the surface is manipulated (e.g. segmenting, sanding, cleaning, repair work or normal use). Care should therefore be taken when determining the measuring strategy.

The clearance levels for direct reuse are derived assuming that the total (fixed plus non-fixed) surface activity is limited. The radiological assessment includes;

- secondary ingestion of surface activity via transfer from the hands,
- skin dose from handling cleared items,
- external irradiation from cleared items and
- inhalation from activity re-suspended during refurbishing and normal use.

In table 6-14 the largest derived individual doses from a surface activity of 1 Bq/cm^2 as well as the limiting scenario are given for a selected set of radionuclides. The detailed description of the scenarios and parameters as well as the calculation of the doses for all the radionuclides can be found in the technical support document [7]. Since the activity is assumed to be surface contamination no attenuation through the material needs to be considered. Therefore the clearance values are independent of the type of metal and are valid for all metal items.

6.7 Collective dose from cleared metal scrap

Besides limiting the individual dose, Safety Series 89 [21] recommends that if the collective dose is less than 1 manSv/y the practice can be considered as optimised and further options need not be investigated. Therefore the collective doses from recycling steel, copper and aluminium scrap were investigated. The collective doses are calculated for one year of clearance and recycling (see table 6-2) and integrated over 100 years assuming that the products are recycled again after reaching the end of their useful life. The collective doses are the sum of the individual doses from a subset of the scenarios described in the previous chapters multiplied by the number of people exposed. The following scenarios are used to calculate the collective doses,

- for steel recycling: scrap pile, smelting, manufacturing, radiator, re-enforcement bars in a building and residence on a landfill,
- for copper recycling: scrap pile, smelting, purification treatments, treatment of by-products, manufacturing, sanitary plate and residence on a landfill,
- and for aluminium recycling: scrap pile, smelting, treatment of by-products, manufacturing, slag in concrete, office ceiling, radiator, car engines and residence on a landfill.

Other scenarios yield significantly lower exposures and their contribution to collective dose is only on the order of 1%. The collective doses are calculated for 1 Bq/g of activity for each nuclide. In order to evaluate the expected collective dose for the clearance levels presented in table 3-1 the collective dose per Bq/g is multiplied by the mass specific clearance level. This is presented in table 6-15 in the units manSv/y for each metal type considered for selected radionuclides. The detailed description of the calculations can be found in the technical support document [6].

For nearly all the radionuclides investigated the collective doses are significantly below 1 manSv/y. In two cases the collective doses are on the order of 1 manSv/y.

Considering that the activity is typically made up of a number of nuclides and that the summation formula (see chapter 3.1) is applied, it is expected that in reality the 1 manSv/y will not be exceeded when the recommended clearance levels are used. Nevertheless for these nuclides the competent authorities may wish to make a more detailed calculation accounting for circumstances specific to the clearance authorization.

The collective dose calculations show that an optimisation is not necessary. Nevertheless the collective dose can be further reduced by recycling within the nuclear industry, helping to fulfil the requirement of keeping the exposure of the whole population as low as reasonably achievable.

Table 6-15: Collective dose from recycling metal scrap cleared at the levels from table 3-1.

Nuclide	Collective dose (manSv/y)		
	Steel scrap	Copper scrap	Aluminium scrap
H 3	6.3E-6	8.4E-6	2.8E-5
C 14	2.0E-5	2.7E-5	9.1E-5
Mn 54	1.6E-2	1.1E-5	2.7E-4
Fe 55	1.8E-3	1.7E-4	2.2E-4
Co 60	3.1E-1	4.3E-4	2.6E-3
Ni 59	1.2E-2	2.1E-2	4.4E-3
Ni 63	3.7E-4	2.8E-2	4.1E-3
Zn 65	9.2E-4	7.9E-6	1.6E-4
Sr 90	8.7E-2	4.6E-2	2.6E-2
Nb 94	2.5E-1	8.8E-2	6.6E-2
Tc 99	4.9E-1	1.0E+0	7.4E-1
Ru 106	1.1E-3	3.9E-5	6.3E-5
Ag 108m	2.2E+0	6.7E-2	9.8E-3
Ag 110m	4.2E-2	8.8E-4	7.2E-4
Sb 125	2.2E-1	5.1E-3	2.6E-3
Cs 134	7.7E-5	1.6E-4	5.9E-4
Cs 137	6.0E-4	4.5E-3	5.0E-3
Pm 147	7.4E-5	1.6E-5	2.2E-4
Sm 151	2.1E-3	3.8E-3	2.8E-3
Eu 152	3.2E-3	4.8E-3	4.5E-3
Eu 154	1.5E-3	2.5E-3	2.6E-3
U 234	1.3E-4	5.4E-4	4.7E-4
U 235	1.1E-2	6.4E-3	4.5E-3
U 238	1.5E-2	4.1E-3	1.4E-3
Np 237	2.0E-2	1.1E-2	5.9E-3
Pu 238	3.4E-4	1.7E-3	4.7E-4
Pu 239	5.4E-4	2.4E-3	8.3E-4
Pu 240	5.3E-4	2.4E-3	8.2E-4
Pu 241	2.6E-5	1.9E-4	2.9E-5
Am 241	5.3E-4	2.1E-3	7.5E-4
Cm 244	8.2E-5	6.0E-4	9.4E-5

7. DISCUSSION

The derived individual doses from 1 Bq/cm^2 surface contamination (see tables 6-8 and 6-14) are converted into the clearance levels which result in a derived individual dose of 10 μSv/y or 50 mSv/y skin dose. The clearance levels are shown in table 7-1. The same calculation is made in table 7-2 for the mass specific concentrations for each of the metals studied (see tables 6-8, 6-11 and 6-13). Comparing the different mass specific clearance levels shows that for most of the radionuclides only minimal differences exist between the various metal types Therefore it seems expedient to recommend only one set of clearance levels for all types of metal scrap, which has been done in chapter 3. The clearance levels are taken from table 7-1 and 7-2 and rounded as described in chapter 3.

7.1 Averaging masses and surfaces

Since the radioactivity in and on metal components, equipment and scrap is not uniformly distributed, the quantity over which averaging is allowed must be specified. If liberal averaging procedures are allowed the radiological assessments no longer hold. This is most easily demonstrated in the following example. Assuming an averaging mass of 1 tonne, it is theoretically possible to have a 100 kg piece with an activity 10 times the clearance level. When this piece is melted, for example in a 1 tonne induction furnace, the fraction of nuclear origin scrap is 0.1 but the activity content is the same as if the entire 1 tonne was radioactive at the clearance level. In other words the products (metal, slag and dust) have an activity up to 10 times that assumed by the radiological assessments and the resulting derived doses would be of the order of 100 μSv/y instead of 10 μSv/y. Therefore it is recommended that the competent authorities set the averaging area for surface contamination and the averaging mass with this in mind. The measurement procedure, including the averaging area and mass, should take into account the type of nuclear facility, the material to be cleared and the radionuclides involved. In general an averaging area of a few hundred to a thousand square centimetres and averaging masses of a few hundred kilograms will probably be appropriate. If the activity is sufficiently homogeneously distributed larger averaging areas (up to 1 m^2) and masses (up to 1 tonne) may be appropriate.

7.2 Removable versus total surface activity

Measurements of removable surface activity depend strongly on the contamination mechanism (e.g. wet or dry), surface characteristics (roughness, chemistry and material), decontamination efforts and the type of wipe test applied. For these reasons measuring the removable activity alone does not represent a reliable method for determining the surface contamination. Furthermore the removable fraction can change with time (e.g. via rust) so that pieces which met the clearance requirements for removable activity at the time of release would not comply with the requirements at a later time. On the other hand direct surface measurements will register γ-emissions from the bulk of the material and miss low energy γ-, β- and α-emissions which are shielded by corrosion, rust or surface coatings like paint. The radiologically important parameter is the total surface activity (fixed plus non-fixed), which the radiological assessment used to derive the clearance criteria. When applying clearance criteria the competent authorities must give special attention to the monitoring difficulties.

7.3 Release of metal after licensed melting

The radiological assessments used to derive the clearance criteria for scrap metal assume that only a fraction of the scrap in the furnace comes from cleared scrap. Ingots produced in a licensed smelting facility are made from 100% radioactive scrap. Therefore the clearance levels for scrap are not appropriate for metal released after being melted in an authorized facility. Nevertheless there are a number of advantages to clearance after melting, such as decontamination effects from nuclide separation and simplification of the monitoring procedures, so that the competent authorities can authorize this practice after an appropriate investigation of the radiological consequences.

Table 7-1: Surface specific clearance levels which result in a derived maximum individual dose of 10 µSv/y

Nuclide	Clearance levels (Bq/cm²)	
	Scrap processing	Direct reuse
H 3	3.7E+4	2.5E+4
C 14	1.2E+3	7.7E+2
Na 22	1.0E+1	1.1E+0
S 35	6.1E+2	1.8E+3
Cl 36	1.3E+2	2.9E+2
K 40	1.6E+2	1.5E+1
Ca 45	2.9E+2	1.2E+3
Sc 46	1.1E+1	3.4E+0
Mn 53	9.3E+4	1.5E+4
Mn 54	2.6E+1	3.7E+0
Fe 55	3.6E+3	1.5E+3
Co 56	6.7E+0	2.1E+0
Co 57	1.9E+2	3.0E+1
Co 58	2.2E+1	8.0E+0
Co 60	9.1E+0	1.0E+0
Ni 59	1.5E+4	7.1E+3
Ni 63	6.4E+3	3.0E+3
Zn 65	4.0E+1	6.3E+0
As 73	3.0E+3	1.1E+3
Se 75	5.6E+1	1.4E+1
Sr 85	4.1E+1	1.6E+1
Sr 90	8.5E+0	1.5E+1
Y 91	1.1E+2	8.1E+2
Zr 93	1.2E+2	2.9E+2
Zr 95	9.2E+0	3.6E+0
Nb 93m	3.9E+3	1.0E+3
Nb 94	1.4E+1	1.4E+0
Mo 93	4.8E+2	1.7E+2
Tc 97	1.2E+3	1.5E+2
Tc 97m	1.2E+3	5.6E+2
Tc 99	1.1E+3	5.7E+2
Ru 106	1.9E+1	1.4E+1
Ag 108m	1.3E+1	1.3E+0
Ag 110m	8.3E+0	1.3E+0
Cd 109	7.0E+1	9.1E+1
Sn 113	7.1E+1	1.8E+1
Sb 124	1.3E+1	5.1E+0
Sb 125	4.8E+1	5.2E+0
Te 123m	1.4E+2	3.7E+1
Te 127m	1.1E+2	3.0E+2
I 125	9.2E+1	1.3E+2
I 129	1.3E+1	4.0E+0
Cs 134	1.4E+1	1.6E+0
Cs 135	6.8E+2	2.2E+2
Cs 137	3.9E+1	3.7E+0
Ce 139	1.3E+2	3.0E+1
Ce 144	2.3E+1	6.8E+1
Pm 147	9.6E+2	1.0E+3
Sm 151	1.3E+3	3.2E+3
Eu 152	2.0E+1	2.0E+0
Eu 154	1.8E+1	1.8E+0
Eu 155	3.5E+2	4.1E+1
Gd 153	1.7E+2	3.1E+1
Tb 160	2.1E+1	7.3E+0

Nuclide	Clearance levels (Bq/cm²)	
	Scrap processing	Direct reuse
Tm 170	6.4E+2	6.6E+2
Tm 171	3.7E+3	3.2E+3
Ta 182	1.8E+1	4.2E+0
W 181	5.1E+2	1.4E+2
W 185	3.0E+3	2.0E+3
Os 185	3.1E+1	8.7E+0
Ir 192	2.6E+1	9.2E+0
Tl 204	1.1E+3	3.1E+2
Pb 210	5.8E-1	6.6E-1
Bi 207	1.5E+1	1.4E+0
Po 210	3.0E-1	3.8E+0
Ra 226	3.0E-1	1.3E+0
Ra 228	3.9E-1	7.0E-1
Th 228	9.7E-2	2.4E-1
Th 229	4.2E-2	1.0E-1
Th 230	1.2E-1	3.0E-1
Th 232	1.2E-1	2.9E-1
Pa 231	3.8E-2	9.4E-2
U 232	1.3E-1	3.2E-1
U 233	4.9E-1	1.2E+0
U 234	4.9E-1	1.2E+0
U 235	5.5E-1	1.4E+0
U 236	5.3E-1	1.3E+0
U 238	5.9E-1	1.5E+0
Np 237	2.2E-1	5.6E-1
Pu 236	2.6E-1	6.4E-1
Pu 238	1.1E-1	2.8E-1
Pu 239	1.1E-1	2.6E-1
Pu 240	1.1E-1	2.6E-1
Pu 241	5.8E+0	1.4E+1
Pu 242	1.1E-1	2.7E-1
Pu 244	1.1E-1	2.8E-1
Am 241	1.2E-1	3.1E-1
Am 242m	1.4E-1	3.5E-1
Am 243	1.2E-1	3.1E-1
Cm 242	9.0E-1	2.3E+0
Cm 243	1.7E-1	4.2E-1
Cm 244	2.0E-1	4.9E-1
Cm 245	1.2E-1	3.1E-1
Cm 246	1.2E-1	3.1E-1
Cm 247	1.3E-1	3.3E-1
Cm 248	3.5E-2	8.8E-2
Bk 249	3.4E+1	8.3E+1
Cf 248	5.5E-1	1.4E+0
Cf 249	7.4E-2	1.9E-1
Cf 250	1.5E-1	3.8E-1
Cf 251	7.3E-2	1.8E-1
Cf 252	2.6E-1	6.4E-1
Cf 254	1.5E-1	3.8E-1
Es 254	5.6E-1	1.4E+0

Table 7-2: Mass specific clearance levels which result in a derived maximum individual dose of 10 µSv/y.

Nuclide	Clearance levels (Bq/g)		
	steel scrap	copper scrap	aluminium scrap
H 3	1.4E+3	8.6E+4	1.8E+4
C 14	7.6E+1	2.7E+3	5.5E+2
Na 22	1.5E-1	1.5E+0	4.0E-1
S 35	5.7E+2	1.1E+4	2.9E+3
Cl 36	1.3E+1	3.0E+2	3.6E+2
K 40	1.8E+0	1.8E+1	5.4E+0
Ca 45	5.8E+2	5.9E+2	1.4E+3
Sc 46	3.0E-1	7.3E-1	4.3E-1
Mn 53	3.0E+4	3.8E+5	1.8E+6
Mn 54	1.6E+0	4.0E+0	3.8E+0
Fe 55	2.7E+4	3.4E+4	7.0E+4
Co 56	4.2E-1	8.0E-1	8.2E-1
Co 57	1.5E+1	1.8E+2	3.0E+1
Co 58	1.4E+0	3.6E+0	3.3E+0
Co 60	5.8E-1	1.2E+0	1.2E+0
Ni 59	3.8E+5	2.0E+4	8.7E+4
Ni 63	3.0E+5	1.5E+4	1.2E+5
Zn 65	5.3E-1	5.2E+0	5.2E+0
As 73	1.4E+3	1.4E+2	4.6E+2
Se 75	3.0E+0	3.9E+0	3.0E+0
Sr 85	1.5E+0	2.7E+0	1.8E+0
Sr 90	1.4E+1	8.9E+0	4.0E+1
Y 91	9.3E+1	3.0E+1	9.2E+1
Zr 93	7.9E+3	5.3E+1	1.1E+1
Zr 95	9.0E-1	9.4E-1	5.7E-1
Nb 93m	1.7E+4	1.8E+3	3.7E+2
Nb 94	4.0E-1	9.0E-1	5.7E-1
Mo 93	1.7E+2	8.1E+3	2.3E+3
Tc 97	3.6E+2	3.5E+3	2.2E+3
Tc 97m	7.1E+3	9.9E+2	1.6E+3
Tc 99	3.9E+1	3.8E+2	5.3E+2
Ru 106	1.4E+0	7.0E+0	9.2E+0
Ag 108m	8.2E-1	8.6E-1	2.2E+0
Ag 110m	5.1E-1	5.3E-1	1.2E+0
Cd 109	2.2E+1	3.2E+2	1.8E+2
Sn 113	1.6E+0	2.0E+1	3.7E+0
Sb 124	7.7E-1	8.1E-1	4.6E-1
Sb 125	3.2E+0	3.9E+0	3.4E+0
Te 123m	1.2E+1	1.1E+1	9.8E+0
Te 127m	1.6E+2	5.2E+1	5.0E+2
I 125	3.0E+0	1.4E+2	1.4E+2
I 129	4.0E-1	1.9E+1	6.3E+1
Cs 134	2.1E-1	2.3E+0	5.8E-1
Cs 135	2.2E+1	8.6E+2	3.3E+2
Cs 137	5.8E-1	6.7E+0	1.6E+0
Ce 139	1.2E+1	1.1E+1	9.4E+0
Ce 144	1.1E+1	1.8E+1	2.1E+1
Pm 147	5.9E+3	7.5E+4	3.0E+4
Sm 151	7.4E+3	1.6E+5	4.1E+4
Eu 152	4.6E-1	2.7E+0	7.9E-1
Eu 154	5.2E-1	2.4E+0	7.3E-1
Eu 155	6.9E+1	6.5E+1	3.0E+1
Gd 153	5.0E+1	4.5E+1	1.9E+1
Tb 160	5.9E-1	1.4E+0	8.2E-1

Nuclide	Clearance levels (Bq/g)		
	steel scrap	copper scrap	aluminium scrap
Tm 170	6.6E+2	7.2E+1	7.1E+2
Tm 171	1.7E+4	7.4E+2	3.7E+3
Ta 182	4.9E-1	1.2E+0	6.9E-1
W 181	1.5E+2	7.0E+2	6.0E+1
W 185	1.0E+3	6.8E+2	6.3E+3
Os 185	5.1E-1	5.6E+0	5.0E+0
Ir 192	1.7E+0	6.4E+0	4.3E+0
Tl 204	3.4E+2	3.5E+2	5.1E+2
Pb 210	6.5E-2	1.3E+0	2.8E-1
Bi 207	9.3E-1	9.6E-1	5.8E-1
Po 210	1.8E+0	2.1E+1	1.5E+0
Ra 226	3.5E-1	8.5E-1	5.0E-1
Ra 228	6.6E-1	1.6E+0	9.5E-1
Th 228	4.0E-1	1.1E+0	6.0E-1
Th 229	1.2E-1	5.8E-1	1.3E+0
Th 230	3.0E-1	1.7E+0	3.8E+0
Th 232	2.7E-1	1.6E+0	3.6E+0
Pa 231	2.1E-1	5.2E-1	1.2E+0
U 232	8.0E-1	1.8E+0	4.1E+0
U 233	3.1E+0	6.7E+0	1.5E+1
U 234	3.2E+0	6.8E+0	1.6E+0
U 235	3.5E+0	7.6E+0	8.1E-1
U 236	3.4E+0	7.4E+0	1.7E+1
U 238	3.7E+0	8.1E+0	1.8E+0
Np 237	5.9E-1	3.1E+0	7.0E+0
Pu 236	7.4E-1	3.6E+0	8.1E+0
Pu 238	2.7E-1	1.5E+0	3.5E+0
Pu 239	2.5E-1	1.5E+0	3.3E+0
Pu 240	2.5E-1	1.5E+0	3.3E+0
Pu 241	1.3E+1	8.0E+1	1.8E+2
Pu 242	2.7E-1	1.5E+0	3.4E+0
Pu 244	2.7E-1	1.5E+0	2.7E+0
Am 241	3.1E-1	1.7E+0	3.9E+0
Am 242m	3.2E-1	1.9E+0	4.4E+0
Am 243	3.1E-1	1.7E+0	3.9E+0
Cm 242	5.0E+0	1.3E+1	2.8E+1
Cm 243	4.3E-1	2.3E+0	5.3E+0
Cm 244	5.2E-1	2.7E+0	6.2E+0
Cm 245	3.0E-1	1.7E+0	3.9E+0
Cm 246	3.0E-1	1.7E+0	3.9E+0
Cm 247	3.3E-1	1.9E+0	2.9E+0
Cm 248	8.3E-2	4.9E-1	1.1E+0
Bk 249	1.9E+2	4.6E+2	1.1E+3
Cf 248	3.4E+0	7.6E+0	1.7E+1
Cf 249	4.2E-1	1.0E+0	2.3E+0
Cf 250	8.7E-1	2.1E+0	4.8E+0
Cf 251	4.2E-1	1.0E+0	2.3E+0
Cf 252	1.5E+0	3.6E+0	8.1E+0
Cf 254	7.3E-1	1.6E+0	4.8E+0
Es 254	3.5E+0	7.7E+0	1.8E+1

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The secretariat of the Working Party and of the subgroup[3] was ensured by A. Janssens and C. Métaine[4] of DG XI.C.1 of the European Commission, with the support of R. Simon (DG XII) and K. Schaller (DG XII, later DG XI.C.3). Technical support was received from representatives of the steel industry (EUROFER, MM Harvey, Keck, Laprun).

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[1] Until 9 July 1992

[2] Starting with the meeting on 21 September 1994

[3] Members of the subgroup in charge of conducting the different studies on steel recycling, copper and aluminium surface contamination and the overall drafting of this document

[4] National expert on secondment with the commission

The technical work was entrusted to different institutes under contract with DG XI.C.1, in particular:

92/3: Revision of Recommendation RP43, "Radiological protection criteria for the recycling of materials from the dismantling of nuclear installations"

Part I: Recycling of Steel (H. Garbay, P. Guétat, IPSN)

Part 2: Recycling of Copper and Aluminium (C. Brun-Yaba, IPSN)

93/17: Scenarios and Dose Calculations appropriate for defining surface contamination limits (A. Deckert, Brenk Systemplanung)

94/10: Calculations of the external exposures for radiation sources of different geometry (L. Bologna, R. Mezzanotte, ANPA)

In addition, models and calculations pertaining to the assessment of collective doses were carried out by P. Govaerts (SCK-CEN).The first full draft of the document was prepared by A. Deckert (contract 94/08) on the basis of the different documents produced by the Working Party and by the other contractors. The detailed analysis of the scenarios and parameter values as described in the documents produced by IPSN, Brenk Systemplanung and ANPA will be published at a later stage in a more uniform presentation enabling unambiguous reference to the spreadsheet calculations undertaken by NRPB (J. Cooper, S. Mobbs, M. Harvey, contracts 94/09 and 97/01).

The final draft of the document is not significantly different from the draft adopted by the Article 31 Group of Experts at the end of 1994 (the draft incorporating the proposed amendments was dated February 1995). In the final draft the clearance values have been recalculated using the dose coefficients laid down in the Basic Safety Standards and the range of radionuclides was considerably extended. The Group of Experts approved the publication of the document at its meeting on 3-4 November 1997. Final editorial corrections were agreed upon at a meeting on 11 December 1997 (Mrs. Brun-Yaba, Mobbs, MM McAulay, Deckert, Harvey, Mezzanotte, Janssens).

Abstract

The recycling and reuse of materials from the dismantling of nuclear installations is subject to prior authorization by national competent authorities and clearance levels shall be established by them for the release of these materials pursuant to Article 5 of the Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers from ionizing radiations ("Basic Safety Standards").

This recommendation gives guidance to the regulatory authorities of the Member States concerning the conditions under which metal scrap, components and equipment from the dismantling of nuclear installations can be released from a radiation protection point of view. Criteria for release have been derived by a Working Party convened by a Group of Experts set up under the terms of Article 31 of the Euratom Treaty in 1990. This work expands the results of a Working Party which have been published in 1988 in recommendation Radiation Protection No. 43.

The radiological assessments have been based on the concept of a "trivial risk" and a corresponding individual dose of "some tens of microsieverts in a year" as proposed in the IAEA Safety Series No. 89 of 1988. This concept has been included in the Basic Safety Standards stating that Member States may decide that a practice may be exempted if the effective dose expected to be incurred by any member of the public due to the exempted practice is of the order of 10 μSv or less in a year and the collective dose committed during one year of practice is no more than 1 manSv. In addition, a limit of 50 mSv per year has been applied for the skin dose to derive clearance levels considering realistic scenarios for the radiological impact of the large amounts of metal materials released from the dismantling of nuclear installations on the workers and the general public as well. These model calculations result in two sets of clearance levels for metal scrap recycling and direct reuse, respectively. For the metal scrap recycling option, nuclide specific clearance levels are given for the mass specific activity and the surface activity concentration together with an instruction for examining the compliance with the clearance criteria in the case of a mixture of radionuclides in the material to be released. For direct reuse, only the surface activity concentration needs to be considered in most cases. The assumptions underlying the model calculations, the methodology and the results are briefly discussed leaving the details for two comprehensive technical reports that will be published later.

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