Proposal of New Clearance Limits for the Safe Transport of Slightly Radioactive Materials

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SUMMARY

Because philosophy on exemption is evolving, it appears necessary to recalculate transport clearance levels on a more modern basis and to combine both types of regulations.
Dose equivalent limits are presented and discussed; calculations based on the adjustement of the "Q system" are explained and the main results are the following :
Mass activity limits should depend on radiotoxicity of nuclides
Surface activity limits should concern the total activity and should be much higher than the present limits.
A dose rate limit of 1 $\mu Sv.h^{-1}$ would be interesting
Clearance levels for transport should be generally higher than the other clearance levels and thus transport of slightly radioactive material would be free for most of the practices considered.

Currently evolving philosophy on exemption and its application to recycle or disposal of radioactive materials is largely independent of transport exemption regulation .

Exemption from compliance with the regulation for the safe transport of radioactive materials is based on mass and surface activity limits (1) ; the massic value used has not been reviewed or updated for some time. It now appears necessary to recalculate these exemption limits on a more modern basis and to combine both regulations.

The methodology to be applied has already been used for the determination of A2 and LSA limits, that is, definition of acceptable dose equivalent levels, choice of scenarios and associated parameter values, definition of practical limits with the choice of the units.

DOSE EQUIVALENT LIMITS

In the regulation for transport, the clearance level of mass activity is independant of the radiotoxicity of nuclides. It is most probable that it has been established for some important nuclides considering practical aspects such as measurements possibilities. No explaination refering to dose limit could be found.

In the case of A2 and LSA limits, several dose equivalent limits have been used : effective dose equivalent limits and equivalent dose limit to organs and to the skin recommended by the ICRP (2). They correspond to the level of risk accepted by workers under radiation protection, and permit to avoid apparition of non-stochastic effects. These limits are higher than the acceptable level for the public.

In the different recommendations concerning clearance levels for very low radioactive wastes (3) (4) some reference values are given. In the case of routine occupational scenarios and considering the effective dose equivalent, arguments are developped for values between 100 and 10 $\mu Sv.y^{-1}$. The final limit adopted by authorities should depend on the possibility of exposure from different practices for a single member of the public. The other reference levels do not reach a general agreement. A level for collective dose is still discussed even if a proposal of 1 man.Sv has been given (3). Limit to the skin is not generally considered even if a value of 5 mSv has been mentionned (5). At last, doses to organs are not considered because the exposure levels are low and out of the range of non-stochastic effects.

The case of low probability scenarios has been studied (3). The application of the ICRP recommendations would allow very high exposure levels when the probability is low, and it appears that experts would prefer to limit accidental exposures to the maximum permissive level for workers or public (5). This aspect remains very theorical as few scenarios of accidental type have been studied.

APPLICATION TO TRANSPORT

In the case of transport, exposure pathways are β and γ external irradiation, hand contamination and inhalation of airborne radioactive particles.

Irradiation and inhalation of radionuclides can easily be expressed in term of effective doses. Hand contamination corresponds to a skin exposure and skin dose can be evaluated. Irradiation at a given distance induces a dose to the skin and to the testes. This last exposure is in fact the limiting pathway.

- Considering the effective dose limit, a value has to be choosen in the preceeding range. The upper value of 100 µSv is the acceptable level for the total of exposures due to exemption practices. The summation of 10 possible practices is strictly unrealistic. The probability that a member of the public could belong to two critical groups corresponding to two different practices is very low. So we shall consider a limit of 50 $\mu Sv.y^{-1}$ for a critical member of the public particularly exposed during his professional work.
- Considering the irradiation of the testes, no dose factors are directly available. It is possible to derive dose factors from the dose factors to the skin considering that the dose to the skin is at least four times greater than the dose to the testes for high β energy emission. Considering a Wt weighting factor of 0.3, we can see that there is an equivalence between 50 µSv effective dose, 166 µSv dose to the testes and about 500 µSv to the skin.
- Considering hand contamination, the reference limit to the skin for workers is 0.5 $Sv.y^{-1}$ (2). The ICRP group recommends a safety factor of 10 to be used for members of the public, to take into account the possible variability of response within a large population. We shall consider a limit of 50 $mSv.y^{-1}$.
- Considering the accidental situation of a fire, the risk of accident is less than 2 E-3 y^{-1} for a complete shipment, nevertheless we shall adopt the limit of 50 mSv for effective dose equivalent and 0.5 Sv for dose equivalent to organs.

Table 1 summarizes the pathways and the limits or levels adopted.

SCENARIOS

A system of scenarios has been determined for the definition of A2 values and is well-known under the name of Q system (6).
These scenarios have been established for accidental conditions while the radioactive material is no longer protected by the package. This situation is very similar to the case of a routine unpackaged shipment of objects without any handling restriction. So we only need to adapt these scenarios to this routine case with some modifications concerning times of exposure and quantities of material transported.

The choice of parameters values is clearly a fundamental element in the determination of derived limits of activity. In the Q system, a pessimistic approach has been used for two reasons : the first one is the fact that dose levels are relatively high, the second one is that, in an accidental situation, people may have unexpected or very specific behaviour. In our case, we consider normal occupational scenarios and they occur many times along the year. So it is easy to demonstrate that mean values have to be choosen even if it is better to remain a little bit pessimistic (i.e. reasonnably)

The following hypothesis have been adopted :

three kinds of material are studied when necessary -concrete blocks - steel - organic polymers.

Working time is 200 days per year. 3 daily journeys of 2 hours each are possible. As the driver transports also other materials, it is supposed that 1/12 of his time is spent for transport of slightly radioactive materials. This lead to a maximum of 50 hours of exposure for 50 journeys. We consider, like in the Q system, the free air exposure rate at 1 m of distance from a point source. Because of autoabsorption, the irradiating mass of material is estimated to be 200 kg (10 cm deep) for γ emission and 20 kg (1 cm deep) for β emission. Comparison with other types of calculations based on infinite slab source and solid angle shows a very good agreement. The shipment volume is 10 m^3 and density are respectiveley 1, 1 and 0.1. To illustrate this scenario, in the case of nuclear plant dismantling, a driver would evacuate 6000 tonnes of material including 500 tonnes of slightly radioactive wastes.

Loading and unloading operations need respectively 15 and 5 mn. The worker remains 25% of his time in the plume and the radioactive dust contents of air are respectively 10, 1 and 0.01 $mg.m^{-3}$.

At last the worker may touch the transported objects at each journey and is supposed to wash his hands at the end of each half-day. The ratio contaminated surface / mass are respectively 5 E-2, 0.25 and 10 $cm^2.g^{-1}$. In case of a fire, hypothesis of the Q system are entirely adopted.

Calculations are deduced from the values of Qa (γ irradiation), Qb (β irradiation), Qc (inhalation) and Qd (hand contamination), correcting factors are R_{exp} for the exposure time and R_{dose} for dose equivalent limits. The mass M or the surface S of the shipment are considered.

The case of ^3H has been treated separately and scenarios are described in (7).

The mean mass activity of material for β and γ external irradiation is :

$$A_m = R_{dose} \cdot R_{exp} \cdot \frac{Qa \text{ or } Qb}{M}$$

The mean surface activity of material for inhalation pathway for routine scenario is :

$$A_s = R_{dose} \cdot \frac{Qc}{1E6} \cdot \frac{1}{1.2\, t_{exp} \cdot \tau} \cdot \frac{M}{S}$$

with Qc/1E6 LAI used in the Q system
t_{exp} exposure time in the plume
τ dust content in air

For the accidental scenario with fire , the mean surface activity becomes :

$$A_s = \frac{Qc}{m} \cdot \frac{M}{S}$$

with m mass of material concerned by the fire (1 tonne).

The mean surface activity of material for hand contamination pathway is :

$$A_s = \frac{Qd}{1E7} \cdot R_{dose} \cdot R_{exp}$$

with Qd/1E7 hand contamination adopted in the Q system .

Table 2 precises the numerical values.

RESULTS AND DISCUSSION

Mean surface and mass activities are given in table 3 for many usual radionuclides.These two kinds of values are obtained independently and correspond to different pathways.Transcription from one type of unit to the other is not possible for a given pathway.For example, γ irradiation depends only on the mass of material, and the mass activity value is the same for all types of material. Expressed in surface activity unit, a large range of values is obtained. The opposite is true for hand contamination and inhalation.

Comparison with present transport regulation

We can notice that for usual γ emitters, mean mass activity varies in the range of 20 to 100 $Bq.g^{-1}$, and the present value fits quite well. Nevertheless, higher levels are obtained for X or pure β emitters like ^{36}Cl, ^{32}P ^{55}Fe ^{14}C ^{3}H ^{99}mTc or ^{63}Ni and mass activity limits are not appropriate for α emitters except for ^{232}Th and ^{226}Ra. From another point of view, it would have been interesting and simple to deduce clearance levels from the A2 values by a single factor. In fact, differences between the Q system and this approach are too big and this method is not suitable.

For surface activity values, many points have to be discussed.
The present values refer to a total activity which is very mobile (10% are easily removed by hand contact). Compared to the non-fixed activity limit of the transport regulation, values are greater by a factor of 50 for α emitters and about 500 for $\beta\gamma$ emitters. Such discrepancies are not acceptable .
Non-fixed activity does not have a clear definition and corresponds more or less to wipe tests. From a practical point of view, it would be much better to define total surface activity limits and let analysts convert results of measurement into the appropriate unit. It can be added that direct measurements are generally possible at these levels of activity.

Surface activity limits raise the question about accessibility of the surface and even its existence (e.g. rubble,soils). For this last point, it is always possible to consider a virtual surface of a material supposed homogeneous. Concerning unaccessible surface, it is possible to consider that the same value as for external surface could be adopted (airborne particles could be emitted in the same way when handling). But this does not solve the problem of measurement.

Comparison with other clearance levels

Very few clearance levels are available in the regulations. Two cases are encountered: A limit of 74 or 100 $Bq.g^{-1}$ associated to small amount of total activity and limits around 1 $Bq.g^{-1}$ for case by case waste elimination.
Generic studies for recycling also lead to values between 1 and 10 $Bq.g^{-1}$ for nuclides like ^{137}Cs or ^{60}Co and to much higher limits for nuclides like ^{3}H, ^{63}Ni ...
Table 4 gives some results for recycling of iron, copper and aluminium (5) (8).
Few values concerning surface activity are available.
From undergoing studies in our laboratory and other European laboratories about landfill disposal, it appears that the levels of activities could be equivalent and even higher to transport levels.

Mean activity levels and limits

In all these different studies ,calculations give mean activity levels and not upper limits. Adopting these levels as limits would include a safety factor without justification. This question has to be discussed and will be developped in a further publication.

Mixture of radionuclides

For mixture of radionuclides whose identities and respective activities are known, the following conditions will apply.

$$\Sigma \frac{A_s}{L_s} < 1 \quad \text{and} \quad \Sigma \frac{A_m}{L_m} < 1$$

CONCLUSIONS

Clearance levels definition raises a lot of problems and studies are still at the beginning.
Presently, it appears that clearance levels for transport will generally be higher than other clearance levels with the possible exception of landfill disposal case.
Nevertheless, a reevaluation of surface activity limits is needed and a better adaptation to the radiotoxicity of nuclides for mass limits would be usefull.
A dose rate limit could be added and this would simplify the controls.

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Table 1 : reference dose equivalent limits or levels

transport regulations		
exemption level		?
A2 dose limit	effective	50 mSv.an-1
	organs	500 mSv.an-1
	skin	500 mSv.an-1
effective dose limits for public		
	occasional	5 mSv.an-1
	permanent	1 mSv.an-1
dose reference levels for exemption		
routine scenarios		
effective		0.01 - 0.1 mSv.an-1
organs		none
skin	(not confirmed)	5 mSv.an-1
collective	(under discussion)	1 man.Sv
accidental scenarios		
effective dose	(proposal)	50 - 5 mSv
risk limit		1.E-6 an-1

Table 2 : mean mass and surface activities levels
and dose rate limit for the safe transport
of slightly radioactive material

mean activities levels		
gamma irradiation	Am = 5.E-11 Qa	Bq.g-1
beta irradiation	Am = 1.E-09 Qb	Bq.g-1
inhalation	As = 1.E-07 Qc	Bq.cm-2
hand contamination	As = 5.E-10 Qd	Bq.cm-2
dose rate limit	D = 1 uSv.h-1	

Table 3 :pathways and mean mass and surface activities
for transport of slightly radioactive material

	pathway	Bq.g-1	pathway	Bq.cm-2
Ag108m	gamma X n	3.1E+01	hand	1.2E+03
Ag110m	gamma X n	1.8E+01	hand	4.6E+02
Al26	gamma X n	1.9E+01	hand	2.3E+02
Am241	gamma X n	2.7E+03	inhal.	2.0E+01
C14	unlimited		hand	1.2E+03
Ca45	gamma X n	1.2E+09	hand	4.6E+02
Cf252	gamma X n	4.8E+00	inhal.	1.0E+02
Cl36	beta irr	2.1E+04	hand	2.3E+02
Co60	gamma X n	2.0E+01	hand	4.6E+02
Cs134	gamma X n	3.3E+01	hand	2.3E+02
Cs137	gamma X n	8.5E+01	hand	2.3E+02
Eu152	gamma X n	4.4E+01	hand	4.6E+02
Eu154	gamma X n	4.1E+01	hand	2.3E+02
Fe55	gamma X n	3.0E+04	inhal.	7.0E+06
I129	gamma X n	2.1E+03	inhal.	1.1E+05
I131	gamma X n	1.3E+02	hand	2.3E+02
Ir192	gamma X n	6.0E+01	hand	2.3E+02
Mn54	gamma X n	6.0E+01	inhal.	3.0E+06
Na22	gamma X n	2.3E+01	hand	4.6E+02
Nb94	gamma X n	3.2E+01	hand	4.6E+02
Ni63	unlimited		inhal.	3.0E+06
Np237	gamma X n	2.2E+02	inhal.	2.0E+01
P32	beta irr	3.2E+02	hand	2.3E+02
Pb210	beta irr	6.3E+02	hand	2.3E+02
Pu238	gamma X n	7.6E+04	inhal.	2.0E+01
Pu239	gamma X n	7.2E+04	inhal.	2.0E+01
Ra226	gamma X n	3.4E+01	hand	2.3E+02
Ru106	beta irr	2.1E+02	hand	2.3E+02
S35	unlimited		hand	1.2E+03
Sr90	beta irr	2.1E+02	hand	2.3E+02
T	unlimited		inhal.	1.3E+03
Tc99m	gamma X n	4.0E+02	inhal.	6.0E+08
Tc99	unlimited		hand	4.6E+02
Te132	gamma X n	2.3E+01	hand	2.3E+02
Th232(nat)	gamma X n	2.0E+01	inhal.	4.9E+12

table 4 : Comparison of different clearance levels (Bq.g-1)

	RECYCLING of STEEL	ALUMINIUM	COPPER	TRANSPORT
dose reference level	10 uSv.y-1	50 uSv.y-1 (critical man) 10 uSv.y-1 (critical group)	50 uSv.y-1 (critical man) 10 uSv.y-1 (critical group)	50 uSv.y-1 (critical man)
Ag 110m	1	1	2	18
Co 60	1	1	3	20
Cs 137	6	60	10	85
Fe 55	1E5	1E7	3E3	3E4
Ni 63	1E5	1E7	232	-
Pu 239	0.7	160	410	7E4
Ru 106	4	130	1	210
Sr 90	10	2E5	0.1	210