CONSIDERATION OF THE OVERALL IMPACT OF AN EMISSION WHEN SETTING STANDARDS FOR AIR POLLUTION CONTROL

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SINOPSIS:

Vrylatings vanaf toenemende hoogtes, lei tot 'n verbetering in die verdunning van die pluim en dus ook tot 'n verhoging in vrylatingstempo wat geduld kan word om dieselfde grondvlakkonsentrasie te handhaaf. Skoorstene word dikwels verkeerd aangewend deur slegs die grondvlakkonsentrasie in aanmerking te neem terwyl die totale invloed van die vrylating buite rekening gelaat word.

In die kernbedryf word die beheer oor radioaktiewe vrylatings aan die omgewing op twee belangrike vereistes gegrond, nl.: dosisperke (luggehaltestandaarde) mag hoegenaamd nie oorskry word nie, en; dosisse moet so laag as wat redelik moontlik is gehou word, wat vereis dat die totale blootstelling vanaf alle stralingsdosisse, selfs dié wat benede die dosisperk is, aan alle lede van die publiek nou en in die toekoms, in ag geneem moet word.

Toelaatbare vrylatings word bepaal met inagneming van die totale invloed van die vrylating en deur die vrylating tot op die punt te optimeer waar die bykomende beskerming wat verkry sal word nie die koste sal regverdig om die vrylating verder te beperk nie.

SYNOPSIS:

By increasing the release height, dispersion of the effluent is improved and thus the release rate that can be tolerated for the same air concentration at ground level is also increased. Stacks are thus often misapplied if the ground-level concentration alone is taken into account, while total release, and thus the overall impact, are disregarded.

In the nuclear industry the control of radioactive releases to the environment is based on two important requirements, viz.: dose limits (air-quality standards) may under no circumstances be exceeded, and; doses should be kept as low as reasonably achievable, which requires that total exposure from all doses, even those well below the dose limit, to all members of the public and for all future time, should be considered.

Permissible releases are determined by taking into account the overall impact of the release and optimising the release to the point where the cost of further decreasing the amount is not justified by the additional protection obtained.

INTRODUCTION:

Present air-pollution control legislation in South Africa does not include any statutory air-quality standards. The approach adopted is to reduce emissions to the atmosphere through the principle of best practical means. This requires that measures be taken which are technically feasible and economically possible, while also bearing in mind the need to protect the public.[1]

This approach introduces a great deal of subjectivity and, in the absence of a quantitative relationship between the environmental concentration and detrimental effect to the individual, it relies heavily on value judgements on the part of the regulatory authority, which could be totally unrelated to the costs and benefits of the particular practice to the public. More effective protection of man and his environment requires that emission levels be based on quantitative standards of permissible ambient concentrations for the various pollutants in the environment. Such a system is not only based on sounder principles but can also be enforced more effectively.

Once a permissible concentration limit (air quality standard) has been established, releases are controlled to ensure that the limits are met by either limiting the rate of release or using the dispersion characteristics of the atmosphere. The latter can be improved by proper siting and by increasing the height of the release points through the use of taller stacks. Although these measures are effective in lowering the ground-level concentration to permissible levels, they do not decrease the total pollution, at the same time disregarding the overall impact of the pollutants.

Furthermore, because the number of individual sources increases, it is important to consider not only local but also regional and global effects. While the contribution from a particular source may meet the local air quality standards, contributions from other similar sources may create an unacceptable situation in which the permissible limits are exceeded. Also, due to the continuous nature of the sources, gradual build-up will occur in the environment and releases must therefore also be considered from the viewpoint of their future potential.

While concentration limits may ensure sufficient protection for those pollutants having a threshold limit, below which no detrimental effects occur, the presence of such a threshold may be difficult to prove due to possible synergistic effects with other pollutants. If no threshold limit exists then all exposures down to the lowest levels must be considered and the collective exposure (persons x dose) must be calculated.

2. *INDIVIDUAL EXPOSURE VERSUS COLLECTIVE EXPOSURE*

To illustrate the concern that has arisen, the average dispersion data for Great Britain[2], shown in Fig. 1, are used to compare the effect of stack height. Let us assume that the air quality standard requires a concentration of 4,5 x 10^{-7} units/m^3 at the boundary of the premises of the particular industry, and that this is 400 m from the release point. From Fig. 1 it may be seen that this norm can be achieved either by constructing a 40 m stack and releasing 1 unit/s from it, or by reducing the release rate from a 10 m stack by a factor 10 to a value of 0,1 unit/s. The latter alternative meets the air quality standard at 400 m and, in addition, results in greatly reduced concentrations at larger distances compared to the release of 1 unit/s at 40 m. The release at 40 m, however, does result in drastically reduced concentration levels close to the release point and up to 400 m from it. As this area falls within the premises of the particularly facility, it is considered an occupational area where less restrictive air quality standards normally prevail. Occupational air quality standards are typically 10 to 50 times less restrictive than those for the general public.

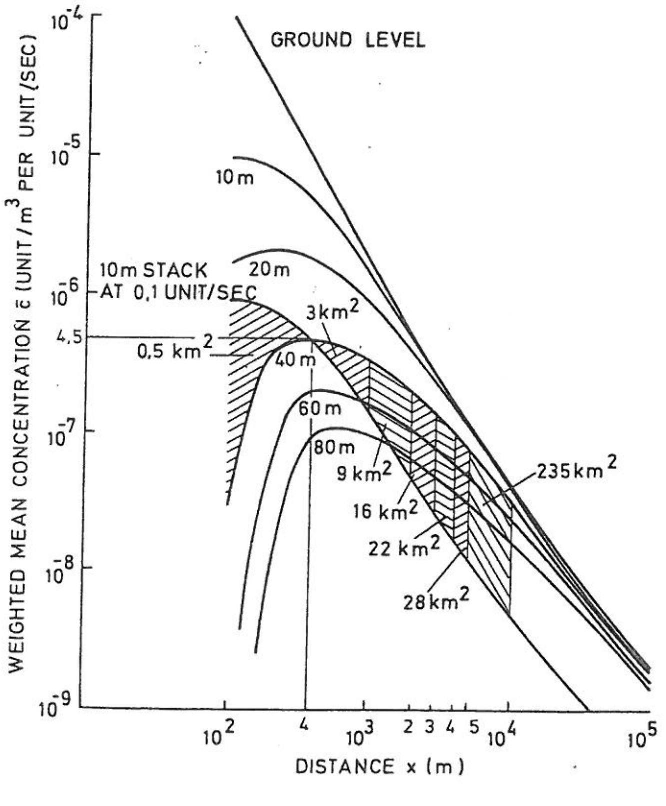

FIGURE 1: Weighted mean concentration from a continuous release from various stack heights.

The hatched areas show the concentration difference resulting from the two release modes. Also indicated are the surface areas of the regions within the respective radii of circles drawn around the release point. If the population density in each of these regions is known, the collective exposure can be calculated. As the concentration levels decline sharply with distance, the collective dose will be strongly dependent on the population distribution close to the site. Furthermore, if air-quality standards were the only norm for determining permissible releases, doubling of the stack height would allow release rates, and therefore also total releases, to be increased 3 to 5 times.

In Fig. 2 the variation in collective exposure is shown as a function of distance from the release point for various release heights at two nuclear power sites in Britain.[3] The release rate for each stack height was such that the concentration at the site boundary was constant and equal to the air-quality standard. The collective exposure varied by two orders of magnitude, depending on the site location,

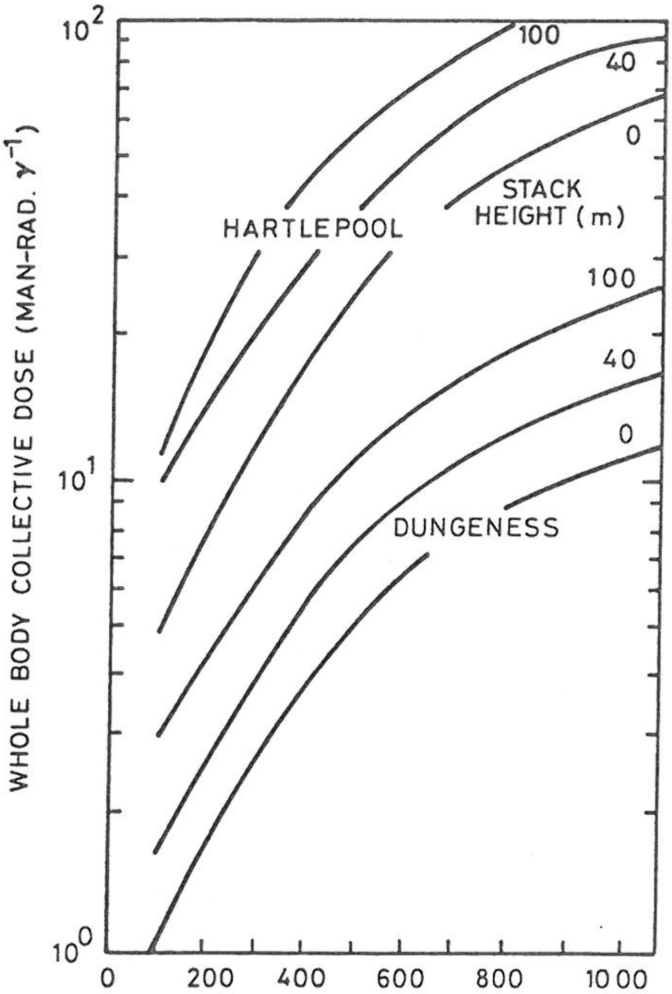

FIGURE 2: Whole body collective dose per year per mrad per year at the site boundary as a function of that distance and height of release for noble gases (Ref. 3).

boundary distance and release height, which demonstrates the major shortcoming of limiting releases to conform only to air-quality standards while disregarding the overall impact.

3. *CONTROL OF RADIOACTIVE RELEASES*

In a manner analogous to the present need for control of conventional pollution, standards for the release of radioactivity to the environment were initially based on dose limits which were defined as levels of exposure not expected to result in any significant increase in harm. These dose limits related both to individuals and the population as a whole; in practice, however, the criteria for releases were set almost entirely in terms of the individual most exposed.

The environmental media of air and water were considered the major carriers of the pollutants from source to man; from the assumed average daily volume of air inhaled and water consumed, as well as from knowledge of the metabolic behaviour of particular elements, maximum permissible concentrations which would not result in the specified dose limits being exceeded were calculated for each individual nuclide. Release limits are calculated by taking into account normal dilution and dispersion that will not lead to the maximum permissible concentration in air or water being exceeded at any point where the public may be exposed. This procedure, although a vast improvement on previous procedures, did not, if effluent rates were high, prevent substantial amounts of radioactive material from reaching the environment, nor did it take ecological concentration processes into account. As a further development of the process of setting emission standards, the principle of the critical pathway was introduced. In this approach all food chains and all the various pathways by means of which the released material could return to man had to be investigated. Those resulting in the highest exposures were termed the critical pathways. A concentration limit was then derived for the critical food product which, if consumed at the rate determined by a 'habits' survey, would result in a dose limit to the critical group. By applying data on environmental dispersion and transfer, a permissible release-rate limit could be determined. These limits were never to be exceeded and encouragement was given to keep the release rate as low as reasonably achievable (ALARA).

More recently the international body responsible for radiation protection became concerned by the rapid growth in the generation of nuclear power and expanded its recommendations to include concern for population exposure and the increase in the number of sources, by introducing the concepts of a collective dose and a dose commitment.

The collective dose is defined as the weighted product of dose due to the source and the number of individuals of the exposed population, and is expressed mathematically as

$$S = \int_0^\infty D.N_D(D).dD$$

where $N_D(D)$ is the population spectrum in dose, $N_D(D)$. dD being the Number of individuals receiving a dose between D and D + dD. The collective dose can be applied to a single person, a population group or the earth's population as a whole.

As the exposure can continue for a considerable time after the original release, normally at a steadily decreasing rate, the dose commitment is the infinite time integral of the collective dose rate and is given by the expression

$$S_k^c = \int_0^\infty S_k(t)dt$$

where S_k^c = the collective dose commitment due a particular practice k

$S_k(t)$ = collective dose rate due to the same practice k.

The principles of radiation protection[4] which must be applied when setting limits for release to the environment can be summarized as follows:

(i) no individual shall receive from all sources radiation doses which exceed the dose limits recommended by the ICRP, either now or at some time in the future when the number of sources of radiation has increased; and

(ii) all radiation doses must be kept as low as reasonably achievable, economic and social considerations being taken into account. This implies optimisation of protection; the value of the annual discharge that meets this requirement is obtained by differential cost-benefit analysis.

3.1 *Dose limits*

Although it would appear that dose limits become superfluous with the introduction of a quantitative measure of ALARA (as low as reasonably achievable), these limits are important to ensure adequate protection for the most highly exposed individuals. Since, in practice, the distribution of costs and benefits is not the same throughout the population, the attempt to justify an installation or practice by a cost-benefit approach will be legitimate only if the detriment to each individual is small – i.e. not exceeding an acceptable limit. Dose limits therefore remain a primary requirement for protection of the public.

In order to ensure that dose limits will also be adhered to in the presence of multiple sources, and in future when contributions from old and new practices must be considered, the collective dose commitment per year of practice of each source must be controlled.

If several practices, j, are continued at a rate R_j (releases per year), the global or regional per capita dose rate will increase and reach a steady-state value given by

$$\bar{D}_\infty = \frac{1}{N} \sum_j R_j S_j$$

where N is the world or regional population and S_j the collective dose commitment per unit practice. Application of a limit to S_j, requires information on the fraction of $\bar{D}_\infty$ which would be allocated for the practice, j, and a projection of $\frac{R_j}{N}$ the per capita practice rate.

In the case of nuclear power production, the annual individual dose limit for all practices of this kind now and in future is set at 10 mrem per person[5]. Therefore

$$\frac{R}{N} . S \leq 10 \text{ mrem/a}$$

Assuming a future global nuclear installed capacity of 1 kW(e) per person, the above dose limit can be met by limiting the collective dose commitment per unit practice to 10 man-rem per MW(e) produced per year.

3.2 *Optimisation*

Although the principle of keeping doses as low as reasonably achievable was always part of radiation protection principles, it has now been quantified and requires optimisation of radiation protection. This involves estimation of the total detriment to the population which, because of the assumption of a linear dose-response relationship, is proportional to the collective dose. Optimisation is achieved by reducing the collective dose to a value such that the cost of further reduction is not justified by the additional protection obtained. This principle is mathematically expressed as

$$B = V - (P + X + Y)$$

where

B is the net benefit
V is the gross benefit
P is the production cost
X is the cost of a selected level of protection
Y is the detriment due to the operation.

The optimum net benefit will be attained at a value of the collective dose commitment (S) such that

$$\frac{dV}{dS} - (\frac{dP}{dS} + \frac{dX}{dS} + \frac{dY}{dS}) = 0,$$

as V P are constant with regard to S

$$(\frac{dX}{dS_s}) = -(\frac{dY}{dS_s})$$

The detriment is directly proportional to the collective dose commitment from the practice during its useful life; therefore

$$\frac{dY}{dS} = \alpha \text{ is the detriment cost per unit}$$

of collective dose, and values between $10 and $250 per man-rem have been suggested by various regulatory authorities, with a value of $100 per manrem as fairly representative[5]. In practice, changes in protection and detriment are achieved in finite increments rather than in continuous fashion. The expression therefore reduces to

$$\frac{X_B - X_A}{S_B - S_A} < \alpha$$

or, expressed in words, the optimisation principle requires that protective action be mandatory when the cost of saving 1 man-rem is less than $100, but is not justified when it exceeds this amount, on condition, however, that the dose limits are adhered to. No costs may be saved on the latter once a practice has been justified.

The following is a practical example[5] of the optimisation procedure for gaseous effluent from a nuclear power station. In this case releases could be controlled by four alternatives, namely:

A delay tank
B delay tank plus recombinator
C delay tank plus recombinator plus charcoal column
D C plus an inactive gland seal system

In the table the integrated exposure over the life of the installation i.e. the collective dose commitment (S) plus the cost of each alternative (X) is given.

Alternative	A		B		C		D
S (man-rem)	12 000		160		12		8
X ($ x10^{-6})	2,32		3,26		4,66		9,32
ΔX		0,94		1,4		4,66	
ΔS		11 840		148		4	
$\frac{\Delta X}{\Delta S}$ ($ per man-rem)		79		9,460		1 165 000	

Thus it is obvious that the introduction of alternative B, which will cost $79 per man-rem saved, is cost-effective, and that alternatives C and D are neither justified nor necessary as the individual dose commitment from alternative B is well below the individual dose limit.

4. *CONCLUSION:*

The control of radioactive pollution as practised in the nuclear industry is based on a system of dose limitation which requires a knowledge of the dose-effect relationship to establish dose limits, and a measure of the total detriment due to the release, which again is related to the collective dose. The detriment is expressed in terms of a monetary value which is then used in a cost-benefit analysis to obtain a level of protection which is optimum in terms of the cost of pollution reduction.

In this system stacks are important in providing dispersion in the case of unplanned releases, but they should not be employed for the purpose of dealing with increased releases during normal operation, in accordance with the principle of ALARA (as low as reasonably achievable) which requires consideration of the overall impact of a release.

In order to apply this approach to the control of non-radioactive pollutants, it would be necessary to establish a common measure of effect which will allow the summation of effects from various pollutants. In addition the exposure-effect relationship for the various pollutants, and a relationship between detriment and collective exposure, must be established. Although this is a formidable task, the system is based on sound principles and may prove to be the most satisfactory approach to pollution control.

5. *REFERENCES*

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