Analysis of Generic Clearance Levels for Radioactive Materials

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ANALYSIS OF GENERIC CLEARANCE LEVELS FOR RADIOACTIVE MATERIALS

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ABSTRACT:

Clearance values were derived for natural and artificial radionuclides. The radiological basis followed for their derivation was the same for both cases, i.e. practically not to modify the natural radiation background, but the approach to obtain the numerical figures was different. For natural radionuclides the values have been chosen by experts judgments as the optimum boundary between, on the one hand, the ubiquitous unmodified soil concentrations and, on the other hand, activity concentrations in ores, mineral sands, industrial residues and wastes. For artificial radionuclides the clearance levels have been derived from the scenarios postulated in the document “Safety Reports Series N° 44” of the IAEA considering quantitative exemption criterion. A set of 8 scenarios were postulated covering external irradiation, ingestion and inhalation exposure pathways. For each radionuclide, the generic clearance level was derived as the more restrictive value obtained from the scenarios, that is the lowest ratio between the applicable individual dose criterion and the dose per unit activity concentration (Bq/g). It was concluded that the clearance levels are conservative given the fact that the scenarios in which they are based are generic, covering a wide range of possible exposure situations.

KEYWORDS: Clearance, Generic Clearance Levels.

1. INTRODUCTION

Terrestial radionuclides (also called primordial radionulcides) have been present in the environment since the beginning of the Earth. They are mainly the product of four natural radioactive decay series, headed by ^{232}Th, ^{237}Np, ^{238}U and ^{235}U. Radionuclides such as ^{226}Ra and the gas ^{222}Rn are found within the chain of ^{238}U, ^{224}Ra and the gas ^{220}Th are found within the chain of ^{232}Th. ^{40}K is also a primordial radionuclide found in a important proportion in the environment.

Other natural radionuclides that are dispersed into the environment are ^{3}H, ^{7}Be and ^{14}C, which are formed as a result of the interaction between cosmic rays and atmospheric gases (called cosmogenic radionuclides) [1][2][3].

All these radionuclides are dispersed in rocks, soils, underground water, atmosphere etc. As consequence, for these radionuclides there is a heterogeneous worldwide distribution of low activity concentrations levels.

In addition to natural origin radionuclides, there are also dispersed in the environment artificial radionuclides, product of human activities. The main activities that contributed to this dispersion were nuclear explosions that liberated or generated various radionuclides, such as ^{14}C, ^{90}Sr,

^{137}Cs, ^{239}Pu, ^{240}Pu and ^{241}Pu. As a result of the Chernobyl accident, ^{90}Sr and ^{137}Cs, as well as isotopes of Pu and ^{241}Am were disperse mainly in Europe.

In a minor proportion, liquid and gaseous discharges from nuclear power plants and reprocessing plants also contribute to the presence in the environment of radionuclides such as ^{3}H, ^{14}C, ^{90}Sr, ^{99}Tc, ^{129}I and ^{137}Cs [4].

Considering that there are cases in which the radioactive materials generated in nuclear activities contain very low activity concentration levels making them not worthy of any further control, there is a regulatory procedure called *"clearance"* that could be applied to enable operators to remove them from the scope of its obligations allowing the cleared material to be recycled, reused or disposed of as non radioactive waste.

A similar situation occurs with radionuclides of natural origin. For those which are not excluded from the scope of the regulatory system, exists the possibility of removing these materials from the regulatory control if they satisfy the clearance criteria.

According to the Safety Guide RS-G-1.7, "Application of the Concepts of Exclusion, Exemption and Clearance" the term "Clearance" is understood as the removal of radioactive materials or radioactive objects under authorized practices from any further control by the regulatory body. Clearance levels were derived for natural and artificial radionuclides, in the document Safety Reports Series N°44 "Derivation of Activity concentration for Exclusion, Exemption and Clearance", (IAEA 2005).

As a result, if within notified or authorized practices, a material containing radionuclides of any origin or mixtures of them, satisfies the clearance levels approved by the regulatory body, they can be automatically cleared from further control. This implies that operators can treat this material as a non radioactive and could be reused, recycle or disposed of as non radioactive waste without any detriment to health and the environment.

It should be bear in mind, that the adoption of generic clearance levels does not preclude the regulatory authority to allow clearance for higher activity concentration levels, in a case by case study if it is proven that this is the best option.

2. METHODOLOGY

Clearance levels were derived for all types of solid materials. The principle followed for their derivation for both natural and artificial radionuclides is the same, but the approach to obtain the numerical values is different. The basis pursuit in both cases seems to be not introducing significant changes on the doses due to the natural radiation background (approximately 2.4 mSv/y, including radon exposures).

In this context, for natural radionuclides, activity concentration levels similar to those existing in the environment are considered acceptable for clearance levels and, for artificial radionuclides activity concentration levels that generate increments of trivial doses are considered acceptable.

An individual radiation dose, regardless of its origin, is likely to be considered as trivial if it is of the order of some tens of microsieverts per year. It was noted that this level of dose corresponds to a few percent of the annual dose limit for members of the public recommended by ICRP and is much smaller than any upper bound set by competent authorities for practices subject to regulatory control. The values of trivial individual doses corresponds to an annual nominal risk of death, which is held to be of no concern to the individual, of 10^{-6} to 10^{-7} [6]. For low probability events that could higher exposure levels, an additional criterion was used: effective doses should not exceed 1mSv per year, and with the purpose of avoiding deterministic effects, 50 mSv per year as equivalent skin dose.

2.1) Natural Radionuclides Approach

As it was explained before, the Earth contains natural radionuclides, such as primordial and cosmogenics radionuclides. These are present with an heterogeneous worldwide distribution of their activity concentrations. For example, the worldwide average activity concentration distribution in soils for K40 is 0.4 Bq/g, for U238 is 0.035 Bq/g and for Th232 is 0.03 Bq/g. According to the report form the UNSCEAR [5] these activity concentration levels generate a doses between 0.3 – 0.6 mSv/year including the one received directly form the soil and the one generated by living in a house constructed with natural materials.

In general, it would not be practicable to implement a control scheme on situations involving natural radionuclides, based on the criterion of an increment to the natural background radiation of 10 μSv, an increment, which is in fact, one or two orders of magnitude below its natural variability. Therefore, clearance values have been chosen by experts judgments as the optimum boundary between, on the one hand, the ubiquitous unmodified soil concentrations and, on the other hand, activity concentrations in ores, mineral sands, industrial residues and wastes. This methodology places greater emphasis on optimization of protection, particularly optimization of regulatory resources rather than just on triviality of individual doses [6] The clearance levels for natural radionuclides are shown in Table 1.

Table 1: Clearance levels for natural origin radionuclides

Radionuclide	Activity Concentration (Bq/g)
^{40}K	10
Rest of radionuclides of natural origin	1

This means, that materials containing natural origin radionuclides could be released from regulatory control if their activity concentration is below the levels established in table 1. Individual doses resulting from the use of these levels are not likely to exceed 1mSv annual, excluding exposure to radon.

The limits of Table 1 are valid for radioactive natural decay series in secular equilibrium, headed by U238, U235 or Th232, applying the established value to the parent. The values can also be applied to each radionuclide product of the decay serie or for those heading subgroups of decay chains.

In the case of mixtures of natural origin radionuclides, the concentration of each radionuclide should be below the correspondent value of activity concentration established in Table 1.

2.2) Artificial Radionuclides Approach

The sequence of calculations for deriving the activity concentration values for all material containing radionuclides of artificial origin, except foodstuffs and drinking water, proceeds as follows:

2.2.1) Selection of radionuclides for which the calculations are carried out;

2.2.2) Definition of suitable scenarios and parameter values;

2.2.3) Calculation of annual doses relating to the unit specific activity (1 Bq/g) for each radionuclide;

2.2.4) Identification of the limiting scenario for each set of calculations (the one that gives the highest dose);

2.2.5) Derivation of the radionuclide specific activity concentration values by dividing the reference dose level (10 μSv/a or 50 mSv/a, as appropriate) by the annual dose calculated for 1 Bq/g for the limiting scenario for that nuclide.

2.2.1) Selection of radionuclides for which the generic clearance levels were derived. Mixture criteria.

The set of radionuclides chosen are those that are most relevant to nuclear installation, such as nuclear power plants or fuel cycle facilities, and the application of radionuclides, including short lived radionuclides, in research, industry and medicine.

To apply the activity concentration values to a material containing a mixture of radionuclides (either artificial or naturally occurring), the concentrations should be determined as follows:

$$\sum_{i=1}^{n} \frac{C_i artificial}{(activity\ concentration)_i} \leq 1$$

Where **Ci** is the concentration (Bq/g) of a radionuclide of artificial origin in the material,

(activity concentration)i is the activity concentration value for the radionuclide of artificial origin in that material and **n** is the number of radionuclides in the mixture.

When dealing with mixtures of natural origin and artificial origin radionuclides both conditions established in points1 and 2 should be met.

It is worth noting that this is a conservative approach since the pathways of exposure of the critical group of exposed individuals are not necessarily the same for each radionuclide.

2.2.2 Definition of suitable scenarios and parameter values.

The scenarios described below were postulated in the safety series report N°44 for the derivation of generic clearance levels for relevant radionuclides. They are divided into those that consider the exposure of a worker in a facility (like a foundry, landfill, etc.) and those that consider the exposure of any other individual (here on, called public) [5].

It is worth pointing out that the worker could also be exposed anywhere i.e., outdoors or at home.

Scenario WL: a worker is exposed from contaminated material dumped on a landfill. Exposure pathways encompass external irradiation from the material, the inhalation of contaminated dust and the inadvertent ingestion of contaminated material.

Scenario WF: a worker is employed in a foundry where contaminated metal is smelted. External exposures arise if the worker stays within the vicinity of piles of contaminated material. In addition, the worker is exposed to dust released from the material during the transport and melting process. This dust can be inhaled and inadvertently ingested.

Scenario WO: a worker comes into contact with contaminated material on a regular basis (e.g. a truck driver). The worker is exposed externally from the material (e.g. from the load on the truck). This scenario also covers the exposure from a large piece of equipment that has been cleared from regulatory control and is reused in other workplace.

Scenarios RL-C and RL-A: scenario RL considers individuals living near a landfill or other facility (C indicates a child, A an adult) who are exposed through contaminated dust harvested foodstuffs in a private garden on the site that has become contaminated through the deposition of contaminated material.

Scenario RF: this scenario considers a child being exposed to a contaminated dust released by a foundry. Unlike scenario RL, no food consumption is considered here, because the presence of contaminated material off –site is already covered by scenario RL.

Scenario RH: contaminated material (building rubble, slag, fly ash) may be used in the construction of buildings as concrete aggregate or cement substitute. This will lead to an external exposure of the building residents, which is addressed in this scenario. Other possible uses in private homes of materials cleared from nuclear facilities are also covered by this scenario (e.g. the use of steel plates for the cladding of walls).

Scenario RP: if contaminated material is used for covering public places. Residents will be subject to external exposure as well as to the inhalation and ingestion of contaminated dust, for example by playing children. This exposure situation is covered in this scenario.

Scenario RW: this scenario emphases in the possible migration to downstream wells of the radionuclides present in cleared material that may lead to the ingestion of contaminated drinking water or of contaminated foodstuff produced in private gardens if the well water is used for irrigation. If the contaminated groundwater discharges into a river, the additional pathway of fish consumption is considered.

Table 2: Exposure Scenarios Considered and Relevant Pathways

SCENARIO	DESCRIPTION	EXPOSED INDIVIDUAL	RELEVANT EXPOSURE PATHWAY
WL	Worker on landfill or in other facility (other than foundry)	Worker	External exposure on landfill
			Inhalation on landfill
			Direct ingestion of contaminated material
WF	Worker in foundry	Worker	External exposure in foundry from equipment or scrap pile Inhalation in foundry
			Direct ingestion of contaminated material
WO	Other worker (e.g. truck driver)	Worker	External exposure from equipment or the load on the truck
RL- C	Resident near landfill or other facility	Child (1-2 a)	Inhalation near landfill or other facility
			Ingestion of contaminated foodstuffs grown on contaminated land
RL- A		Adult (>17 a)	Inhalation near landfill or other facility
			Ingestion of contaminated foodstuffs grown on contaminated land
RF	Resident near foundry	Child (1-2 a)	Inhalation near foundry
RH	Resident in house constructed of contaminated material	Adult (>17 a)	External exposure in house
RP	Resident near public place constructed with contaminated material	Child (1-2 a)	External exposure
			Inhalation of contaminated dust
			Direct ingestion of contaminated material
RW- C **RW- A**	Residents using water from private well or consuming fish from contaminated river	Child (1-2 a) Adult (>17 a)	Ingestion of contaminated drinking water, fish and other foodstuffs

The specific parameters of each scenario (dosimetric factors, inhalation rate, ingestion rate, dust concentration, etc.) have been assessed in order to determine if they lead to representative doses and if they allow the adoption of activity concentration values as clearance levels.

Description of the main parameters.

The differences between the same parameter are due to the consideration of, in one hand realistic assumptions, and on the other hand, more conservative assumptions.

a) Exposure times: exposure times, decay time allowed before the scenario starts and decay time during the scenario have been considered.

   - The exposition times varies between 1 whole year of work (conservative assumption) to half or a quarter of the year (realistic assumption).

   - The decay time allowed before the scenario starts varies between 30 to 100 days (realistic assumption) and for certain situations from 1 to 365 days.

   The decay time during the scenario can last the whole year (realistic assumption) or not be taken into account at all (conservative assumption).

b) Dilution Factor: the factors have been selected in order to cover a wide range of possible situations. As consequence, there are factors where the dilution is relevant as in the case of disposal of decommissioning materials in landfills or piles of scrap in a foundry and more conservative factors which do not contemplate the dilution of the material, as in the case of ingestion.

c) Skin contamination: it is assumed that there is no dilution of the suspended material in the environment. This is an conservative assumption.

d) Density of the materials: the density of the materials has little effects on the results, given that in the materials of higher density selfabsortion becomes relevant. It is adequate to assume an homogeny density of a 1.5 g/cm^3.

e) Annual ingestion rate: the rate of ingestion for workers is around 10g/y. If the scenario contemplates public members, like a child that inadvertently ingests contaminated material, the value increases up to 25g/y. For low probability exposure situations the rate increases up to 50g/y.

f) Dust concentration in air: Dust concentration in air depends of various factors, among them, the physical condition and quantity of the managed material. Given the difficulties of predicting the dust concentration, reference concentration values that vary between 10^{-5} a 10^{-3} g/m^3 are applied.

2.2.3 Calculation of annual doses relating to the unit specific activity (1 Bq/g) for each radionuclide.

The activity concentration levels arise as the lowest values obtained from the following approaches:

- Calculations with realistic scenario parameter values using an effective dose criterion of 10 μSv/year.

- Calculations using a set of low probability scenario parameter values with an effective dose criterion of 1 mSv/a and a skin equivalent dose limit of 50 mSv/a.

2.2.4 Identification of the limiting scenario for each set of calculations.

Although the limiting scenario could be different for each country due to possible differences in the specific parameters, such as working hours, shape of transport vehicles or geometries factors, the results are conservative enough as not to justify the need of development of national scenarios.

2.2.5 Derivation of the radionuclide specific activity concentration values by dividing the reference dose level (10uSv/a or 50mSv/a, as appropriate) by the annual dose calculated for 1 Bq/g for the limiting scenario for that nuclide.

Once identified the critical pathway, highest dose per unit activity, it is compared to the dose criteria corresponding to that pathway obtaining the clearance value for the given radionuclide. Clearance levels are shown in Table 3.

Table 3: Clearance values for artificial radionuclides

Radionuclides	Level (Bq/g)
I-129	0.01
Na-22; Sc-46; Mn-54; Co-56; Co-60; Zn-65; Nb-94; Ru-106; Ag-110m; Sb-125; Cs-134; Cs-137; Eu-152; Eu-154; Ta-182; Bi-207; Th-229; U-232; Pu-238; Pu-239; Pu-240; Pu-242; Pu-244; Am-241; Am-242m; Am-243; Cm-245; Cm-246; Cm-247; Cm-248; Cf-249; Cf-251; Es-254	0.1
C-14; Na-24; Cl-36; Sc-48; V-48; Mn-52; Fe-59; Co-57; Co-58; Se-75; Br-82; Sr-85; Sr-90; Zr-95; Nb-95; Tc-96; Tc-99; Ru-103; Ag-105; Cd-109; Sn-113; Sb-124; Te-123m; Te-132; Cs-136; Ba-140; La-140; Ce-139; Eu-155; Tb-160; Hf-181; Os-185; Ir-190; Ir-192; Tl-204; Bi-206; Th-232 [1], U-233; U-235 [2]; U-238 [3] Np-237; Pu-236; Cm-243; Cm-244; Cf-248; Cf-250; Cf-252; Cf-254	1
Be-7; F-18; Cl-38; K-40; K-43; Ca-47; Mn-51; Mn-52m; Mn-56; Fe-52; Co-55; Co-62m; Ni-65; Zn-69m; Ga-72; As-74; As-76; Sr-91; Sr-92; Zr-93; Zr-97; Nb-93m; Nb-97; Nb-98; Mo-90; Mo-93; Mo-99; Mo-101; Tc-97; Ru-97; Ru-105; Cd-115; In-111; In-114m; Sn-125; Sb-122; Te-127m; Te-129m; Te-131m; Te-133; Te-133m; Te-134; I-126; I-130; I-131; I-132; I-133; I-134; I-135; Cs-129; Cs-132; Cs-138; Ba-131; Ce-143; Ce-144; Gd-153; W-181; W-187; Pt-191; Au-198; Hg-203; Tl-200; Tl-202; Pb-203; Po-203; Po-205; Po-207; Ra-225; Pa-230; Pa-233; U-230; U-236; Np-240; Pu-241; Cm-242; Es-254m	10
H-3; S-35; K-42; Ca-45; Sc-47; Cr-51; Mn-53; Co-61; Ni-59; Ni-63; Cu-64; Rb-86; Sr-85m; Sr-87m; Y-91; Y-91m; Y-92; Y-93; Tc-97m; Tc-99m; Rh-105; Pd-109; Ag-111; Cd-115m; In-113m; In-115m; Te-129; Te-131; I-123; I-125; Cs-135; Ce-141; Pr-142; Nd-147; Nd-149; Sm-153; Eu-152m; Gd-159; Dy-166; Ho-166; Er-171; Tm-170; Yb-175; Lu-177; Re-188; Os-191; Os-193; Ir-194; Pt-197m; Au-199; Hg-197; Hg-197m; Tl-201; Ra-227; U-231; U-237; U-239; U-240; Np-239; Pu-234; Pu-235; Pu-237; Bk-249; Cf-253; Es-253; Fm-255	100
Si-31; P-32; P-33; Fe-55; Co-60m; Zn-69; As-73; As-77; Sr-89; Y-90; Tc-96m; Pd-103; Te-125m; Te-127; Cs-131; Cs-134m; Pr-143; Pm-147; Pm-149; Sm-151; Dy-165; Er-169; Tm-171; W-185; Re-186; Os-191m; Pt-193m; Pt-197; At-211; Th-226; Pu-243; Am-242; Cf-246	1000
Co-58m; Ge-71; Rh-103m; Fm-254	10 000

[1] The thorium series, headed by thorium-232 and constituted by ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl, and ^{208}Pb.

[2] The actinium series, headed by uranium-235 and constituted by ^{231}Th, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Fr, ^{223}Ra, ^{219}Rn, ^{215}Po, ^{211}Pb, ^{211}Bi, ^{207}Tl, and ^{207}Pb.

[3] The uranium series, headed by uranium-238 and constituted by ^{234}Th , ^{234}mPa, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi , ^{210}Po, and ^{206}Pb.

3. RESULTS

Typical exposure scenarios for solid materials, including external irradiation, inhalation of dust and ingestion (direct and indirect) have been taken into account for the calculations. The activity concentration values adopted were the lowest, this means, the more restrictive ones.

The results obtained and presented in Tables 1 and 3, can assure an adequate protection level to the critical group (workers and public).

Considerations about the selected radionuclides

The set of radionuclides chosen are those that are most relevant to nuclear installations, such as nuclear power plants or fuel cycle facilities, and the application of radionuclides, including short lived radionuclides, in research, industry and medicine.

Considerations about the scenarios considered

These scenarios are based in considerations that require a certain degree of conservatism in order to cover the wide variety of exposure situations around the world. More than one scenario has been considered for each exposure pathway in order to reflect the generality of the materials that would produce doses.

Considerations about the values of the parameters

The parameters considered for normal exposure are mainly realistic, but for low probability cases including exposure situations that tend to overestimate doses, a more conservative criterion has been adopted.

4. CONCLUSION

The specifics parameters used in each scenario postulated to derive the clearance values are conservative. These values have been derived for bulk amounts of homogeneous materials, so in order to apply them it is necessary to calculate the average activity concentration within the material.

According to the assessment carried out, it was suggested that the ARN should adopt the use of Generic Clearance Levels, in order to improve the regulatory management's efficiency and to optimize the utilization of its human and economic resources. This initiative is presently in course of implementation

Finally, it is worth pointing out that the adoption of these generic values has to be universal given that the materials can be exported or imported without any restrictions based on their radioactive content. This means, one material cleared in one country, should be considered cleared in other country.

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Analysis Of Generic Clearance Levels For Radioactive Materials

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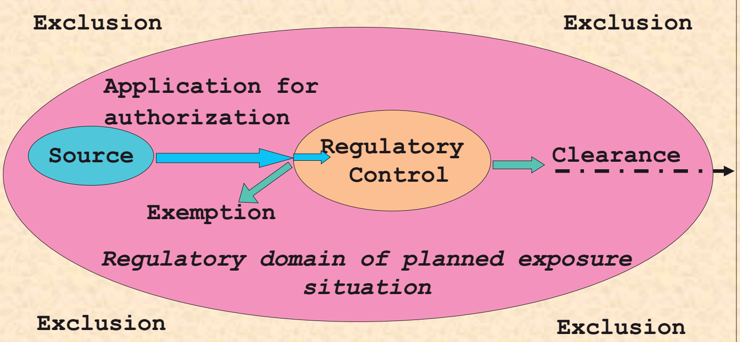
Introduction

There are cases in which radioactive materials generated in nuclear activities are not worthy of further control.

Operators of Nuclear Power Plants require Clearance Levels.

Current optimization phase of Waste Management Regulatory System.

ARN´s necessity of evaluation and assessment of clearance levels.



OBJECTIVE: Analyse the basis followed for the derivation of Generic Clearance Levels for natural and artificial radionuclides and evaluate the possiblity of their adoption by the Argentinean Nuclear Regulatory Authority.

METHODOLOGY

CRITERIA: not introducing significant changes on the natural radiation background doses

Natural Radionuclides

- Activity concentration levels similar to those existing in the environment
- Chosen by experts judgements as the optimum boundary between the ubiquitous unmodified soils concentrations an the activity concentration in ores, mineral sands, industrial residues and waste.
- Based on document of UNSCEAR

Artificial Radionuclides

- Derived from 8 scenarios postulated in Document Safety Reports Series N°44
- Scenarios cover external irradiation, ingestion and inhalation
- For realistic situations: 10 μS/y
- For low probability situacions: 1mSv/y - Skin 50mSv/y
- Activity concentration level obtained by dividing the reference dose level by the annual dose for the limiting scenario

TABLE 1. VALUES OF ACTIVITY CONCENTRATION FOR RADIONUCLIDES OF NATURAL ORIGIN

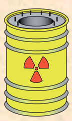
Radionuclide	Activity concentration (Bq/g)
^{40}K	10
All other radionuclides of natural origin	1

TABLE 2. VALUES OF ACTIVITY CONCENTRATION FOR RADIONUCLIDES OF ARTIFICIAL ORIGIN IN BULK (see para. 4.4)

Radio-nuclide	Activity concen-tration (Bq/g)	Radio-nuclide	Activity concen-tration (Bq/g)		Radio-nuclide	Activity concen-tration (Bq/g)
H-3	100	Mn-56	10	*	Se-75	1
Be-7	10	Fe-52	10	*	Br-82	1

Results

- ✓Scenarios and parameters conservative enough as not to justify the need to develop national scenarios
- ✓Scenarios envelop wide range of possible exposure situations



- ✓Need of calculating avarage activity concentration within the material

- ✓Materials could be reused, recycled or disposed of as non radioactive

- ✓Possible application for decommisioning of nuclear power plants, metalic scrap, radioactive wastes

CONCLUSIONS

1) It was suggested that the ARN should adopt the use of Generic Clearance Levels. This intiative is presently in course of implementation.

2) The adoption of the Generic Clearance Levels has to be universal given that materials can be worldwide exported or imported.

3) Higher activity concentration levels could be cleared based on a case by case study if it is proven that clearance is the best option.