PLANNING OF COMBINED EXTERNAL IRRADIATION AND INTERNAL CONTAMINATION TO REDUCE DOSE IN NUCLEAR POWER PLANT OPERATIONS

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In nuclear power plants many operations, especially during inspection, maintenance and repair, have to be carried out in cramped conditions for lack of space. Gradually the need is growing to omit, where acceptable, the hampering use of protective breathing apparatus. This may improve the quality of work - which can have a safety aspect - and it speeds up the work - which may reduce the dose from external irradiation. Though a dose by internal contamination is added, in many cases a lower total dose can be reached. This praxis however requires the introduction of a practical system of planning, controlling and accounting for internal contamination based on the evaluation of the consequences of single organ doses. For lack of time and space this paper is mainly restricted to the last aspect.

The combination of total body dose by external irradiation and organ doses by internal contamination has to be based on the sum of the respective effects. In 1969 suggestions in this direction were made by an ICRP task group [1] and more recently by Jacobi [2]. They abandoned the critical organ concept rooted in the original 15 rem/year limit for the total body (before 1956), later restricted to a maximum of 5 rem/year for gonads and blood forming organs and, consequently, for (homogeneous) total body irradiation. As far it regards somatic effects - the only effects discussed in this paper - this concept is mainly based on cancer inductions observed in atomic bomb survivors and ankylosing spondylitis patients, both groups being more vulnerable than radiological workers. This basis accounts, more or less, for synergism.

In this paper the work of ICRP and Jacobi is modified and extended

a) by using the BEIR-1972-model [3] of latent periods (2 years for leukaemia, 15 years for other cancers) and risk periods of 25 and 30 years, respectively, with constant absolute risks per rem per year per 10^6 persons (r) ;

b) by considering life expectancies which may reduce risk periods for doses given at later ages ;

c) by introducing a worst-cases-system for the organ dose reduction factors f_o, which are used to derive an equivalent total-body-dose-equivalent Δ from the organ dose D_o ($\Delta_o = f_o D_o$, subscript o means organ). For this purpose the risk estimates derived from [1], [2], [3] and from the 1972-UNSCEAR [4] are compared.

Points a) and b) will be elucidated with an example based on risks r given by BEIR, [3] p.171. These values (see table 1) are multiplied by 5, the number of rems for the yearly maximum permissible total body dose MPD, nowadays accepted, and by the number of years at risk. These products give the lifetime risks R.

Two cases are considered :

a) a single dose of 5 rem at a relatively low age so that the full risk periods lay within the life expectancy (lifetime risk $R_{5,1x}$).

b) yearly doses of 5 rem from 18 till 65 years of age. Lifetime risk $R_{5,y}$. Here a number of the risk periods are limited by death. The life expectancies of Dutch men and women were used.

The sum of the risks of the various organs, ΣR, is the total risk. The relative contribution per organ is indicated by $f_o = R_o/\Sigma R$. Results are given in table 1. It can be seen that the risk $R_{5,y}$ for women is 90 % higher than for men. The risk of breast cancer accounts for 74 %, higher life expectancy for the other 16 %. Therefore the MPD for women has to be taken about half of that of men.

The risk figures of [1], [2] and [4] have been worked out in the same way as the figures of the BEIR-report. The UNSCEAR-figures of [4], p.441, table 22, column 8, were used. For each organ the relevant groups were taken and their minimum and maximum were averaged. Jacobi and ICRP, [1] p.112, worked with relative numbers, normalized on r = 1 for leukaemia, which just happens to be the absolute risk for leukaemia per rem per year per 10^6 persons (BEIR). This simplifies a comparison as given in table 2. They also considered curable cancers but introduced a relative severity factor s, expressing the differences in hurt of suffering and based on s = 1 for cancer death. They used rough values s = 0.1 and s = 0.3 indicating resp. 1 order of magnitude lower and half an order lower ($10^{1/2} \approx 0.3$)The starting points are given in table 2. The totals of the various systems are reasonably in accordance, the variations in the subdivisions over the organs are greater.

From these values coefficients $f_o = R_o s_o / \Sigma R_o s_o$ were derived and worst factors chosen (table 3).

The maximum values of the whole system are given in the last column. It would be wise to change the value 0.44 for bone marrow into 1 because there are strong indications that the linear dose-effect relation holds for leukaemia, whereas this relation is sigmoidal for most of the other cancers. This underestimates the relative contribution of leukaemia. Starting from table 3, a grouping as given in table 4 is suggested. The MPD_o follows from $MPD_o = 5/f_o$ rem/year. The values suggested in table 4 show only small deviations.

The system obtained in this way is non-consistent and overestimates the influence of single organ doses. A homogeneous total body dose-equivalent of 5 rem to men considered as the sum of single organ doses would yield :
$\Delta = 5\ (1 + 0.4 + 2 \times 0.2 + 5 \times 0.07 + 12 \times 0.02) = 12$ rem.

The above system is one of the items necessary to calculate the equivalent total body dose commitment per μCi inhaled nuclide as well as per μCi incorporated nuclide. The former is used for planning after measuring air contamination and radiation fields, the latter is used for control based on whole body counting. For the dose planning the equivalent total body dose reserve ΔR has to be known, on a year basis as well as on a quarterly basis. To avoid unnecessary restrictions corrections have to be subtracted from the used dose commitments. This requires graphs of the change with time of the tail area in the dose rate vs time graph. Then the equivalent total body dose reserve is $\Delta R = MPD - D_e - \Sigma_i \Delta_i$ rem/year (or quarter). Here D_e is

Organ (tissue)	r	Dose of 5 rem at relative low age			Dose of 5 rem yearly from 18 till 65 years of age: Men			Women			Maximum (worst) factor
		Y	$R_{5,1x}$	$f_o=R/\Sigma R$	Y	$R_{5,Y}$	f_o	Y	$R_{5,Y}$	f_o	f_o
bone marrow (leukaemia)	1.0	25	125	0.19	1060	5300	0.27	1120	5600	0.29	0.29
lung	1.3	30	195	0.30	810	5300	0.27	960	6300	0.32	0.32
G.I.	1.0	30	150	0.23	810	4100	0.21	960	4800	0.25	0.25
bone	0.2	30	30	0.05	810	800	0.04	960	1000	0.05	0.05
rest	1.0	30	150	0.23	810	4100	0.21	960	4800	0.25	0.25
together	$\Sigma r=4.5$		Σ R=650	1.00		19600	1.00		22500	1.16	
breast (women)	3.0	30	450	0.7				960	14500	0.74	
				1.7						1.9	
Y = years at risk r = risk per year per rem per 10^6 persons R = lifetime risk per 10^6 persons			x 1/650			x 1/19600			x 1/19600 !		

Table 1. : Derivation of organ dose reduction factors $f_o=\Delta_o/D_o$ from BEIR-cancer death risks /3/p.171

A Severe cancers (cancer deaths). factor s = 1

organ	UNSCEAR	BEIR	JACOBI	ICRP
bone marrow	1.4.	1.0	1	1
lung	1.5.	1.3	1	0.9
rest 1	1.2	2.2.	2.7	2.7
Σr	4.1.	4.5	4.7	4.6

Relative hurt of suffering

Rest 1

organ	BEIR	JACOBI	ICRP
G.I.	1.0	1	0.7
bone	0.2	0.3	0.1
rest 2	1.0	1.4	1.9
	2.2.	2.7	2.7

Rest 2

organ	JACOBI	ICRP
kidneys	0.3	0.1
liver	0.3	0.1
testis	0.3	0.1
rest 3	0.5	1.6
Σr	1.4	1.9

Rest 3

organ	ICRP
pancreas	0.3
lymphnodes + reticular tissue	0.3
10 organs x) each 0.1	1.0
	1.6

B Curable, s in brackets

organ	UNSCEAR	JACOBI	ICRP
thyroid	2.5	1 (0.3)	1 (0.3)
skin		0.3(0.3)	0.1(0.1)
eyes		1. (0.1)	
rest		0.5(0.1)	

x) oesophagus, salivary gland, gall bladder and bile ducts, brain and nervous tissue, bladder, larynx, prostate, breast, connective tissue, eyes (cataract inst. cancer).

Table 2. : Risk on tumour induction per rem per year per 10^6 men (r)

the external irradiation dose and Δ_i a corrected dose commitment from inhalation in the past year (quarter).

[1] ICRP, publ. 14, Radiosensitivity and spatial distribution of dose (1969)

[2] W.Jacobi, How shall we combine the doses to different body organs ? Problems and ideas-, Int. Symp. on Rad. Prot., Aviemore June 1974 paper SR P.AV.43

[3] BEIR Adv. Comm., The effects on populations of exposure to low levels of ionizing radiation, Nov. 1972

[4] UNSCEAR, Ionizing radiation, Vol.II : Effects, 1972.

Organ	UNSCEAR	BEIR	JACOBI	ICRP	Absolute maximun
bone marrow	<u>0.44</u>	0.29	0.26	0.26	0.44→1 x)
lung	<u>0.40</u>	0.32	0.22	0.14	0.40
bone		<u>0.25</u>	0.22	0.16	0.25
kidney			<u>0.07</u>	0.02	0.07
liver			<u>0.07</u>	0.02	0.07
testis			<u>0.07</u>	0.02	0.07
pancreas				<u>0.07</u>	0.07
lymphnodes, etc				<u>0.07</u>	0.07
10 various organs (note of table 2)				<u>0.02</u>	0.02
thyroid	<u>0.18</u>		0.02	0.07	0.18
skin			<u>0.02</u>	0.002	0.02
eyes			<u>0.02</u>	<u>0.02</u>	0.02
breast (w)	0.28	<u>0.74</u>		0.02	0.74
ovary				<u>0.02</u>	0.02
uterus				<u>0.02</u>	0.02
x) suggestion on base of differences in dose-effect relations (see text)					

Table 3. : Maximum f_o

Group	Organ(s)	f_o	MPD_o Rem/year
1	bone	1	5
2	breast (women)	0.7	7
3	lung	0.4	12
4	bone, thyroid	0.2	30
5	kidney, liver, testis, pancreas, lymphnodes and reticular tissue	0.07	70
6	skin, eyes, ovary, uterus and other organs and tissues (note of table 2)	0.02	200

Table 4. : Suggested values of f_o and the connected MPD_o