The Alpha Value Decrease When the Annual Individual Effective Dose Decreases?

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Abstract: A recent IAEA Publication tells that a few entities took different alpha values for maxima individual doses. Beyond to disregard the international agencies, that recommend only one alpha value for each country, the alpha values decreases when the individual doses decreases and the practice happens exactly the conversely as we will show in this paper. We will prove that the alpha value increase when the maximum individual doses decreases in a four different manner. The first one we call the theoretical conception and it is linked to the emergent of the ALARA policy and to the purpose that led to the 3/10 of the annual limits, for to decrease the individual doses as a first resort and a 1/10 as a last resort. The second prove will be based in a small mine example used in the ICRP publication nº 55 concerning to the optimization and the quantitative decision-aiding techniques in radiological protection where we will determine the alpha value ranges in which each radiological protection options becomes the analytical solution. The third prove will be based in the determination of the optimized thickness example of a plane shielding for a radiation source exposed in the ICRP publication nº 37. We will use, also, the numerical example provided there. Eventually, as four prove we will show that the alpha value dos not only increases with the maximum individual dose decrease, but also, with the shielding geometry.

KEYWORDS: Alpha Value; Radiological Protection Optimization; Individual Annual effective Dose

1. Introduction

The fact that made us write about this intriguing matter is a recent International Atomic Energy Agency, IAEA, publication that, in disagreement with the international recommendations to maintain a single alpha value for each country, showed that utilities, in several countries, adopted different alpha values for different maxima individual doses. We will transcribe the table presented in the IAEA publication [1].

Table 1: Monetary value of a man-sievert used by different utilities (system of values depending on the level of the annual individual dose)

Country	Utility	Year of adoption	Monetary value of a man-sievert in the national currency	Monetary value of a man-sievert in US $
Belgium	SCK.CEN	1995	<1 mSv: B.Fr. 1 000 000 1-2 mSv: B.Fr. 2500 000 2-5 mSv: B.Fr. 10 000 000 5-10 mSv: B.Fr. 25 000 000 10-20 mSv: B.Fr. 50 000 000 20-50 mSv: B.Fr. 200 000 000	<1 mSv: 27 000 1-2 mSv: 67 000 2-5 mSv: 267 000 5-10 mSv: 667000 10-20 mSv: 1 333 000 20-50 mSv: 5 333 000
Canada	Darlington: System dependent on	-	From a few thousand Can $ to Can $2 000 000 Example: workers in general:	From a few thousand US $ to 1 500 000 Example: workers in

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	the category of workers		Can $200 000, reactor maintenance teams: Can $1 500 000	general: 150 000, reactor maintenance teams: 1 130 000
France	Electricité de France	1993	0-1 mSv: EFr. 100000 1-5 mSv: EFr. 500 000 5-15 mSv: EFr. 2 300 000 15-30 mSv: F.Fr. 6700 000 30-50 mSv: EFr. 15 000 000	0-1 mSv: 17000 1-5 mSv: 83 000 5-15 mSv: 383 000 15-30 mSv: 1 117 000 30-50 mSv: 2 500 000
Germany	Proposal of the VGB under trial by the utilities	1996	<1 mSv: no value 1-10 mSv: DM 300 000 10-20 mSv: value growing linearly to reach DM 3 000 000 at 20 mSv	<1 mSv: no value 1-10 mSv:.170 000 10-20 mSv: value growing linearly to reach 1 695 000 at 20 mSv
Netherlands	Borselle	1992	<15 mSv: NLG 1 000 000 > 15 mSv: NLG 2 000 000	<15 mSv: 500 000 >15 mSv: 1 000 000
Spain	Cohrentes: system of values dependent on the annual collective dose level	1994	<3 man.Sv per reactor per year on average over 3 years: ESP 100 000 000 >3 man.Sv per reactor per year on average over 3 years: ESP 150 000 000	<3 man.Sv per reactor per year on average over 3 years: 667 000 >3 man.Sv per reactor per year on average over 3 years: 1 000 000
UK	Sizewell	-	NRPB set for workers: between £ 10 000 and £ 50 000	NRPB set for workers: between 17 000 and 85 000
USA	South Texas	1993	<10 mSv: US $500 000 >10 mSv: US $2 500 000	<10 mSv: 500 000 > 10 mSv: 2 500 000
Note: I US $ = B.Fr. 37.5, Can $1.33, EFr. 6, DM 1.77, NLG 2, ESP 150, £ 0.6 (as at 1998). SCK.CEN: Studiecentrum voor Kernenergie Centre d' étude de l'Energie Nuc1éaire. VGB: Technische Vereinigung der Grosskraftwerkbetreiber. NRPB: National Radiological Protection Board.				

Disobedience to the International Agencies recommendations is not so unusual; what surprise us is that, as the maximum annual effective dose increases, the suggested alpha value also increases and in practice what happens is the opposite.

We believe that this sophism, is due to the fact that the radiological protection optimization, as has been taught so far, starts assuming that the alpha value is higher for high individual doses and lower for smaller individual doses.

This kind of reasoning is based on the policy assumed by the International Commission on Radiological Protection, ICRP, according to which there is a dose-effect linearity, that is, in each increase in the radiation dose there is a proportional increase in the risk of a harmful effect to health.

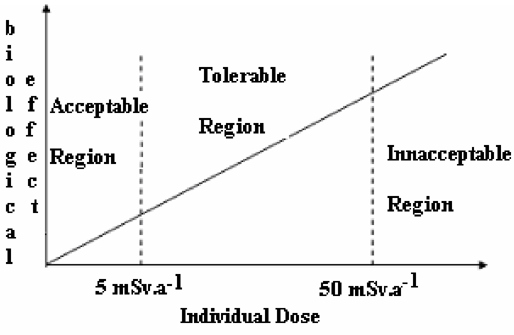
Actually, this is a sophism, for the alpha value is not associated with the dose-effect curve and, in practice, its value highly increases when the annual individual dose decreases. In this paper we intend to discuss this matter and, therefore, show that the table presented in the IAEA publication [1] is not practicable.

We will prove what we say by giving, at first, a theoretical basis of how the optimization principle was introduced and, consequently, the alpha value. Then we will give practical examples exposed in the ICRP publications number 55 [2] and 37 [3]. Eventually we show that the alpha value also increases according to the protection shielding geometry selected for the source, when the annual individual dose decreases, to below 5 mSv^{-1} the record level.

2. Theoretical Basis

According to the ICRP [4] the annual individual doses were classified in three regions, as shown in the graph below:

Figure 1: The three regions where the annual individual dose are classified



For the doses in the tolerable region we must to apply the optimization principle to reduce their values till they reach the acceptable region.

Making use of the quantitative decision-aiding techniques to make our decision we need to introduce the alpha value [5]. In the graph we can see that 50 $mSv.y^{-1}$ is the annual limit, AL, of effective dose, limit between the unacceptable and tolerable region while 5 $mSv.y^{-1}$, is the limit between the tolerable and acceptable region corresponding to the average dose of all workers monitored in the period and in the more developed countries. The ICRP decided to share the tolerable region in two, assuming the 3/10 of the annual limit value to reduce the individual dose, in the first instance, and 1/10, as a second choice.

Has 3/10 of the annual limit value been selected and not the other value?

At that time it was verified that all the Institutions dedicated to developing peaceful uses of ionizing radiation, independently of their size had a similar distribution of the workers individual doses. Also, independently of the number of type and sources, about 1.5% to 3.0% of the workers received doses above 3/10 of the ALs.

As a remark about what was declared, we remember that at that time, by suggestion of the deceased Dr. Walter Stephen Snyder we compared the IPEN individual dose distribution statistics with those of the Oak-Ridge National Laboratory about 10 times highest in number of workers but with a similar type of source although in a much higher number. The result was a similar individual dose distribution during the four years of research.

As 1.5% to 3.0% of workers is a very small quantity related to the total amount of workers and as we have a small number of place when make improvements in protection, was considered an adequate value to begin with and we will give priority to this worker category (1.5% to 3.0%). In this case the cost must not be high because only particular situations and a reduced number of people are involved.

The dose reduction from 3/10 to 1/10 of the AL, was left as a second choice because:

a) We will have acquired experience with the first group and so we will can have a solid judgement to know if is justifiable in terms of cost a second reduction to 1/10 ALs.

b) The number of workers from 1.5% to 3.0% will increase to 40% or more and, therefore, the number of situations and places that needed improvement will be very high and the cost can be unjustifiable.

From what we have exposed we can conclude that the attempt to reduce the annual doses to 3/10 is small if with its reduction from 3/10 to 1/10.

With this argument we believe that we have given a theoretical policy insight of why the alpha value increases when the annual individual dose decreases. Now we presents practical examples cited in the introduction of this paper, starting with a small uranium mine presented by ICRP in its publication number 55(2).

3. The Small Uranium Mine Example

In this example five radiological protection options were considered. There are 17 persons distributed in 3 (three) groups according to their occupational level in the several mine zone. The first two groups are composed of 4 (four) miners each and the third group of 9 (nine) miners. In table two the average individual doses of each group are shown in $Sv.y^{-1}$ and the collective dose of each protection option.

Table 2: Data for the options considered in the uranium mine example

Protection Option	**1**	**2**	**3**	**4**	**5**
Annual protection cost, $	10400	17200	18500	32200	35500
Annual collective dose, man Sv	0.561	0.357	0.335	0.196	0.178
Annual average individual doses to workers in group, mSv					
I	40.8	28.4	26.0	17.5	15.8
II	34.5	22.3	21.0	12.6	11.3
III	28.9	17.2	16.3	8.4	7.8
Discomfort from ventilation	No problems	slight	slight	severe	Difficult to work

In table 3 there is the option number, the average individual doses presents to the group that present the highest doses, that is, group I, radiological protection cost X, collective doses S, detriment cost α.S and X + α.S showing in bold-faced type the analytical solution identified in ICRP publication number 55(2). The alpha value used in the calculation is α = US$ 20,000.00.

Table 3 – Option number, higher average individual doses for each option, radiological protection cost, collective dose, detriment and total cost.

Option	**Maximum individual dose, $mSv.y^{-1}$**	**X US$**	**S Person-Sv**	**α.S US$**	**(X + α.S) US$**
1	40,8	10,400.00	0.561	11,200.00	**21,620.00**
2	28,4	17,200.00	0.357	7,140.00	24,320.00
3	26,0	18,500.00	0.335	6,700.00	25,200.00
4	17,5	32,200.00	0.196	3,920.00	36,120.00
5	15,8	35,500.00	0.187	3,560.00	39,060.00

The ICRP publication 55(2) also presents a graph where each point represents an option and is linked by straight lines, assuming that they are linear functions.

Considering the linearity we can make a study about the sensibility in relation to the alpha value, that is, we intend to verify what is the alpha value range, I which each of the five options is maintained as analytical solution. Using the equation $(X + \alpha.S)_{min}$ we will see that the range limitation between the five options will be obtained by the following equation in which the indices in X and S represents the option number:

$$(X_1 + \alpha_2 S_1) = (X_2 + \alpha_2 S_2)$$
$$(X_2 + \alpha_3 S_2) = (X_3 + \alpha_3 S_3)$$
$$(X_3 + \alpha_4 S_3) = (X_4 + \alpha_4 S_4)$$
$$(X_4 + \alpha_5 S_4) = (X_5 + \alpha_5 S_5)$$

In this case, the α_2 is the alpha value in the linear limit between the option 1 and 2, α_3 between the option 2 and 3, and so on.

Solving in relation to the alpha value we obtain:

$$\alpha_2 = \frac{X_2 - X_1}{S_1 - S_2}; \quad \alpha_3 = \frac{X_3 - X_2}{S_2 - S_3}; \quad \alpha_4 = \frac{X_4 - X_3}{S_3 - S_4}; \quad \text{and} \quad \alpha_5 = \frac{X_5 - X_4}{S_4 - S_5};$$

In table four we show the maxima individual doses, the decrease in the individual doses for the different options and the corresponding alpha value range.

Table 4: Option number, maximum individual doses, decrease in the individual dose for the different options and the alpha value range.

Option	E_{max} mSv	Decrease E	Alpha value range US$
1	40,8	-	≤ 33,333.33
2	28,4	12,4	33,333.33 < α ≤ 59,090.91
3	26,0	2,4	59,090.91 < α ≤ 98,561.15
4	17,5	8,5	98,561.15 < α ≤ 183,333.3
5	15,8	1,7	α > 183,333.3

As we can see in the column two and four, as the maximum individual doses decreases the alpha value increases continually.

4. Determination of an Optimized Plane Shield Thickness for a Radiation Sources, with an Example Presented in the ICRP Publication nº 37[3]

In this example, it is assumed that the effective dose rate, $\dot{H}_E$ at a point on the external face of a simple planar shield is, approximately,

$$\dot{H}_E = \dot{H}_u . e^{-\Gamma . w} \quad (1)$$

where $\dot{H}_u$ is the maximum effective dose rate, that would be incurred by a hypothetical receptor in contact with the external face of a minimum thickness shield (in the practical shielding design, $\dot{H}_u$ can be taken as the maximum dose-effective rate at the point of occupancy considered outside the shield) in any case $\dot{H}_u \le \dot{H}_L$;

where

$\dot{H}_L$	is the individual effective dose annual limit.
Γ	is the effective attenuation coefficient (including the build-up effect);
w	is the thickness of the extra shield; and, therefore,
$e^{-\Gamma w}$	is the dose reduction factor of the extra shield.

Assuming a constant ratio, ρ, between average and maximum individual doses the average effective dose-equivalent rate incurred by the exposed person will be:

$$\overline{\dot{H}_E} = \rho.\dot{H}_u.e^{\Gamma.w}$$

Assuming that the lifetime of the shield in the example is τ and that N persons are exposed in the radiation field during a fraction of time f_t (occupancy time factor), the collective dose, S_E can be represented by the following equation:

$$S_E = Nf_t\tau\overline{\dot{H}_E} = Nf_t\tau\rho\dot{H}_u.e^{-\Gamma w}$$

The function of the cost of detriment, Y = Y (w), can, therefore, be formalized as follows:

$$Y(w) = \alpha Nf_t\tau\rho\dot{H}_u e^{-\Gamma w}$$

Further, assuming that the shield in the example is rectangular, the function of protection cost, X = X(w), (cost of the shield as a function of thickness) is

$$X(w) = X_S = X_V hlw + X_I$$

Where

X_v	is the cost per volume unit of shielding material installed
H	is the shield height;
L	is the shield length;
w	is the shield thickness; and
X_I,	is the cost of the support installation, which, in the case of this example, is assumed to be constant in the small range of thickness variation.

The objective function of the example results from the sum of the cost equations:

$$U = X(w) + Y(w) = X_V hlw + X_I + \alpha Nf_t\tau\rho\dot{H}_u e^{-\Gamma w}$$

In order to obtain the optimum shield thickness, w_0, the objective function must be minimized with respect to w. This can be done by differentiating the objective function with respect to w and equation to zero. Thus,

$$X_V hl - \alpha Nf_1\tau\rho\dot{H}_u\Gamma.e^{-\Gamma w_0}$$

From this equation the optimized dose reduction factor, $e^{-\Gamma w_0}$, can be derived

$$e^{-\Gamma w_0} = \frac{X_V hl}{\alpha Nf_t\tau\rho\dot{H}_u\Gamma} \qquad (2)$$

Applying the napierian logarithm, we have

$$-\Gamma w_0 = \ln X_V \lambda h - \ln \alpha N f_t \tau\rho \overset{\bullet}{E}_u \Gamma \qquad \text{or} \qquad w_0 = \frac{(\ln \alpha N f_i \tau\rho \overset{\bullet}{E}_u \Gamma - \ln X_V \lambda h)}{\Gamma}$$

The optimized shield thickness will be equal to the sum of the initial thickness plus the extra thickness resulting from the above optimized dose reduction factor.

Now we present a numerical example of optimization of a simple shield in a "hot" corridor of a controlled laboratory. It is assumed that the shield material is standard concrete and that its installed cost is 100 \$ m^{-3}. The value of α is assumed to be 10^4 S (man Sv)$^{-1}$. The gamma-radiation energy is about 0.7 MeV, so that the effective attenuation coefficient is ~ 14 m^{-1}. The value of ρ is assumed to be 10^{-1}. The total time of exposure (i.e. the lifetime of the installation times the occupancy factor) is taken to be 20 years. The number of people working is assumed to be one worker per 15 square meters of shield surface. The maximum effective dose-rate without extra shielding, $\overset{\bullet}{H}_u$ is taken to be 0,05 Sv.y^{-1} (5 rem.y^{-1}).

Under the above assumption and using the expression (1), an optimum dose reduction factor can be obtained:

$$e^{-\Gamma w_0} = \frac{X_V h l}{\tau\alpha\Gamma \overset{\bullet}{H}_u f_t \rho N} = \frac{10^2\$.m^{-3}15m^2.man^{-1}}{10^4\$(man.Sv)^{-1}.14m^{-1}.5.10^{-2}Sv.y^{-1}.0.1.20y} \quad (3)$$

Thus,

$$e^{-\Gamma w_0} = 0{,}1 \quad (4)$$

Therefore, the optimized dose reduction factor becomes 10^{-1}. This means that in this example it is worthwhile, as a design objective, to reduce the limit dose rate (i.e. that ensuring compliance with the dose limits) by a factor of ten.

The thickness to be added will be:

$$\Gamma w_0 = -n0.1 \qquad \text{or} \qquad \frac{\ln 0.1}{14} = 0.16m$$

And doses by equation (1) and (4) will be:

$$\overset{\bullet}{H}_E = 5.10^2.0.1 = .10^{-3}Sv.y^{-1}$$

From these results if we perform a new optimization using the data from equation (3) and the new value of the doses, we obtain

$$e^{-\Gamma w_0} = \frac{10^2.\$.m^{-3}.15m^2.man^{-1}}{10^4.\$.(man.Sv)^{-1}.14m^{-1}.5.10^{-3}Sv.y^{-1}.0.1.20y} \qquad \text{or} \qquad e^{-\Gamma w_0} = 0{,}54 \quad \text{and}$$

$$\Gamma w_0 = \frac{-\ln 0{,}54}{14} = \frac{0.616186}{14} = 0.044m$$

In the first optimization if we change the alpha value to US$ 5,000.00 instead of US$ 10,000.00 using the equation (3) we have:

$$e^{-\Gamma w_0} = 0.2 \text{ and}$$

$$\Gamma w_0 = -\ln 0.2 \quad \text{or} \quad w = \frac{-\ln 0{,}2}{14} = 0{,}11m$$

From these three results we can conclude:

a) When we change the alpha value from US$ 5,000.00 to US$ 10,000.00, assuming that the shield cost is directly proportional, the shielding thickness is changed from 11 cm to 16 cm and not 22 cm as would be expected in case of linearity;

b) When we perform a second optimization considering the alpha value of US$ 10,000.00 the thickness increases only 4.4 cm instead of 16 cm as occurred in the first optimization;

c) Starting with the second optimization if we want to obtain the same thickness of 16 cm as a result we need to increase the alpha value higher than the US$ 10,000.00 initially used.

These results can also be deduced by this example:

Assuming:
1 – Planar shield, the decrease of the doses is given by the shielding thickness.
2 – The half layer value is 1 cm.
3 – With 10 cm thickness. The effective dose is 1,024 mSv.y^{-1}.
4 – Involved People l: 1 person and then the individual dose is also the collective dose.
5 – The shielding cost is A times the shielding thickness in cm.

Having in mind the following equations of the optimization

$$\frac{-dX}{dS^H} = \frac{dY}{dS^H} == \alpha$$

we conclude that when we add a half layer value the collective doses will decrease from 1,024 mSv.y^{-1} to 512 mSv.y^{-1} and, therefore, the alpha value will be (A. 1.1000)/512 ≅ 2.A because it is defined per Sv. Number 1 means that only one individual is involved.

But when we change from 20 cm to 21 cm thickness, adding the same half layer value of 1 cm the dose decrease will be from 2 mSv.y^{-1} to 1 mSv.y^{-1} but the alpha value will be:

$$\frac{A.1.1000}{(2-1)} = 1000.A \text{ in place of 2.A}$$

The alpha value is increased by a factor of 500.

5. Alpha Value Increase as a Function of the Shielding Geometry.

We will start by considering a particular shielding with the following assumptions;

a) The source shielding is spherical, for it does not have shielded regions in excess.
b) The radioactive source remains in the shielding center and the used space iis 2 cm in diameter.

c) The half value layer of the source is 1 cm of lead thickness.
d) 11 (eleven) cm of thickness present an individual effective dose of 1024 mSv.y^{-1}.
e) The number of workers is constant for different thickness shielding. We will consider an individual; so the collective effective dose is the same as the individual effective dose.
f) The lead cost per cm^3 is A
g) The total cost is X.

Thesis: To determine the different alpha values, US$ Sv^{-1} person^{-1} as the shielding thickness increases.

Deduction: Volume space used by the source, V_f:

$$V_f = \frac{4}{3}\pi.R^3 = \frac{4}{3}.3.14.1^3 = 4.19cm^3$$

5.1 To Determine Alpha value When the Shielding Thickness is Increased from 11 cm to 12 cm.

Shielding volume: V
Shielding radius: R
Shielding cost: X = (V –V$_f$)A

$$V_{11} = \frac{4}{3}.\pi.R_{12}^3 - 4.19 = 7{,}236cm^3 \qquad X_{11} = 7{,}236.AUS\$ \ ;$$

$$V_{12} = \frac{4}{3}.\pi.R_{13}^3 - 4.19 = 9{,}201cm^3 \qquad X_{12} = 9{,}201.AUS\$$$

Using the optimization differential equation $\frac{dX}{dS} = \alpha$ we obtain:

$$\frac{dX}{dS} = \frac{(9{,}201 - 78{,}236).A}{(1{,}024 - 512).10^{-3}} = \frac{1{,}965.A}{512.10^{-3}} = 3.84.10^3.AUS\$.(Sv.person)^{-1}$$

Observation: 10^{-3} represents the change from mSv to Sv.

5.2 Alpha Value Calculation When We Change Shielding Thickness from 19 cm to 20 cm.

Assumption: collective dose: 4mSv.y^{-1} for 19cm thickness and 2 mSv.y^{-1} for 20 cm thickness.

$$V_{19} = \frac{4}{3}.\pi.R_{20}^3 - 4.19 = 33{,}516cm^3 \qquad X_{19} = 33{,}516.AUS\$$$

$$V_{20} = \frac{4}{3}.\pi.R_{21}^3 - 4.19 = 38{,}799cm^3 \qquad X_{20} = 38{,}799.AUS\$$$

$$\frac{dX}{dS} = \frac{(38{,}799 - 33{,}516).A}{(4-2).10^{-3}} = \frac{5{,}283.A}{2.10^{-3}} = 2{,}641.50.AUS\$.(Sv.person)^{-1}$$

5.3 Alpha Value Calculation When We Change Shielding Thickness from 20 cm to 21 cm

Collective dose: 2 mSv.y^{-1} for 20 cm of thickness and 1 mSv.y^{-1} for 21 cm thickness:

$$V_{20} = 38{,}799 cm^3 \qquad X_{20} = 38{,}799.A.US\$$$

$$V_{21} = \frac{4}{3}.\pi.R_{22}^3 - 4.19 = 44{,}611 cm^3 \qquad X_{21} = 44{,}611.A.US\$$$

$$\frac{dX}{dS} = \frac{(44{,}611 - 38{,}799).A}{(2-1).10^{-3}} = 5{,}812.10^3.A.US\$.(Sv.person)^{-1}$$

5.4 Results:

a) When we added 1cm of lead thickness, from 11cm to 12cm, the alpha value was 3.84.10^3 A US\$.(Sv person)$^{-1}$, the collective dose avoided, reduced the individual effective dose of 512 mSv.y^{-1}.

b) From 19 cm to 20 cm the alpha value was 2,641.50x10^3.A.US\$.(Sv.person)$^{-1}$ and the avoided collective dose has 2 mSv.y^{-1} per Sv.person. The avoided collective dose was 1mSv.y^{-1}.

If the source shielding geometry is different from the spherical ones, the alpha value will increase more with the decrease of the maximum annual individual doses because there is shielding material in excess in specific places depending on the geometric buck, such as cubic, parallelepiped, cylindrical etc.

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