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RESEARCH ESTABLISHMENT
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ABSTRACT

The risks (probabilities of subsequently developing cancer) associated with UK and US recommendations on dose limits for specific radiological emergency situations are examined and used as a basis for recommending levels of risk at which consideration should be given to specific countermeasures. These emergency reference levels for risk provide a generalised means of deriving consistent emergency reference levels for dose and other hazard parameters applicable to any radiological emergency situation.

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The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA–INIS–12 (INIS: Manual for Indexing) and IAEA–INIS–13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

DOSE LIMITS; HUMAN POPULATIONS; INTEGRAL DOSES; IODINE 131; LEUKEMIA; RADIATION ACCIDENTS; RADIATION DOSES; RADIATION HAZARDS; RADIATION PROTECTION; RADIOACTIVITY; RECOMMENDATIONS; THYROID; WHOLE-BODY IRRADIATION

CONTENTS

1. INTRODUCTION

In the event of an accident involving radiation or radioactivity,involuntary exposure of both radiation workers and members of the general public may occur. Those responsible for the artefacts giving rise to such exposure may be expected to take or organise action to minimise it, because of its adverse effects on public health. As the effort available for such action is not unlimited, and remedial action is not without its hazards, the question arises - are there levels of exposure and dose below which it may be justifiable not to implement countermeasures?

The International Commission on Radiological Protection has discussed the problem but has made no recommendations (ICRP 1966a). In the case of radiation workers it concluded that under abnormal circumstances doses in excess of the maximum permissible for normal practice may be justified, but that it is unrealistic to recommend dose limits; on the other hand, for abnormal exposure of populations:

> "the possibility that exposures might be received under a ... variety of conditions and circumstances (geographical, meteorological, social) ... makes it impossible to lay down recommendations that would be universally applicable."

The ICRP has argued that the hazard or social cost involved in any remedial measure must be justified by the resultant reduction of risk and, because of dependence on local circumstances, that the setting of levels is the responsibility of national authorities. It does however commit itself to saying that a likelihood of whole body doses of 100 rads would always call for action.

Recommendations for specific cases, in terms of dose to the individual, have been made in the UK (MRC 1959, 1960, 1961) and in the US (USAEC 1961, FRC 1964, 1965). The UK figures are known as 'emergency reference levels' (Dunster 1969), the phrase being defined as follows:

> "A value, usually of dose but sometimes of an environmental measurement, which divides situations in which counter-measures are unlikely to be justified from those in which counter-measures are desirable if they can be carried out safely and effectively."

This definition conveys the function of emergency reference levels but does not provide any immediate numerical generalisation of the specific UK recommendations.

The above recommendations were made before figures for the numerical risks of long term adverse effects of radiation exposure were established in the literature. Since then a number of reviews of available information have been published (ICRP 1966b, 1969, Dolphin and Marley 1969, UNSCEAR 1972, BEIR 1972).

The risks to the individual associated with the dose levels specified in the above recommendations will be examined and recommendations made for a more generalised numerical definition of emergency reference levels for risk, from which emergency reference levels for dose, exposure and environmental contamination may be derived.

2. UK EMERGENCY REFERENCE LEVELS

Tables 1, 2 and 3 list emergency reference levels (ERL) published in the UK (Dunster 1969). The emergency reference levels for dose are the same as in MRC 1959, 1960 and 1961 but, since the publication of these earlier papers, metabolic and other data have been reviewed and emergency reference levels for exposure and environmental contamination have been modified accordingly.

TABLE 1

EMERGENCY REFERENCE LEVELS FOR EXTERNAL EXPOSURE

(After Dunster 1969)

Exposure Group	Type of Exposure		
	Gamma Radiation	Beta and Gamma Radiation (1)	Skin Contamination (2)
Children up to 16 years Pregnant women	20 R in free air	75 rads to superficial tissue	75 rads to superficial tissue
Other persons	30 R in free air	150 rads to superficial tissue	150 rads to superficial tissue

Notes:

(1) Subject to a limit of 15 rads gamma, corresponding to 20 R in free air, or 25 rads gamma corresponding to 30 R in free air.

(2) Limited to 1/10 of the body surface and in addition to (1).

(3) A further 30 R may be permitted for essential duties by a special category comprising adult males (preferably in the older age group) or females above reproductive age.

TABLE 2

EMERGENCY REFERENCE LEVELS FOR IODINE-131 AND CAESIUM-137

(After Dunster 1969)

Parameter	Units	Iodine-131		Caesium-137	
		6-Month Old Child (1,2)	Adult	6-Month Old Child (1)	Adult
Critical organ	-	Thyroid	Thyroid	Whole Body	Whole Body
ERL of dose to critical organ	rad	25	25	10	10
Dose per micro-curie inhaled	rad μCi^{-1}	11.6	1.23	0.049	0.047
Dose per micro-curie ingested	rad μCi^{-1}	15.5	1.64	0.066	0.062
ERL of cloud dosage	Ci s m^{-3}	0.03 (0.031) (3)	0.088	2.9	0.93 (4)
ERL in milk (5)	$\mu Ci\ \ell^{-1}$	0.25 (0.23)	3.0	6.7	9.8
ERL on pasture (6)	$\mu Ci\ m^{-2}$	1.5 (1.6)	22	22	33

Notes:

(1) The values for the 6-month old child can be taken as typical of children in the first year of life.

(2) Values recommended by the Medical Research Council. Values in brackets are the calculated figures.

(3) Where there is a dose contribution from other iodine isotopes and tellurium-132, the values for iodine-131 should be reduced by a factor of two or, in the case of a release of short-lived fission products from a criticality accident, by a factor of ten.

(4) The adult is the limiting case due to the much shorter half-life of caesium-137 in children than in adults.

(5) The tabulated values are for the maximum levels reached after a single deposition.

(6) The levels on pasture are the initial activities of the total deposits.

TABLE 3

EMERGENCY REFERENCE LEVELS (1) FOR STRONTIUM-89 AND STRONTIUM-90

(After Dunster 1969)

Parameter	Units	Strontium-89		Strontium-90	
		6-Month Old Child (2)	Adult	6-Month Old Child (2)	Adult
Critical organ	-	Bone	Bone	Bone	Bone
ERL of dose to critical organ	-	15 rads	15 rads	1.5 rads y^{-1}	1.5 rads y^{-1}
ERL of cloud dosage	Ci s m^{-3}	0.079	0.36	0.00083	0.0036
ERL in milk	μCi (g Ca)$^{-1}$	0.2	0.2	0.002	0.002
ERL in pasture	μCi m^{-2}	10	10	0.1	0.1

Notes:

(1) The basis for these emergency reference levels, i.e. the assumption that the criterion should be local dose to mineral bone, is being reconsidered and it is likely that the basis may be changed and the values of the reference levels increased.

(2) The values for the 6-month old child can be taken as typical of children in the first year of life.

3. US RECOMMENDATIONS

The USAEC (1961) has recommended as reference values in the evaluation of reactor sites a whole body dose limit of 25 rem and an adult thyroid dose limit of 300 rem as a result of exposure to airborne radioactivity of persons at a reactor site boundary in the two hour period following a reactor accident. (An adult thyroid dose of 300 rem by inhalation implies a child thyroid dose of 850 rem, using the data of Table 2.) The Federal Radiation Council (FRC 1964, 1965) has recommended protective action guides of 30 rad thyroid from iodine-131, 10 rad whole body from caesium-137 and 10 rad bone marrow from strontium-89 and strontium-90 following the ingestion of these isotopes in contaminated foodstuffs.

The differences in these two sets of figures are related to the difference in circumstances in which they apply. The countermeasure applicable to the circumstances of the Federal Research Council's recommendation is the restriction of the use of contaminated foodstuffs whereas the circumstances of the USAEC recommendation require the evacuation of the potentially affected population. This requires a more concentrated and larger effort involving more social upheaval, the risk of traffic accidents and shock to invalids amongst the population, justifying in principle a higher limit.

4. RISK COEFFICIENTS

Information on the probability of developing adverse somatic and genetic effects, mainly following external radiation of whole or part of the body, has recently been reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1972) and by the US National Academy of Science/National Research Council Committee on the Biological Effects of Ionising Radiation (BEIR 1972). Earlier reviews were prepared by the ICRP (ICRP 1966b , 1969) and summarised for those effects with associated high mortality by Dolphin and Marley (1969) for use in assessing the significance of accidental exposure of the public. The latters' recommendations are reproduced in Table 4. The effects considered are the production of all malignant neoplasms, and the specific production of leukaemia, thyroid cancer, lung cancer and stomach cancer. Table 5 summarises comparable figures for all malignant neoplasms, leukaemia and thyroid cancer derived from the UNSCEAR and BEIR 1972 reports.

TABLE 4

SUMMARY OF THE ESTIMATED RISK COEFFICIENTS AND RECOMMENDED VALUES FOR USE IN CALCULATING THE EXPECTED NUMBER OF CANCERS IN A POPULATION FOLLOWING AN ACCIDENTAL RELEASE OF RADIOACTIVITY

(After Dolphin and Marley 1969)

Biological Effect	Irradiated Population	Risk Coefficients, Cases per 10^6 man-rads	
		Estimated in this Report	Recommended
Leukaemia	Japanese survivors Women, artificial menopause Ankylosing spondylitics	40 20 10	20
Thyroid cancer	X-irradiated infants External irradiated population ^{131}I infants ^{131}I adults	100 30 - -	100[a] 30[a] 30[a] 10[a]
All malignant neoplasms (except leukaemia)	Ankylosing spondylitics Japanese survivors American radiologists	4 times leukaemia risk 3 times leukaemia risk 4 times leukaemia risk	80
All malignant neoplasms in childhood (< 20 yrs)	Foetus in latter part of pregnancy	100 - 200	200
Lung cancer	Japanese survivors Ankylosing spondylitics	9 37	10
Stomach cancer	Ankylosing spondylitics	14	10
All other organs	-	-	10

(a) These risk coefficients apply to incidence but for death from thyroid cancer the recommended value is only 10% of these values.

TABLE 5

RISK COEFFICIENTS FROM UNSCEAR AND BEIR 1972 REPORTS

Biological Effect	Age Group (years)	Risk Coefficient (Cases per 10^6 man-rem)		Period of Occurrence (years)	
		UNSCEAR	BEIR	UNSCEAR	BEIR
Leukaemia	in utero 0 - 9 10+	100 } 40	250 50 } 30 25 }	10 25	10 25 25
Thyroid cancer	any	40	-	25	-
All other malignant neoplasms	in utero 0 - 9 10+	100 } 90	250 30 } 126 150 }	10 25	25 30 30

In the main there is seen to be reasonable agreement between the 1969 Dolphin and Marley recommended figures (Table 4) and those given in the 1972 UNSCEAR and BEIR reports (Table 5). The biggest difference is that between the UNSCEAR and BEIR in utero risk figures, where the BEIR Committee has made a significantly more conservative interpretation of the available data than has UNSCEAR.

As this paper is not intended to provide a critical review of risk coefficients and as all the UK and US figures for dose limits were produced before any of the above risk coefficients were readily available, the earlier figures for risk of Dolphin and Marley will be used to assess the risks associated with the UK and US recommendations rather than the more recent figures; this procedure will more closely estimate the risks which the recommending bodies thought they were considering.

Other adverse somatic effects of radiation are the production of thyroid nodules (Dolphin and Marley 1969, UNSCEAR 1972) and of cataract and (temporary) impaired fertility (observed in man, followed by recovery, at doses down to 10 rem) (ICRP 1969). Neither of the latter effects are lethal. As the probability of either effect is low at the dose levels of interest to the present discussion they are not considered further.

Thyroid nodules have been recorded in Marshall Islanders exposed in childhood to internal and external radiation from nuclear weapons test fallout (Conard et al 1967), and in persons irradiated in infancy about the neck with X-rays (Pincus,Reichlin and Hempelmann 1967). The long term incidence of such nodules appears to be about 1000 cases per 10^6 thyroid rads (UNSCEAR 1972). The medical significance of such nodules is not entirely clear, nor is their normal frequency of occurrence well established.

Other non-lethal somatic effects are not included as their risk coefficients appear to be no greater than those for carcinogenesis and as they would rate lower in a scale of adversity relative to mortality, if such a scale could be constructed.

At one time long-term genetic effects of population exposure were considered more limiting than somatic effects (ICRP 1964) but further animal studies suggest that this is not the case (UNSCEAR 1972, BEIR 1972). For this reason genetic risks are not included in the discussion.

5. ASSESSMENT OF RISKS ASSOCIATED WITH THE UK AND US RECOMMENDATIONS

Table 6 summarises the UK and US recommendations and gives the risk for the individual subsequently developing cancer from the dose specified using the risk coefficients of Table 4. The estimated risk of thyroid nodule development for children and irradiation of the thyroid is also included because of its relevance to the assessment of fission product releases.

The cancer risks range numerically from 1.5×10^{-4} (for bone cancer following 15 rads to bone from internal strontium-89 or strontium-90) up to 2.5×10^{-2} (for thyroid cancer following 850 rem to the child thyroid from internal iodine-131), while for the case of thyroid nodules there is the possibility of a risk as high as 0.85, following the USAEC dose of 850 rem to the child thyroid.

In terms of currently published risk coefficients the recommendations are not consistent. This arises partly because the basis of the USAEC recommendations (carrying the greatest risks) is somewhat different from the UK and FRC recommendations and partly because of changes in estimates of risk since the time the recommendations were formulated. The risk estimate associated with whole body dose has risen, while that for bone dose has decreased relative to that for thyroid dose, particularly if thyroid nodule production is established as a general possibility.

6. ACCEPTABLE RISKS UNDER ACCIDENT CONDITIONS

The risk figures associated with the UK and US recommendations shown in Table 6 fall in the two decades from 10^{-4} to 10^{-2} (excluding thyroid nodules, not considered at the time the recommendations were made). The risk of cancer associated with the ICRP's advice that a likelihood of a whole body dose of 100 rads would always call for action is also 10^{-2}. If the consensus generally represented in the ICRP and in the UK and US recommendations remains unchanged, it appears that acceptable risks to the individual in terms of major adverse somatic effects in the event of involuntary exposure lie in the

TABLE 6

ASSESSMENT OF RISKS ASSOCIATED WITH UK AND US RECOMMENDATIONS

Source of Recommendation	Nature of Exposure	Age Group	Recommended Limit	Possible Consequence	Risk to Individual
UK, MRC	Whole body, external radiation	Under 16 years (a)	20R (15 rads)	Unspecified cancer	1.5×10^{-3}
		Pregnant women (a)	20R (15 rads)		1.5×10^{-3}
		Others	30R (22 rads)		2.2×10^{-3}
	Whole body, internal ^{137}Cs	All ages (a)	10 rads	Unspecified cancer	1.0×10^{-3}
US, FRC	Whole body, internal ^{137}Cs	All ages (a)	10 rads	Unspecified cancer	1.0×10^{-3}
USAEC	Whole body, external mixed fission products	All ages (a)	30 rems	Unspecified cancer	3.0×10^{-3}
UK, MRC	Thyroid, internal ^{131}I	Child	25 rads	Thyroid nodules (b)	2.5×10^{-2}
		Child	25 rads	Thyroid cancer	7.5×10^{-4}
		Adult	25 rads	Thyroid cancer	2.5×10^{-4}
US, FRC	Thyroid, internal ^{131}I	Child	30 rads	Thyroid nodules (b)	3.0×10^{-2}
	Thyroid (ingestion)	Child	30 rads	Thyroid cancer	9.0×10^{-4}
		Adult	30 rads	Thyroid cancer	3.0×10^{-4}
USAEC	Thyroid, internal ^{131}I (inhalation)	Child	850 rem	Thyroid nodules (b)	0.85
		Child	850 rem	Thyroid cancer	2.5×10^{-2}
		Adult	300 rem	Thyroid cancer	3.0×10^{-3}
UK, MRC	Bone, internal ^{89}Sr	All ages	15 rads	Bone cancer	1.5×10^{-4}
	Bone, internal ^{90}Sr	All ages	1.5 rad/yr	Bone cancer	1.5×10^{-4} (c)
US, FRC	Bone marrow, internal $^{89}Sr/^{90}Sr$	All ages	10 rads	Leukaemia	2.0×10^{-4}

(a) The risk to children of pregnant women is twice that to other members of the population.

(b) Included because of higher risk, although not as well established as other consequences.

(c) Assuming that the projected dose is 15 rads.

range 10^{-4} to 10^{-2} depending on circumstances, and that a guide to the necessity for emergency action in terms of risk (irrespective of age or occupational status) can be given as follows:

(i) Where individual risks are less than 10^{-4} emergency action is uncalled for (i.e. where risks are less than 10^{-4} the situation is not an emergency).

(ii) Where individual risks fall in the range 10^{-4} to 10^{-3} remedial action is indicated provided it does not entail risks to others and does not entail significant social upheaval (for example, control of the use of contaminated foodstuffs should be considered when risks exceed 3×10^{-4}).

(iii) Where individual risks fall in the range 10^{-3} to 10^{-2} remedial action is indicated provided the overall risk can be reduced and the action is socially feasible (for example, evacuation of a limited number of people to avoid airborne contamination should be considered when risks exceed 3×10^{-3}).

(iv) Where individual risks exceed 10^{-2} the case for inaction must be clearly agreed and stated by those responsible for emergency procedures.

It is to be noted that the decision to act or not to act in any particular situation is always that of the authorities responsible for emergency procedures. At the Research Establishment the AAEC has only the responsibility for advising on the need and type of countermeasures; the responsibility for implementing countermeasures rests with NSW State Authorities (e.g. Department of Public Health, Police Force).

7. RECOMMENDED EMERGENCY REFERENCE LEVELS

The numerical values for individual risk as a function of action to be taken in the event of an accident outlined in Section 6 are recommended as emergency reference levels for risk; the individual risk values are contained in Table 7.

In an accident situation individual risks must be derived from the assessment or measurement of environmental levels of radiation and radioactivity, the prediction of possible doses to exposed individuals and an application of dose-risk relationships. Table 7 also contains emergency reference levels for whole body and thyroid dose corresponding to the risk levels given, using the dose-risk coefficients given in Table 4.

In any preplanning for emergencies it is appropriate to derive emergency reference levels for dose, environmental contamination and even of airborne

TABLE 7

EMERGENCY REFERENCE LEVELS FOR RISK, WHOLE BODY DOSE AND THYROID DOSE (FROM IODINE-131)

Emergency Reference Level					Action
Individual Risk of Major Adverse Somatic Effect	Whole Body Dose rads		Thyroid Dose rads (^{131}I)		
	Adults Children	Foetus	Adults	Children	
10^{-4}	1	0.5	10	3	Consider possible countermeasures.
3×10^{-4}	3	1.5	30	10	Control consumption of contaminated foodstuffs.
3×10^{-3}	30	15	300	100	Consider evacuation of potentially exposed persons.
10^{-2}	100	50	1000	300	Take appropriate countermeasures. unless agreed otherwise by competent authorities.

release appropriate to the local situation and potential hazards, in order to expedite assessment of the seriousness of the situation in the event of an actual accident. However, as the values of the required parameters are in part determined by local circumstances and are in part subject to revision with time (arising, for example, from the current uncertainty in the dose-risk relationships, illustrated by Table 4, the present necessity for adopting a linear dose-risk hypothesis, and the lack of a common scale of adversity for adding lethal and non-lethal effects), the ERLs for dose (see Table 7) are given only to illustrate the current numerical values associated with the recommended ERLs for risk and not as recommended values. It is recommended that ERLs for dose and environmental contamination corresponding to the recommended ERLs for risk be derived by those responsible for preparing emergency schemes using the best available supporting data.

8. COMPARISON OF RECOMMENDED LEVELS WITH OTHER RISK FIGURES

To consider the recommended emergency reference levels of risk in relation to risks currently experienced, Australian data on the risk of accidental death from a variety of causes and on the risk of dying of cancer are given in Tables 8 and 9. These figures do not provide any basis for deriving emergency reference levels. They do, however, illustrate that the recommended levels are neither excessively low nor excessively high in relation to the risks experienced generally by the population at large.

TABLE 8

RISK OF DEATH BY ACCIDENT, FROM AUSTRALIAN FIGURES FOR THE PERIOD 1968-1970

(After CBC & S 1970, 1972)

Cause of Death	Risk Over 10 years[a]	Risk Over 30 years[a]
Motor vehicle	2.9×10^{-3}	8.7×10^{-3}
Falls	9.2×10^{-4}	2.8×10^{-3}
Drowning	2.9×10^{-4}	8.9×10^{-4}
Fire	1.7×10^{-4}	5.1×10^{-4}
Choking	1.0×10^{-4}	3.0×10^{-4}
Rail transport	7.2×10^{-5}	2.2×10^{-4}
Poisoning	5.3×10^{-5}	1.6×10^{-4}
Air transport	4.1×10^{-5}	1.2×10^{-4}
Bites and stings	4.0×10^{-6}	1.2×10^{-5}
Lightning	2.9×10^{-6}	8.7×10^{-6}
All causes	5.3×10^{-3}	1.6×10^{-2}

Note:

(a) Risks have been expressed as those over 10 and 30 years for direct comparison with the radiation risk figures which relate to 10 to 30 year periods (see Table 6).

TABLE 9

RISK OF DEATH FROM CANCER FROM AUSTRALIAN FIGURES FOR THE PERIOD 1964-1968

(After CBC & S 1966-1970)

Age Range (years)	Risk of Death from Cancer over Subsequent Period		
	10 years	30 years	50 years
0-9	7.4×10^{-4}	2.9×10^{-3}	1.9×10^{-2}
10-19	7.7×10^{-4}	6.0×10^{-3}	4.5×10^{-2}
20-29	1.4×10^{-3}	1.7×10^{-2}	1.2×10^{-1}
30-39	3.9×10^{-3}	4.3×10^{-2}	-
40-49	1.3×10^{-2}	1.1×10^{-1}	-
50-59	2.8×10^{-2}	-	-
60-69	7.4×10^{-2}	-	-

9. CONCLUSIONS

The risks of major adverse somatic effects (e.g. carcinogenesis) associated with UK and US recommended dose limits for various emergency situations have been derived from dose-risk relationships currently available in the literature. From an inspection of these risks a set of emergency reference levels for individual risk have been derived, i.e. actions appropriate to particular circumstances as a function of risk to the individual are recommended. It is further recommended that emergency reference levels for dose and environmental contamination corresponding to the recommended risk levels be derived by those responsible for preparing emergency schemes using the best available supporting data. As an example, emergency reference levels for whole body dose and thyroid dose from internal iodine-131 are given.

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