Technical Memorandum 38

Radiotoxicity hazard classification
— the basis and development of a new list

MW Carter, P Burns and L Munslow-Davies

Supervising Scientist for
the Alligator Rivers Region

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Contents

Abstract

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The new ICRP recommendations contained in ICRP Publications 60 (ICRP 1991a) and 61 (ICRP 1991b) mean that all radiological regulations, standards and codes of practice based on the earlier recommendations need to be reviewed and revised.

In Australia national recommendations on radiation protection are promulgated by the National Health and Medical Research Council and these are used by the Standards Association of Australia, National Occupational Health and Safety Commission (Worksafe Australia), state governments and other bodies, in their standards, codes and regulations.

As part of the review and revision process, NHMRC and SAA recognised the need to produce a new radiotoxicity hazard classification, and formed a small working party to carry out this task. This paper is the report of the working party and summarises the work carried out and presents the recommendations for the revised radiotoxicity hazard classification.

Previous classifications have been examined and the basis for such classifications has been considered. The working party propose that the most appropriate basis is the most restrictive inhalation ALI, and that there is a need to consider this ALI in terms of both mass and activity. Using an index based on mass and activity, the radionuclides listed in ICRP 61 have been divided into four classes of radiotoxicity hazard. This list of revised radiotoxicity hazard class is presented in the paper and a floppy disk of the data is available.

Radiotoxicity hazard classification
—the basis and development of a new list

Introduction

Over the years a number of lists of radionuclides in order of radiotoxicity have been produced (IAEA 1963, CEC 1980). These lists divided radionuclides into three, four or five classes, which were then used for generic decisions in regulation and in design of facilities or systems that use radionuclides.

Classification of radionuclides according to radiotoxicity has, at one time or another, found application in transport regulations, generic air and surface contamination limits and in laboratory design rules; in Australia in recent years, the Commission of the European Communities classification (CEC 1980) has been the most widely used. In a study of the existing radiotoxicity classifications, based on ICRP 30 data, Furness (1990) showed that on the basis of ALI, both in Bq and mg, there was significant overlap between the classes; furthermore it was clear that for some radionuclides of low specific activity the toxicity classification was highly dependent on whether the classification list was based on ALI in Bq or ALI in mg. This study had already indicated a need to revise the existing classifications, and the publication in 1991 of ICRP Publications 60 and 61 (ICRP 1991a & 1991b) and the consequent revision of codes and standards which use such classifications, eg NHMRC Surface Contamination Code (Burns & Melbourne 1993) and SAA Laboratory Safety Standard (SAA 1986), reinforced this need. Since regulatory bodies around the world are still in the process of introducing the revisions necessary to adopt the ICRP 60 recommendations, there is no current classification list available for the NHMRC to adopt. Needing such a list to be included in revised documents, the NHMRC and SAA set up a small working party to consider the basis for a revised radiotoxicity classification and to produce a classification list to replace the CEC list; this paper describes the new list proposed for use by the National Health and Medical Research Council (NHMRC), Standards Association of Australia (SAA), and National Occupational Health and Safety Commission (Worksafe Australia) in their Codes, recommendations and standards. It is hoped that it may also be useful to regulators and designers in other countries as a tool in controlling radiation doses received by workers and the public.

Previous classifications

Not all previous radiotoxicity classification lists have clearly explained the basis on which they were produced. Two options were discussed by the IAEA in its 1963 listing: based on MPC_a in µCi/cc, or based on maximum permissible annual intake in mg as a result of exposure at 1 MPC_a (IAEA 1963). The problem of rating radionuclides of very low specific activity was also considered: '...radionuclides of very low specific activity... have such a large mass associated with a unit of activity that it would be impossible for the body to take in sufficient quantity of material for it to become radiologically toxic... the specific activity cannot be ignored in making a classification. Otherwise... some low-specific-activity radionuclides may be assigned an absurdly high toxicity.' The IAEA presented two lists: Table 1 in order of the most restrictive MPC_a value and Table IV 'according to their radiotoxicity'. The IAEA Table IV was based on a combination of Maximum Permissible Intake (MPI) in µCi and MPI in µg.

The basis of some other lists is less clear. Several lists have followed the 1963 IAEA Table 1 approach of using MPC_a values only, which means they are based on activity without consideration of specific activity. In the Medical and Dental Code issued in the UK in 1964 (Department of Education and Science 1964) the list is 'according to relative radiotoxicity per unit activity', which would imply that the list was based solely on MPC activity values. The 1970 UK Road Transport Code (Department of the Environment 1970) and the 1967 IAEA Transport Regulations (IAEA 1967), however, gave a rule for allocating unlisted radionuclides to groups on the basis of their atomic number and physical half-life; this made specific activity the sole basis for classification. Subsequently the IAEA Transport Regulations abandoned classification into four or five groups, but used a system of maximum activity per package (IAEA 1979, 1990). This is an appropriate system for transport regulations but not for more general application. Even so, in the 1979 regulations the maximum activity of alpha emitters is based on half-life and atomic number, i.e. on specific activity, and in the amended version of 1990, using the 'Q' system (Macdonald & Goldfinch 1981), materials with low specific activities, such as natural uranium and natural thorium, are listed as 'unlimited' in relation to activity limits which would produce an inhalation or skin contamination hazard, lending some support for using ALIs in mass units as a basis for classification. It should be noted that the 'Q' system includes consideration of gamma dose rate, an aspect not included in other classifications.

For many radionuclides the classification will be the same whether activity or specific activity (mass) is used, e.g. ^{90}Sr and ^{227}Ac are high toxicity radionuclides in both cases. Some radionuclides, however, such as natural uranium or natural thorium, are 'high toxicity' when based on MPC_a (activity) but low toxicity when specific activity (mass) is considered. For lists that do not give the basis used for toxicity classification (that is, almost all lists), it can be assumed that, if natural uranium and natural thorium are classed as low toxicity, the list is based on, or includes consideration of, specific activity; a list for use in the Nordic countries (Radiation Protection Institutes 1976) is an example. Previous classifications have thus been based on the MPC (or ALI) in activity units, the specific activity or some combination of these.

Proposed new classification

Basis

As indicated earlier the use of radiotoxicity classification lists has been principally in setting generic contamination limits and in laboratory design rules. That is, the use has been for unsealed radioactive materials rather than sealed sources, and external radiation has not been taken into account. While external radiation could in principle be included in the basis for a radiotoxicity hazard classification, this would require a specific exposure model to be assumed, reducing the generality of the classification. Because of this, and because it does not appear to have been considered necessary in any of the previous classifications (apart from the special case of 'Q' system used in the current transport regulations), the working party has decided not to include consideration of external dose.

The data considered for use as the basis of the revised radiotoxicity hazard classification were the inhalation ALI, the ingestion ALI and the specific activity. The most restrictive ALIs given in ICRP 61 were used.

To prevent any confusion about the term 'radiotoxicity hazard' it is defined by the working party as follows: the radiotoxicity of a radionuclide is the risk that that radionuclide, following an intake to the body, will harm organs and tissues and is directly related to the committed equivalent dose to those organs and tissues, which is in turn related to the ALI in Bq. The probability of material getting into the body is, however, related to the mass of material being used, and the conditions under which it is being used. Some combination of the probability of the material entering the body (related to mg) and the probability of the material, once in the body, of producing a health effect (related to Bq) determines the risk in using the material. The working party uses the term 'radiotoxicity hazard' to describe such a combination.

The risk involved in using a radionuclide is closely related to the mass of that material that may escape and end up being inhaled or ingested and the activity of the material has little to do with its mobility. This is because pathway transport mechanisms, eg transfer from surfaces to skin, suspension and resuspension, are predominantly mechanical; the activity of the particle transported will not affect its rate of transport.

For most models of potential exposure relevant to radiotoxicity hazard classification, the inhalation pathway is more likely than the ingestion pathway. This is certainly the case in the derivation of surface contamination limits (Dunster 1970, Carter 1982). Additionally, control of the ingestion pathway, by for example banning eating, drinking and smoking in work areas, is generally easier than the control of the inhalation pathway. For this reason the working party decided to develop a classification based on inhalation ALIs. The order within any classification list would, however, be almost the same whichever route was chosen since there is a reasonably close relationship between inhalation and ingestion ALIs as is illustrated in figure 1.

Data

The full ICRP 61 (ICRP 1991b) list of radionuclides and their most restrictive ALI (ing) and ALI (inh) values was transferred to a personal computer, and specific activities were calculated for each pure radionuclide (misprints of half-life, for ^{40}K, ^{129}I, ^{138}La, ^{146}Sm, ^{147}Sm, ^{152}Gd, ^{166m}Ho, ^{176}Lu, were noted). For radionuclides that are commonly present with daughter products, such as natural uranium, natural thorium, ^{226}Ra and ^{90}Sr, both the specific activity and the mixture ALI were calculated. This is necessary because ICRP ALI values only allow for daughters that are formed after the radionuclide enters the body, but not daughters that enter the body with the parent. Table 1 presents a summary of the data for these radionuclide chains. An example of these calculations is given in tables 2 and 3. For the special cases of uranium and thorium, specific activities were calculated for the refined metal and for their ores (assuming an ore grade with a default value of 1% by weight) since these radionuclides are often transported or used in these forms. The calculated specific activities were used to convert the ALI (inh) from Bq to mg.

In order to be able to include them in the list, gaseous radionuclides, which irradiate by cloud dosage rather than uptake in the body, have been given a notional ALI based on assumptions of a room ventilation rate of three air changes per hour, the ICRP 30 derived air concentration limits for a 1000 m^3 room and a correction for the reduction in occupational dose limit introduced in ICRP 60 (ICRP 1991a) by multiplying by 20/50. These are given in table 4.

Figure 1 shows that the ICRP 61 ALI (ing) and ALI (inh) values for over 700 nuclides are directly related and that a classification based on ALI (ing) would not be significantly different from one based on ALI (inh). A large range of ALI values are covered and the classification of radionuclides into a few groups using such a listing requires rather coarse divisions. Of over 700 ALI values listed, there are less than 100 nuclides at each end of the plot that have very small values or have very large values. The remainder all fall within three decades in the middle of the list and this needs to be considered when determining the divisions between the radiotoxicity groups.

Figure 2 shows the ICRP 61 ALI (inh) in Bq and the ALI (inh) in mg plotted against the CEC classification. It is clear that on the basis of activity there is considerable overlap between the classifications and at least one Class 4 radionuclide would appear to be more correctly Class 1 or 2 on the basis of ALI in Bq. On the basis of mass the CEC classification appears to provide very little discrimination between groups, with groups 1 and 3 having virtually the same range. In fact the basis of the CEC list is not clear, but figure 2 suggests that a combination of ALI by mass and by activity with most weight given to the ALI by activity was used. Some of the apparent anomalies in figure 2 will be due to the changes between ICRP 30 and ICRP 61.

Development of a classification system

As indicated earlier, ALI (inh) is preferred to ALI (ing) as the basis of a radiotoxicity hazard class, because in most operational and minor accident situations the inhalation exposure pathway is likely to be more important than the ingestion exposure pathway. Consequently the working group considered ALI (inh) as a basis of classification rather than ALI (ing).

The first approach to producing a radiotoxicity classification was based solely on ALI (inh) in mg. Examination of the list produced on this basis revealed that a few radionuclides with very low values of ALI in Bq, ie of clearly high radiotoxicity hazard, were not classified in the high radiotoxicity group. For example ^{232}U, ^{238}Pu, ^{242m}Am, ^{250}Cm, ^{241}Am, ^{251}Cf and ^{247}Bk all with ALIs of 300 Bq or less were classified in group 2 rather than group 1. A different approach to producing a radiotoxicity classification, with the aim of ensuring that radionuclides with very low activity ALIs were assigned to group 1 was, therefore, considered necessary. Several approaches were tried using the product or addition of activity and mass ALI and the one selected was a hazard index based on an addition in quadrature of the ALI in mg and the ALI in Bq, as explained below.

The 1963 IAEA Classification (IAEA 1963) combined activity and mass into a hazard index by plotting the values of 'maximum permitted intake' on a graph with axes in mass units and activity units. The graph was divided into sections and the classification was based on the section into which a particular radionuclide fell. A similar approach has been used here. If each radionuclide is plotted on a graph with ALI in mg as one axis and ALI in Bq as the other axis, then the length of a line from the origin to the plotted point is an index of hazard (with shortest length indicating greatest hazard) combining the mass and activity of the ALI. Figure 3 shows such a plot. In order to give similar weighting to each axis, when calculating the length of such a line the axes have to be 'normalised'. Normalisation has been carried out by dividing the values on each axis by the value at the false origin in figure 3, that is ALI values in mg have been divided by 10^{-10} and ALI values in Bq by 1. Thus the hazard index (length of a line from the false origin to the point representing the radionuclide on a normalised version of figure 3) is given by:

$$\text{Index}_1 = \sqrt{\left(\frac{\text{ALI}_{mg}}{10^{-10}}\right)^2 + \left(\frac{\text{ALI}_{Bq}}{1}\right)^2} \qquad (1)$$

The value of this index ranges from 70 to 4 x 10^{22} and the divisions between groups have been set at 3 x 10^5, 3 x 10^7 and 3 x 10^9. These divisions, which are of course arbitrary, have been selected to give 100 radionuclides or less in each of groups 1 and 4, to give a fairly even range of ALI (mg or Bq) in each group (see figure 4) and as far as possible to minimise changes from previous lists.

The numbers in each group are given in table 5. When grouped according to this index those radionuclides that had appeared to be wrongly classified in the other classification systems considered now appear to be in the appropriate group. Table 6 lists radionuclides which are used but are not listed in ICRP 61 and so no ALI is currently available. When ALIs are published for these radionuclides, equation 1 can be used to allocate them to a radiotoxicity hazard group. If there is considered to be a need for a finer division of hazard, so that radionuclides could be ranked within the groups, the index given by equation 1 could be used but a more convenient conversion for this purpose is given by:

$$\text{Index}_2 = \frac{\text{Log}_{10}(\text{Index}_1/30)}{2} \qquad (2)$$

Using equation 2, radionuclides with an Index_2 less than 1.99 are in group 1, those with an Index_2 between 2 and 2.99 are in group 2, those with an Index_2 between 3 and 3.99 are in group 3 and those with an Index_2 greater than 4 are in group 4.

Figure 4 shows the relationship of the ALI in both Bq and mg to these radiotoxicity hazard groups. It can be seen that while there is considerable between 3 and 3.99 are in group 3 and those with an $Index_2$ greater than 4 are in group 4. Figure 4 shows the relationship of the ALI in both Bq and mg to these radiotoxicity hazard groups. It can be seen that while there is considerable overlap between groups, there is a steady progression from group to group. The full list of radionuclides in order of hazard index in alphabetic order is given in table 7. A previous publication (Carter *et al* 1993) presented a reduced list with only the most common radionuclides.

Conclusion

Classification of radionuclides into groups that indicate their relative hazards in normal use depends on a number of assumptions and so is somewhat subjective. It must, however, be remembered that the purpose of the classification is to make broad divisions for general use in hazard assessment and in design of operations or facilities.

The working group considered possible bases for a radiotoxicity hazard list and concluded that a list based on the most restrictive inhalation ALI with consideration of both the activity and the mass is appropriate. A listing of the radionuclides contained in ICRP 61, plus some other radionuclides in common use has been produced and is recommended for use by the relevant authorities.

Advantages of a hazard index in the form of Equation 1 are that unlike most previous classifications the basis of the classification is clear and extra radionuclides can be added to the list once their ALI is determined. The ALI values given in ICRP 61 will be superceded when ICRP produces a full revision of ICRP 30 and the new values of ALI may result in some radionuclides being reclassified into a different radiotoxicity hazard group. The use of an equation, such as proposed in this report, to determine radiotoxicity hazard classification, allows for the classification of any radionuclide to be re-assessed after any change in the recommended ALI. The list of radionuclides with the relevant data is available on a floppy disk in the form of a Microsoft Excel spreadsheet.

Acknowledgements

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Table 1 Data for radionuclides with daughters

Radionuclide description	Radionuclides present	Mixture ALI (inh) Bq	Specific activity Bq/g
Natural uranium (as metal)	$^{238}U + ^{234}U + ^{235}U$	600	2.5×10^4
Natural uranium	^{238}U + all daughters	660[a]	1.55×10^5
Natural thorium (as metal)	$^{232}Th + ^{228}Th$	145	4.08×10^3
Natural thorium	^{232}Th + all daughters	600[a]	4.22×10^4
^{226}Ra	^{226}Ra + all daughters	4.2×10^4	4.3×10^{11}
^{90}Sr	$^{90}Sr + ^{90}Y$	5.95×10^4	10.12×10^{12}

a rounded value assuming approximately 50% loss of short-lived radon daughters.

Table 2 Derived limits for uranium based on ICRP 61

Nuclide	Number of Bq per Bq of U-238 Alpha	Beta	ALI (inh)
^{238}U	1		600
^{234}Th		1	2×10^6
^{234}Pa		1	1×10^8
^{234}U	1		600
^{230}Th	1		400
^{226}Ra	1		9000
* ^{222}Rn	1		
* ^{218}Po	1		
* ^{214}Pb	1		1×10^7
* ^{214}Bi		1	1×10^7
* ^{214}Po	1	1	
^{210}Pb		1	1×10^4
^{210}Bi		1	4×10^5
^{210}Po	1		1×10^4
^{235}U	4.5×10^{-2}		600
^{231}Th		4.5×10^{-2}	8×10^7
^{231}Pa	4.5×10^{-2}		100
^{227}Ac		4.5×10^{-2}	70
^{227}Th	4.5×10^{-2}		5000
^{223}Ra	4.5×10^{-2}		1×10^4

Total Bq per Bq U-238 (ie sum of activities given above)	Alpha (without RnD)	Alpha (RnD)	Beta (without RnD)	Beta (RnD)
	5.18	3	4.09	2

	ALI and DAC ALIm	DAC
Total Bq		
U chain without Rn daughters	516	0.215
U chain with Rn daughter	798	0.333
Alpha Bq⁺		
U chain without Rn daughters	288	0.120
U chain with Rn daughters	446	0.186

* These five nuclides, radon and its short-lived daughters may or may not be present depending on the physical form and history of the material. ALIs have been calculated with all these nuclides present and with all mssing. A rounded value between these calculated ALIs is recommended for general use where radon/radon daughter activity is unknown.

+ Total Bq ALI and DAC reduced by the appropriate fraction of alpha activity to total activity.

Table 3 Specific activity of uranium with all daughters [a]

Radionuclide	Bq per gram of U-238	Mass per gram of U-238
^{238}U	1.25×10^4	1
^{234}Th	1.25×10^4	1.5×10^{-11}
^{234}U	1.25×10^4	5.4×10^{-5}
^{230}Th	1.25×10^4	1.7×10^{-5}
^{226}Ra	1.25×10^4	3.4×10^{-7}
^{222}Rn	1.25×10^4	-
^{218}Po	1.25×10^4	-
^{214}Pb	1.25×10^4	1×10^{-14}
^{214}Bi	1.25×10^4	7.6×10^{-9}
^{210}Bi	1.25×10^4	2.7×10^{-12}
^{210}Po	1.25×10^4	7.5×10^{-11}
^{235}U	5.6×10^2	7.0×10^{-3}
^{231}Th	5.6×10^2	2.8×10^{-13}
^{231}Pa	5.6×10^2	3.2×10^{-6}
^{227}Ac	5.6×10^2	2.0×10^{-9}
^{227}Th	5.6×10^2	4.9×10^{-12}
^{223}Ra	5.6×10^2	2.9×10^{-12}
Totals	**1.66×10^5**	**1.007**

Specific activity $= 1.66 \times 10^5/1.007$
$= 1.65 \times 10^5$

a Used as the basis for calculating the specific activity of uranium ore. Th at is ore with 1% U content would have a specific activity of $1.65 \times 10^5 \times 1/10^2 = 1.65 \times 10^3$ Bq/g.

Table 4 Gaseous radionuclides which were in the CEC list but are not in ICRP 61 and which have been given a provisional radiotoxicity hazard group

Radionuclide	CEC Class	Recommended group [a]
^{242}Am	2	1
^{41}Ar	3	4
^{74}Kr	3	4
^{77}Kr	3	4
^{87}Kr	3	4
^{88}Kr	3	4
^{76}Kr	4	4
^{81}Kr	4	4
^{83m}Kr	4	4
^{85m}Kr	4	4
^{85}Kr	4	4
^{123}Te	4	2
^{135}Xe	3	4
^{131m}Xe	4	4
^{133}Xe	4	4

a These classifications will need to be reviewed when ICRP publishes revised ALIs for these radionuclides.

Table 5 Number of radionuclides in each class or group

Group or class	CEC list	Revised list	
		Most common radionuclides[a]	Full list
1	42	41	56
2	52	118	212
3	182	101	388
4	80	20	101

a Short list published in Carter et al (1993)

Table 6 Radionuclides not yet classified

Ar37
Au196
Au196m
Ba137
Cm62
Es255
N13
O15
Re183
Rn222

Table 7 List of radionuclides by radiotoxicity hazard group in alphabetic order

Group 1

Ac225	Cd113	Cf251	Cm244	Fm253	Pa228	Pu24	Sr90+Y90
Ac226	Cd113m	Cf252	Cm246	Fm257	Pa230	Ra223	Th227
Ac227	Ce144	Cf253	Cm250	Gd148	Pa232	Ra224	Th228
Am241	Cf246	Cf254	Es253	Hf178m	Pb210	Ra225	Th229
Am242m	Cf248	Cm240	Es254	In115	Po210	Ra228	Ti44
Bk247	Cf249	Cm242	Es254m	Md258	Pu236	Ru106	U230
Bk249	Cf250	Cm243	Fm252	Os194	Pu238	Sr90	U232

Group 2

Ac224	Bi214	Eu146	I126	Nd147	Pu239	Se75	Te132
Ac228	Bk245	Eu148	I130	Ni56	Pu240	Si32	Th226
Ag105	Bk250	Eu150	I131	Ni66	Pu242	Sm145	Th230
Ag106m	Ca45	Eu152	I133	Np236	Pu246	Sn113	Th234
Ag108m	Ca47	Eu154	In114m	Np236m	Ra226	Sn117m	Tm167
Ag110m	Cd109	Eu155	Ir190	Np238	Ra226+d	Sn119m	Tm170
Ag111	Cd115	Eu156	Ir192	Os185	Rb83	Sn123	Tm171
Am242	Cd115m	Fe59	Ir192m	Os191	Rb84	Sn125	Tm172
Am243	Ce134	Fm254	Ir194	P32	Rb86	Sr82	U233
Am244	Ce139	Fm255	Ir194m	Pa227	Rb87	Sr85	U234
As72	Ce141	Fr222	La140	Pa231	Rh101	Sr89	U237
As73	Ce143	Fr223	Lu171	Pa233	Rh102	Ta179	V48
As74	Cf244	Gd146	Lu172	Pb211	Rh102m	Ta182	W188
As76	Cm238	Gd151	Lu173	Pb212	Rh182m	Ta183	Y88
At211	Cm241	Gd153	Lu174	Pb214	Rh184	Tb149	Y90
Au195	Cm245	Ge68	Lu174m	Pd100	Rh184m	Tb156	Y91
Au198	Cm248	Ge69	Lu177m	Pm143	Rh186	Tb158	Yb166
Au198m	Co56	Hf172	Md257	Pm144	Ru103	Tb160	Yb169
Ba128	Co57	Hf175	Mg28	Pm145	Sb120m	Tb161	Zn65
Ba133	Co58	Hf179m	Mn52	Pm146	Sb122	Tc95m	Zn72
Ba140	Co60	Hf181	Mn54	Pm147	Sb124	Tc97m	Zr88
Bi205	Cs134	Hg194	Mo93	Pm148	Sb125	Te121m	Zr95
Bi206	Cs136	Hg203	Mo99	Pm148m	Sb126	Te123m	Zr97
Bi207	Cs137	Ho166	Na22	Pm149	Sb127	Te125m	
Bi210	Dy166	Ho166m	Nb93m	Pr142	Sc 44m	Te127m	
Bi212	Er172	I124	Nb95	Pr143	Sc46	Te129m	
Bi213	Es251	I125	Nb96	Pu234	Sc48	Te131m	

Group 3

Ag102	C14	Ga66	In117	Ni57	Pt199	Sm156	Th231
Ag103	Cd104	Ga67	In117m	Ni63	Pt200	Sn110	Ti45
Ag104	Cd107	Ga68	In119m	Ni65	Pu237	Sn121	Tl194m
Ag104m	Cd117	Ga70	Ir182	Np232	Pu243	Sn121m	Tl195
Ag106	Cd117m	Ga72	Ir184	Np234	Pu245	Sn123m	Tl197
Ag112	Ce135	Ga73	Ir185	Np235	Ra227	Sn127	Tl198
Ag115	Ce137	Gd145	Ir186	Np237	Rb 82m	Sn128	Tl198m
Am238	Ce137m	Gd147	Ir187	Np239	Rb79	Sr80	Tl199
Am239	Cl38	Gd149	Ir188	Np239	Rb81	Sr81	Tl200
Am240	Cl39	Gd159	Ir189	Np240	Rb88	Sr83	Tl201
Am244m	Cm247	Ge66	Ir190m	Os181	Rb89	Sr87m	Tl202
Am245	Cm249	Ge67	Ir195	Os182	Rh100	Sr91	Tl204
Am246	Co 58m	Ge71	Ir195m	Os191m	Rh101m	Sr92	Tm166
Am246m	Co 62m	Ge75	K42	Os193	Rh105	Ta172	Tm173
As69	Co55	Ge77	K43	P33	Rh106m	Ta173	U231
As70	Co61	Ge78	K44	Pa234	Rh181	Ta174	U236
As71	Cr48	H3	K45	Pb195m	Rh182	Ta175	U239
As77	Cr49	Hf170	La131	Pb198	Rh188	Ta176	U240
As78	Cr51	Hf173	La132	Pb199	Rh188m	Ta177	V47
At207	Cs125	Hf177m	La135	Pb200	Rh189	Ta178	V49
Au193	Cs127	Hf180m	La141	Pb201	Rh99	Ta180m	W176
Au194	Cs129	Hf182m	La142	Pb202m	Rh99m	Ta185	W177
Au199	Cs130	Hf183	La143	Pb203	Ru105	Tb147	W178
Au200	Cs131	Hf184	Lu169	Pb209	Ru94	Tb150	W181
Au200m	Cs132	Hg193	Lu170	Pd101	Ru97	Tb151	W185
Ba126	Cs134m	Hg193m	Lu176m	Pd103	S35	Tb153	W187
Ba131	Cs138	Hg195	Lu177	Pd109	Sb116m	Tb154	Y86
Ba133m	Cu60	Hg195m	Lu178	Pm141	Sb118m	Tb155	Y86M
Ba135m	Cu61	Hg197	Lu178m	Pm150	Sb119	Tb156m	Y87
Ba139	Cu64	Hg197m	Lu179	Pm151	Sb126m	Tb156m	Y90m
Ba141	Cu67	Hg199m	Mn 52m	Po203	Sb128m	Tb157	Y91M
Ba142	Dy155	Ho155	Mn51	Po203	Sb129	Tc104	Y92
Be10	Dy157	Ho167	Mn56	Po205	Sb130	Tc93	Y93
Be7	Dy159	I120	Mo101	Po207	Sb131	Tc93m	Y94
Bi200	Dy165	I120m	Mo90	Pr137	Sc43	Tc94	Y95
Bi201	Er161	I121	Mo93m	Pr138m	Sc44	Tc94m	Yb175
Bi202	Er169	I123	Na24	Pr139	Sc47	Tc95	Yb177
Bi203	Er171	I128	Nb89	Pr142m	Sc49	Tc96	Yb178
Bk246	Es250	I132	Nb89m	Pr144	Se 73m	Tc99m	Zn62
Br 74m	Eu145	I132m	Nb90	Pr145	Se70	Te116	Zn63
Br 80m	Eu149	I134	Nb94	Pr147	Se73	Te121	Zn69
Br74	Eu152m	I135	Nb95m	Pt186	Se81m	Te123	Zn69m
Br75	Eu157	In109	Nb97	Pt188	Se83	Te123	Zn71m
Br75	Eu158	In110	Nb98	Pt189	Si31	Te127	Zr86
Br77	F18	In110m	Nd136	Pt191	Sm141	Te129	Zr89
Br80	Fe52	In111	Nd138	Pt193m	Sm141m	Te131	
Br82	Fe55	In113m	Nd139m	Pt195m	Sm142	Te133	
Br83	Fe60	In115m	Nd149	Pt197	Sm151	Te133m	
Br84	Ga65	In116m	Nd151	Pt197m	Sm153	Te134	

Group 4

A126	Gd152	Kr76	Nd139	Pu244	Sb128	Tc96m	U238
Am237	Hf182	Kr77	Nd141	Rb 81m	Se79	Tc97	W179
Ar41	Ho157	Kr81m	Ni59	Rh103m	Se81	Tc98	Xe131m
Au201	Ho159	Kr83m	Np233	Rh107	Sm146	Tc99	Xe133
Ba131m	Ho161	Kr85	Os180	Rh177	Sm147	Th nat	Xe133m
Bi210m	Ho162	Kr85m	Os189m	Rh178	Sm155	Th ore	Xe135
C11	Ho162m	Kr87	Pb202	Rh186m	Sn111	Th232	Xe135m
Ca41	Ho164	Kr88	Pb205	Rh187	Sn126	Tl194	Yb162
Cl36	Ho164m	La137	Pd107	Sb115	Sr85m	Tm162	Yb167
Co 60m	I129	La138	Po203m	Sb116	Ta180	Tm175	Zr93
Cs135	In112	Lu176	Pr136	Sb117	Ta182m	U nat	
Cs135m	K40	Mn53	Pt193	Sb120	Ta186	U ore	
Er165	Kr74	Nb88	Pu235	Sb124m	Tc101	U235	

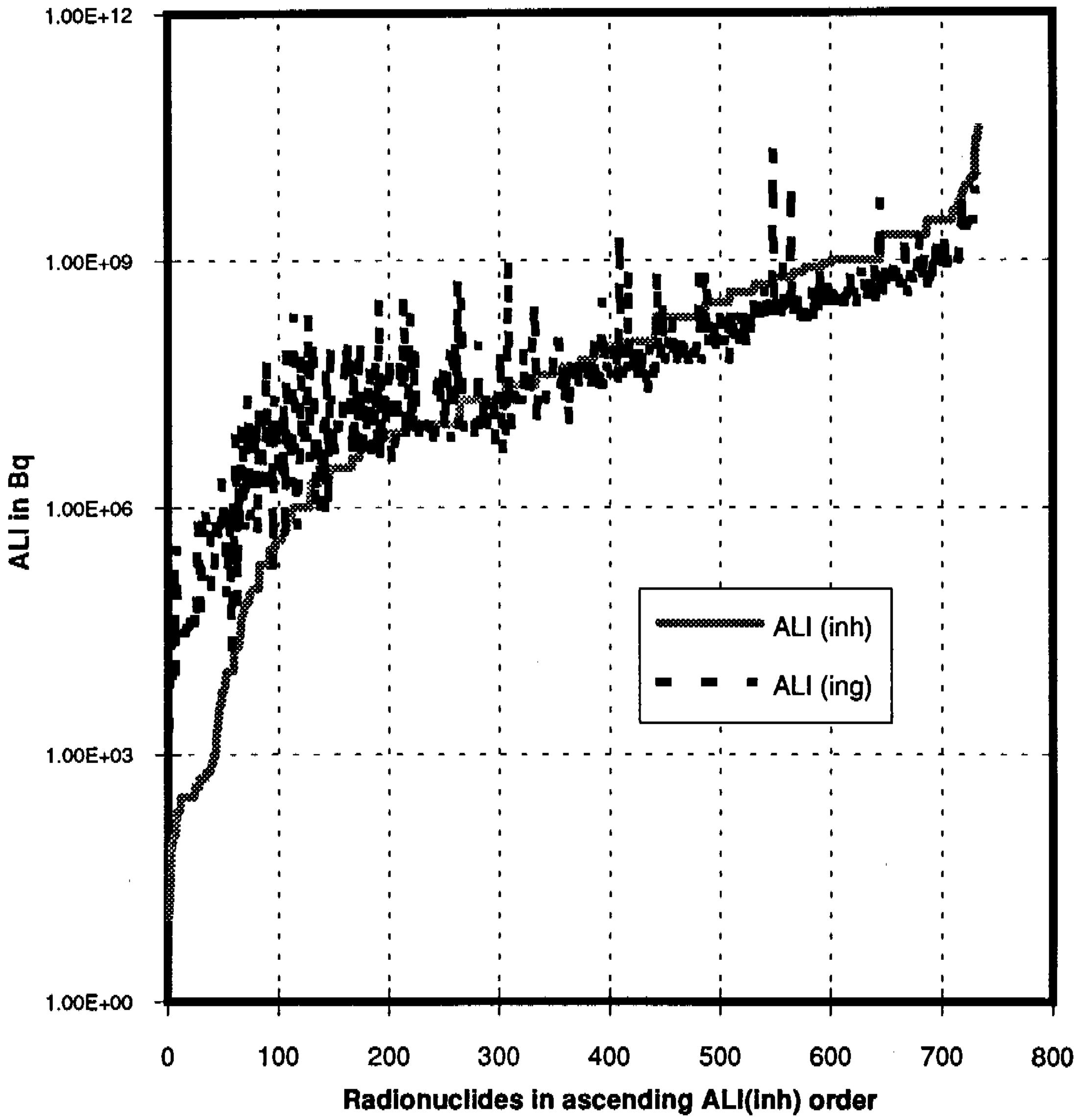

Figure 1 Most restrictive inhalation and ingestion ALIs from ICRP 61

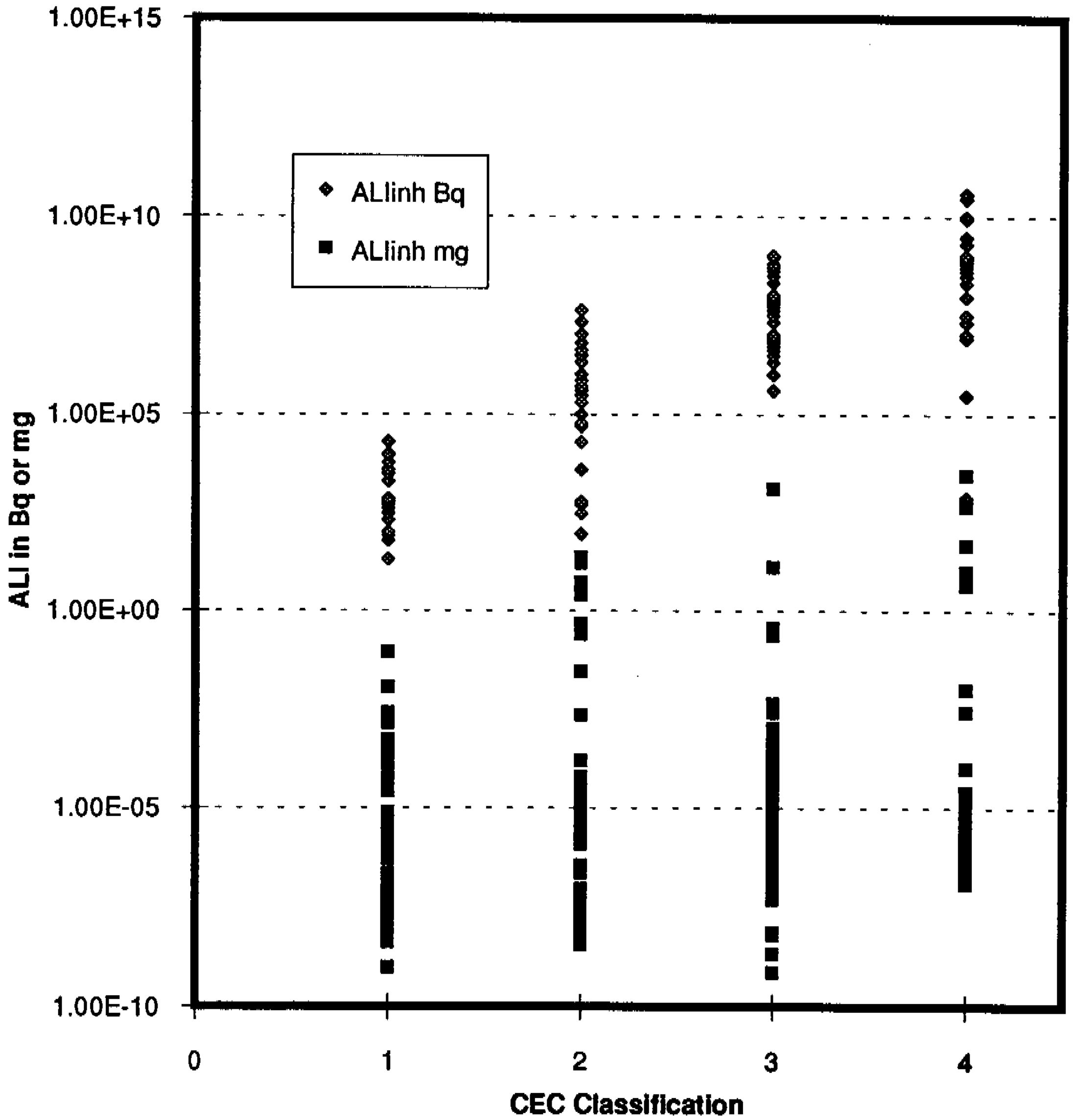

Figure 2 Comparison between CEC classification and ALI (inh) in Bq and in mg

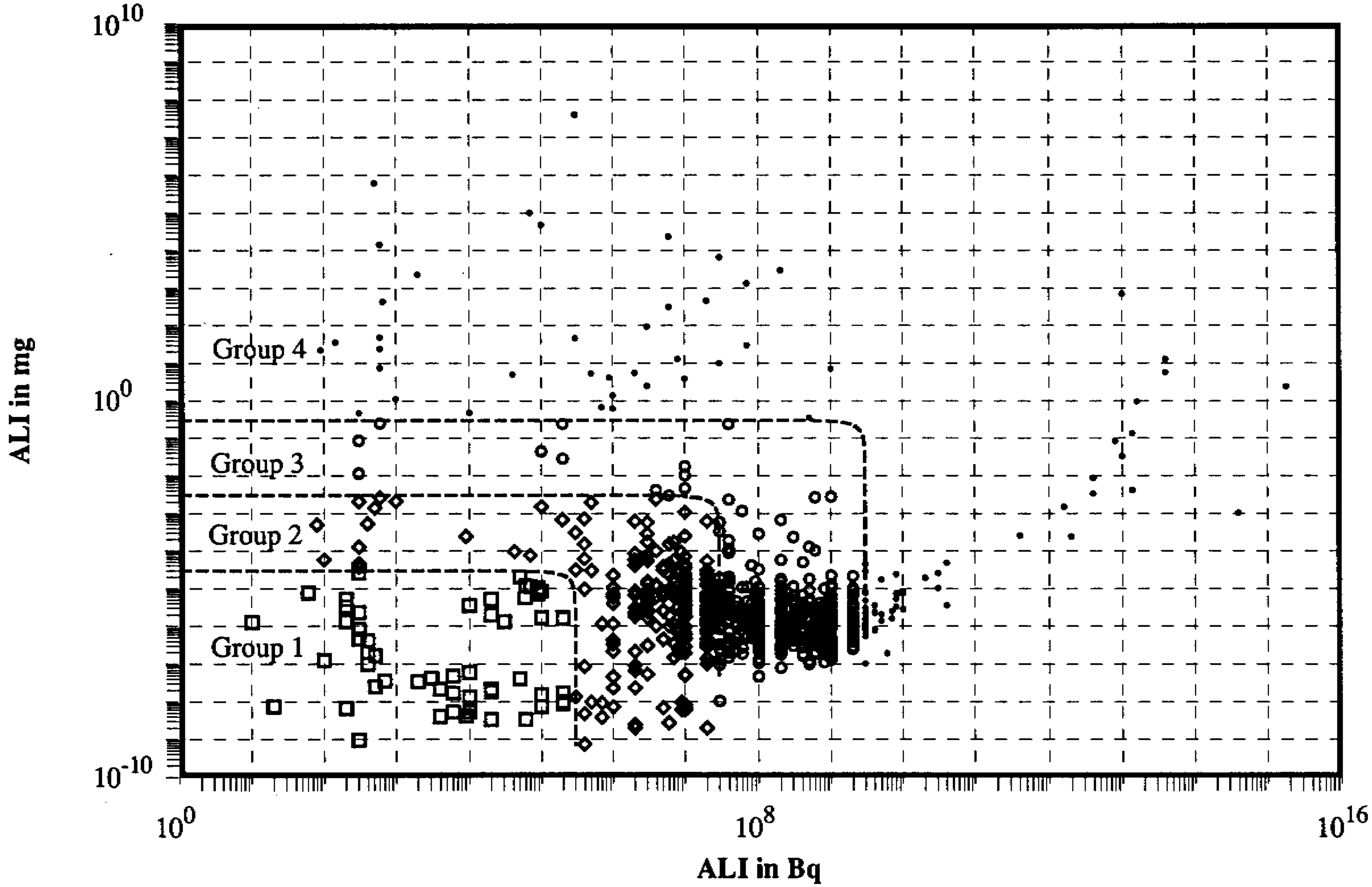

Figure 3 Distribution of ALIs in Bq and in mg showing the divisions between the hazard groups

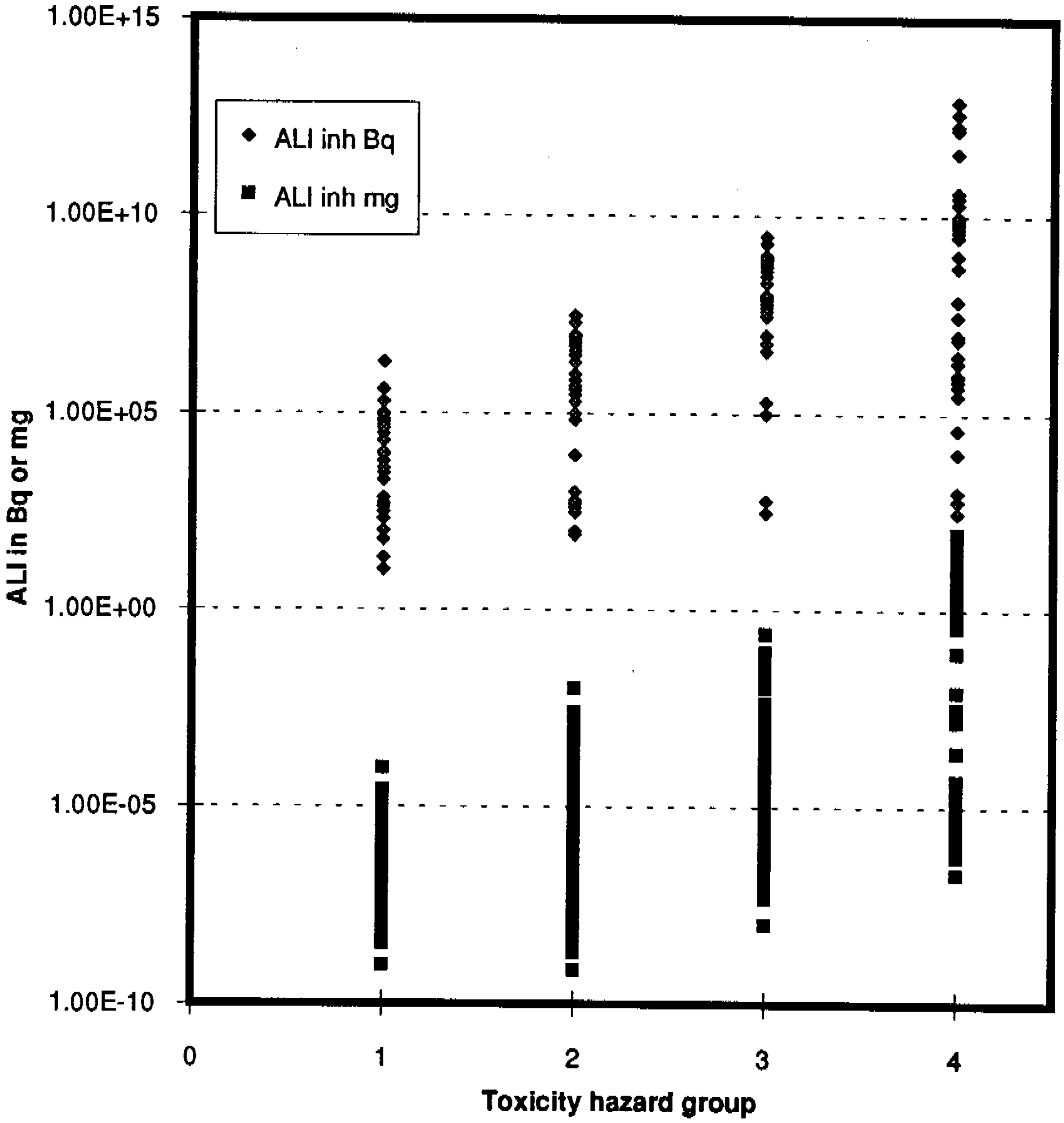

Figure 4 Range of ALIs in Bq and in mg in the proposed Australian radiotoxicity hazard groups