Volume 1 No. 4 1977

Annals of the ICRP

ICRP PUBLICATION 27

Problems Involved in Developing an Index of Harm

Pergamon Press OXFORD · NEW YORK · FRANKFURT

RADIATION PROTECTION

ICRP PUBLICATION 27

Problems Involved in Developing an Index of Harm

A report prepared for the International Commission on Radiological Protection

ADOPTED BY THE COMMISSION IN MAY 1977

PUBLISHED FOR

The International Commission on Radiological Protection

by

PERGAMON PRESS

OXFORD · NEW YORK · TORONTO

SYDNEY · BRAUNSCHWEIG

PREFACE

In April 1973, the International Commission on Radiological Protection asked Sir Edward Pochin to prepare a report on the problems entailed in comparing the safety of different industries including those involving radiation exposure, taking account of the fact that the types of injury or induced diseases, and their severity and relative frequencies, might differ completely in different occupations.

Much of the material in this report is complementary to and should be read in conjunction with the Commission's Recommendations issued in 1977 as *ICRP Publication 26.*

CONTENTS

INTRODUCTION

(1) In recommending appropriate limits for any occupational or other exposure to radiation, it is obviously desirable to estimate the types and frequencies of harmful effects that may result from any given radiation exposure. Moreover, in assessing the safety of an occupation involving such exposure and comparing it with the safety of other occupations, it is important to compare the total harm that may be caused by the radiation, both in those exposed and in their descendants, with the total harm involved in other occupations, whether by fatal or minor injury, occupational disease, or the effects of mutagens in the working environment.

(2) Any formal solution to this problem is obviously impossible since various harmful effects of radiation and of other occupational injuries are not only different from each other in kind, but are likely to be regarded as of different importance by different individuals. And yet coherent opinions clearly are held as to the relative importance of different types of disability or disease, even though they are incommensurable in any formal sense. No scientist can add apples and pears, but any child can.

(3) The initial need, therefore, seems to be, not for any series of arbitrary weighting factors for different types of harm, but for a study of the frequency with which harmful effects of different kind and severity occur in different occupational contexts, so that an opinion can be more readily formed as to the major contributors to harm and the comparisons between them. Unless these rather difficult questions are clearly and exactly formulated, one cannot hope for a clear answer. It may be difficult to say in general whether one prefers apples or pears, but easy to say whether one would rather have seven apples or two pears. The following notes are, therefore, intended to help in formulating, rather than answering, questions.

FATALITY AS A CRITERION

(4) Death has commonly been used as an index of the comparative safety or harm of different industries,[1] and the frequency of deaths attributable to occupational causes clearly has a certain validity. In this way, estimates of the risk of radiation exposure have been based on the probability that a fatal form of cancer might be induced by a given exposure, and the estimated fatality rate compared with that from the frequency of accidental deaths in other occupations.[2]

(5) This simple criterion, although readily calculable and unequivocal, has numerous limitations. Firstly, it omits consideration of all non-fatal injuries, diseases and permanent disabilities, which may be very frequent in many occupations. It is, however, claimed that radiation, at the low doses involved in most occupational exposure, is unlikely to cause any substantial number of non-fatal injuries, and therefore that, if an occupation involving radiation exposure is safer than other occupations in terms of induced fatalities, it is safer still in terms of non-fatal effects.

A second limitation lies in the difference between a certain frequency of immediate deaths from accidents and an equal frequency of delayed deaths from various forms of malignant disease, and the greater apprehension that is likely to attach to the latter. Moreover, the former may be attributed, rightly or wrongly, to a lack of skill on the part of the victim, whereas the latter may be regarded as a more random hazard, involving a certain proportion of people who are all working correctly and equally within permitted limits of exposure.

A third defect in the use of fatality rates alone is that the length of life lost by the deaths is more important than the fact of death alone. The observed or expected age distribution of fatalities needs some consideration, therefore.

Age distribution of occupational fatalities

(6) The average age at death from fatal accidents at work has been examined by establishing the age, sex and occupation of those dying of accidental injuries in manufacturing industries and in construction work during 1971 in the U.K. and relating these data to the numbers employed at different ages in these occupations.* Only six deaths occurred in females and the analysis has therefore been made for males only. Results are given in Table 1, for the 246 and 188 deaths in manufacturing industries and constructional work respectively for which ages were ascertained (ages being unrecorded in 4 and 13 further fatal accidents in the respective occupations). In the manufacturing industries, the mean age at accidental death was 43.3(±0.8 S.E.) years, while the mean age of workers was 40.1 years. In constructional work, the mean age at death was 40.9 (±1.0 S.E.) years, while the mean age of workers was 38.0 years. In both groups therefore, the age at accidental death is slightly but significantly greater than that of the exposed population. This is apparently due to the fact that the fatality rate (per year per million employed) rises until the age of about 30 in manufacturing industries, and until about 20 or 25 in constructional work, and then remains approximately constant with age until ages of 65 or over (Table 1). This

TABLE 1. FATAL ACCIDENTS, MALES, U.K., 1971

	Manufacturing industries			Construction		
Age groups	No. employed (thousands)	No. of deaths	Deaths per million per year (±SE)	No. employed (thousands)	No. of deaths	Deaths per million per year (±SE)
15-	450	6	13±5	117	7	60±23
20-	1 330	36	27±4	340	45	132±20
30-	1 200	52	43±6	270	46	170±25
40-	1 300	62	48±6	240	26	108±21
50-	1 170	61	52±7	200	43	215±33
60-	460	23	49±10	90	16	180±45
65-	140	6	43±18	26	5	192±86
All ages	6 050	246	41±3	1 280	188	147±11
Mean age (years)	40.1	43.3		38.0	40.9	

*In this report, references are given where appropriate to publications from which data have been derived. On many points no published information was available, and reference is made under "acknowledgements" to sources of unpublished data.

appears to be a rather uniform characteristic of such occupations since, when the fourteen manufacturing industries were examined individually, the mean age at death was greater than that of workers in thirteen of them, having a mean excess of 3.2 ($\pm$0.8 S.E.) years.

(7) A similar examination has been made for other occupations, using information from a further U.K. source.[3] This gives for a large number of occupations the age distribution of workers and of fatal accidents. The latter are listed as traffic accidents, accidents in the home, and other accidents, the great majority of these "other accidents" being accidents at work. For the seven groups of occupations in which rates for such "other" accidents exceeded the national average, the mean age at death was 42.5 years, being 0.8 ± 0.45 years greater than the mean age of workers. The mean age at accidental death did not vary considerably in the twenty-six occupational groups listed, except for the low value of 28.8 years in members of armed forces.

In Japanese manufacturing industries during 3 months in 1971[4] the mean age at death from 185 fatal accidents was 38.1 years. The mean age of the 12.91 million workers was 35.1 years.

Canadian data also suggest that the mean age at death from industrial accidents in males is little different from that of those employed. The mean age at death in 1970 from "accidents mainly of industrial type"[5] in males of age between 15 and 64 was 38.1 years, while the mean age of all males living between these ages was about 36.5 years. The mean age of working populations will differ somewhat from the latter value according to the mean ages of starting and leaving work, but is unlikely to differ greatly from this figure.

(8) The mean loss of years of life from fatal occupational accidents has been estimated from the expectation of life at the ages at which the accidental deaths occur. Using estimates applicable to England and Wales,[6] the mean loss for men killed in manufacturing industries was 28.6 years, and in constructional work 30.2 years, while for the seven high risk industrial groups it was 29.3 years. It would be useful to check further the way in which this value varies with the type and degree of risk in different industries. Meanwhile, however, it seems reasonable to take occupational accidental fatalities as involving an average loss of about 30 years of life.

Mean loss of life from radiation-induced fatalities

(9) A comparable figure could be estimated for any fatal conditions induced by radiation which, at normal levels of occupational exposure, probably involves only the induction of fatal malignancies. (Deaths due to genetic damage or foetal irradiation are considered later.) For such an estimate, information is required on six points:

(1) the age distribution of radiation exposures received in the course of various forms of occupation;
(2) the distribution of time intervals from exposure until death from induced fatal diseases;
(3) any dependence of latency upon the age at the time of the relevant exposure;
(4) the age structure of the exposed population;
(5) the distribution of ages at death from natural causes;
(6) knowledge of whether a certain accumulation of exposures is needed to initiate the development of a malignancy.

(10) Information has been obtained, for various types of occupation involving radiation exposure, indicating the relationship between the mean age at which exposure

occurs and the mean age of the working population (points 1 and 4 of paragraph 9).*

(a) In 123 industrial radiographers in employment during 1973, there was no significant correlation of dose received during that year with age ($r=0.17$). The population had mean age 33.2 years, and radiation was received at mean age 32.8 years. In addition, the cumulated dose (D in rem) from the total recorded occupational exposure at the time of survey was linearly related to the age (N in years) of the worker, the regression of D on N being given by $D=0.44(N-17)$.

(b) In 614 workers at a radiochemical centre the exposure, d, during one year (1973) showed a weak positive correlation with age, N, such that $d=0.18\pm0.012N$. The mean age of exposure was 45.3 years in a population of mean age 41.1 years.

(c) In a general hospital there were no significant correlations between annual exposure and age, either within a group of seventy diagnostic radiographers ($r=+0.17$) or in small groups of ten therapeutic radiographers ($r=+0.07$) or ten radiologists ($r=-0.17$). The radiographers (seventy seven females, three males) had mean age 24.5 years, and the radiologists (one female, nine males) 33.6 years.

(d) In three atomic energy establishments, the mean ages of workers were 44.3, 41.3 and 40.4 years, and the corresponding ages at which the mean cumulative dose had been received were 48.0, 43.4 and 45.2 years, with an average interval, over all 7005 monitored workers, of +3.3 years between mean age and mean age of exposure.

TABLE 2

Age (years)	18-20	21-30	31-40	41-50	51-60	>60	All
% of workers	2.2	18.7	28.6	29.6	18.0	2.9	100
Mean dose (rem y^{-1})	0.23	0.34	0.42	0.42	0.40	0.33	0.39
S.E.	0.06	0.10	0.10	0.10	0.10	0.07	

TABLE 3

Work group	No. of workers	Mean period (years since hiring) of work	to mean dose	difference
Reactor operators	438	5.92	5.97	+0.05
Mechanical maintainers	270	4.86	5.15	+0.29
Control technicians	234	5.29	5.49	+0.20
Other exposed	1 137	4.60	5.57	+0.97
All exposed workers	2 079	4.99	5.34	+0.35

*DEFINITION

The mean age $\bar{A}_D$ of exposure in a population of ages from A_1 to A_2 is given by

$$\bar{A}_D = \frac{\int_{A_1}^{A_2} NDAdA}{\int_{A_1}^{A_2} NDdA}$$

where N is the number of workers at any age, and D is the mean dose received at that age. The mean age of workers is given by:

$$\bar{A}_N = \frac{\int_{A_1}^{A_2} NAdA}{\int_{A_1}^{A_2} NdA}.$$

(e) At eight U.K. nuclear power stations, the mean annual dose in 3 587 male workers was slightly higher between the ages of 30 and 60 than in younger or older men (Table 2), but the mean age of exposure (41.65 years) did not differ substantially from that of the workers (41.05 years).

(f) A similar small difference between mean age and mean age of exposure is indicated by dose records of workers in Canadian reactor stations. The mean dose was thus received 0–1 year later than the mean period of employment in different types of work (Table 3), but the average interval was only 0.35 years.

(g) In eight Japanese occupations involving radiation exposure, the distribution of annual dose with age of worker was available for 6 500 workers (6 246 male and 254 female). The mean age of exposure exceeded that of the total working population by an average of 1.4 years. In individual occupations the difference varied from excesses of 3.2 and 2.5 years in groups of atomic energy workers, to a deficiency (mean age of exposure being lower than that of workers) of 3.1 years in a company concerned with construction and maintenance of atomic power facilities. For workers in medicine, research and education, and industry including non-destructive inspection, the differences in mean values were less than 1 year.

It appears, therefore, that occupational exposure to external radiation occurs at about constant rate with age. As an average for all the data given above, the mean age of exposure has been 1.9 years greater than the mean age of the workers exposed.

(11) No data have been obtained on the more difficult question of internal exposure. It is clearly to be expected, however, that annual dose will increase with age in the cases of materials such as ^{239}Pu and ^{226}Ra which are retained with long effective half period within the body. For an exposed population with equal numbers at all ages from 18 to 65, and an equal intake at each age of a material of long effective half period, the total retention, and so the dose rate, would in this case increase about linearly with age. In these circumstances, it can be shown (by evaluating the integrals defining mean age and mean age of exposure) that the mean age of exposure would be $65 - \frac{1}{3}(65-18) = 49.3$ for a working population of mean age $\frac{1}{2}(18+65) = 41.5$. Even in these circumstances, therefore, the mean age of exposure would only exceed that of the exposed population by about 8 years.

(12) To derive an approximate estimate of the mean length of life lost owing to a radiation-induced malignancy, it is assumed:

(a) that the mean age of the exposed population is in the region of 40 years, as in the industrially exposed male populations discussed above;

(b) that the mean age of exposure in such a population is a little greater, say 42 years, given the small difference in the occupations examined and the possibility of exposure from long-lived internal emitters;

(c) that each component of dose is associated with a component of risk expressed as a malignancy causing death after a certain latent interval, and that no threshold of accumulated dose is required to initiate such a malignancy;

(d) that neither the length of this "latent interval", nor the risk of malignancy for a given exposure, varies with age at exposure, at least for exposure during adult life;

(e) that the mean interval from the relevant exposure to death from an induced malignancy is between 20 and 25 years, say 23 years. This value is consistent with 20% such deaths resulting from leukaemia of mean interval 13 years, with remaining fatal malignancies having a mean interval of 25 years.

(13) On this basis the mean age at death from an induced malignancy would be at $42+23=65$ years. At this age, the mean life expectancy is about 10 years on data for the U.K.[6] The average period of life lost per fatal malignancy would thus be about one-third that lost per accidental death, taken as 30 years as discussed in paragraph 8. A somewhat higher estimate is obtained, of about 13 years life lost per fatal malignancy, if allowance is made for the shorter mean loss due to malignancies induced by exposures occurring late in working life than for those induced at younger ages.

(14) The estimate of years lost per fatal malignancy will in any case differ substantially in different types of occupation. If in a population of female radiographers the mean value for the age at exposure was 25 and for latency was 23 years, the average loss of life per malignancy would be about 30 years, and could thus equal that from industrial accidental fatalities. Or, for a male population exposed to internal radiation by continuing uptake of a long-lived emitter, and so having a mean age of exposure of 48, a latency of 23 years would imply an average loss of a few years only. In a typical male population occupationally exposed to radiation, however, the mean loss of life per induced fatal malignancy seems likely on average to be about 10–15 years, or from one-third to one-half of that from a fatal industrial accident.

(15) If therefore a comparison were being made solely on the basis of duration of life lost, one could consider an annual rate of induction of fatal malignancies of, for example, 60 cases per million employed per year—resulting from a typical average occupational exposure rate of 0.6 rem y^{-1} and a mean fatal cancer induction rate, or maximum expected rate, of 100 10^{-6} rem^{-1} as discussed below. With a life loss of 10 to 15 years per case, this would correspond—in terms solely of the length of life lost—with an industry having a fatal accident rate of about 25 $10^{-6}y^{-1}$, with 30 years of life lost per fatality. This fatal accident rate is similar to that observed in most conventional manufacturing industries in the U.K., where an average occupational fatality rate of 56 10^{-6} y^{-1} was observed for the period 1959–1970 in the thirteen manufacturing industries for which the fatal accident rate was reported annually by the Chief Inspector of Factories.[7] This comparison assumes that any life shortening from radiation due to non-malignant causes is small compared with that from malignant causes, as seems likely to be true for man on present evidence. It however relates only to industrial fatalities from accidents, and not to occupational injuries, or to deaths from various types of occupationally induced disease.

Such a comparison of harm, therefore, clearly needs to be extended to include non-fatal accidents and industrial diseases, as well as such effects of radiation as genetic injury, foetal damage during pregnancy, non-fatal malignancies and the periods of illness involved in those which subsequently prove fatal.

OCCUPATIONAL INJURIES

(16) In examining the impact of occupational injuries, two types of information can be used.

Firstly, the frequency of injuries of a more or less arbitrarily defined severity can be examined, to see how this frequency varies with age or other circumstances in a given occupation, or with the accidental fatality rate in different occupations.

Secondly, an attempt can be made to assess the total impact of all injuries, for example, by taking account of the length of time off work resulting from injuries of different severity, and so the mean working time lost per year owing to such accidents. This figure can then be related to the associated frequency of accidental deaths to obtain an estimate, for different occupations, of the total period of working time lost owing to non-fatal accidents for every one accidental death.

Each method has severe and obvious limitations but each reveals some relationships which may be of value in comparing the total impact of occupational injuries with that of diseases or accidental deaths from occupational causes.

Frequency of injuries of defined severity

(17) Various definitions of "severity" of accidents are in common use, such as those involving specified periods of time off work, or permanent partial or total disability, or the payment of compensation or pension. Each definition clearly involves a large component of administrative procedure, and, for example, the periods spent off work from a given accident may vary considerably with medical or certification arrangements in different occupations or countries, with the age or economic status of the worker, with the day of the week on which the accident occurs, with the time of year and doubtless with many other factors. Subject to reservations on such grounds, however, certain conclusions seem possible.

(18) When the frequencies of accidental deaths in different occupations are plotted against those of accidental injuries of a given severity, the death rate ordinarily appears to increase more rapidly than the accident rate, as the general level of industrial hazard increases. Indeed, in the data shown in Fig. 1, the ratio of death rate D to that of "disabling" accidents A is about proportional to the rate of accidents classified within this category so that

$$A \propto D^{0.5}.$$

The eight main classes of employment had widely different accident rates (Table 4) and D/A had a linear regression on A, with $r = +0.95$ and $+0.97$ for the 2 years examined.[8]

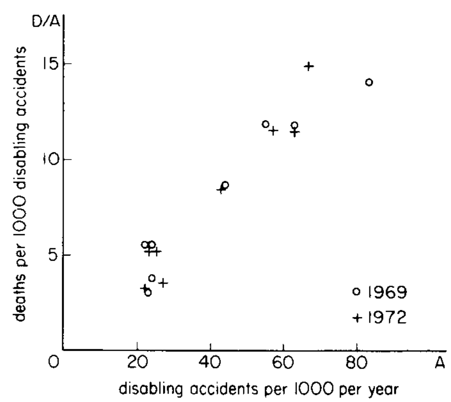

FIG. 1. Ratio of fatal to disabling occupational accidents, in relation to frequency of such accidents. Data for 8 types of U.S. industry (as in Table 4) in 1969 and 1972.

TABLE 4. RELATIONSHIP BETWEEN FREQUENCY OF ACCIDENTS AND ACCIDENTAL DEATH IN VARIOUS U.S. OCCUPATIONS

	1969			1972		
	D Accidental deaths	A accidents		D Accidental death	A accidents	
Occupation	per million	per year	$D/A^2 \times 10^{-7}$	per million	per year	$D/A^2 \times 10^{-7}$
Trade	72	23 000	1.4	72	22 000	1.5
Manufacturing	93	24 000	1.6	96	27 000	1.3
Service	121	22 000	2.5	120	23 000	2.3
Government	132	24 000	2.3	131	25 000	2.1
Transport	378	44 000	2.0	362	43 000	2.0
Agriculture	650	55 000	2.1	657	57 000	2.0
Construction	736	63 000	1.9	710	63 000	1.8
Mining	1 167	83 000	1.7	1 000	67 000	2.2
Mean			1.9			1.9

(19) Similar increase of D/A with A have been seen in three other groups of industries examined, with values of n in $A = KD^n$ varying between 0.5 and 0.8. In a group of thirteen U.K. factory occupations[7] with moderate differences in risk level, n had the value of 0.8 at best fit to a power function of this sort (at which value log D and n log A correlated with $r = +0.92$). A group of Japanese industries[4] showed $n = 0.8$, $r = +0.80$ and a further group gave $n = 0.5$, $r = +0.97$. Too few situations have been examined in which the criteria for classification of accidents can be assumed to be uniform, but it seems likely that, as occupations become more hazardous, fatalities commonly constitute an increasing proportion of the total harm.

TOTAL OF WORKING DAYS LOST FROM ACCIDENTAL CAUSES

(20) What is needed, however, is an estimate of *what* proportion of total harm should be regarded as due to fatal accidents. Some perspective on this question may perhaps be obtained by examining the total number of days off work from non-fatal accidents (e.g. per million employed per year) and comparing this with the corresponding number of accidental deaths in the same period. The ratio of the total calendar period off work from non-fatal accidents (including periods of permanent disability) per one accidental death has been derived for several occupations and countries (Fig. 2 and Table 5).

(21) Table 5A gives data from a Eurostat report on European steel industries for 1960–1972.[9] Table 5B gives values published by the U.S. Department of Labor[10]—the lost workdays being those from "recordable occupational injuries and illnesses" including periods of part-time work, partial duties and transfers to temporary jobs (with 200 workdays assumed per calendar year). Table 5C gives data published by the U.K. Department of Health, grouping three occupations of high fatality and fourteen others of low fatality rates.[11]

(22) When these estimates, of "time lost per life lost", are related to the hazard of the occupation, expressed in accidental deaths

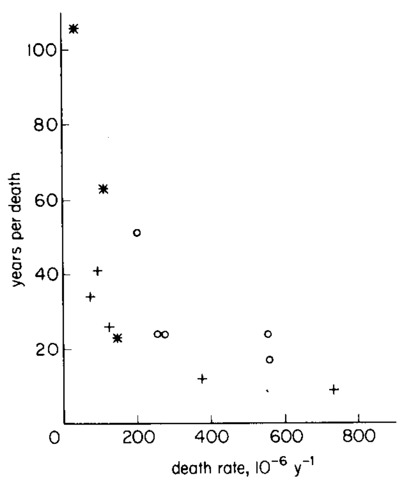

FIG. 2. Ratio of total periods (calendar years) off work, to deaths, from occupational accidents, in relation to accidental death rate (deaths per million employed per year). Data for industries in three countries (as in Table 5). Values for EEC as circles, for U.S. as crosses, and for U.K. as asterisks.

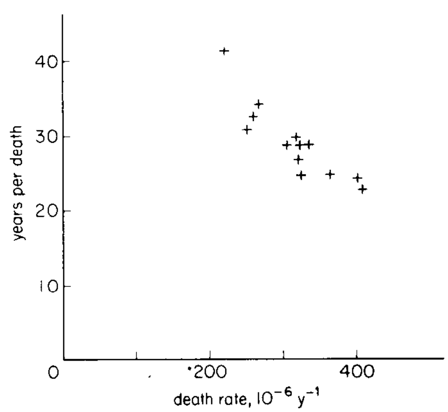

FIG. 3. Ratio of total periods (calendar years) off work to deaths from occupational accidents, in relation to accidental death rate (deaths per million employed per year). Data for European Steel Industries in successive years, 1960–1972 (as in Table 6).

TABLE 5. DAYS LOST OWING TO ACCIDENTS AT WORK

A. European Steel Industries 1960/72

Activity	Deaths	Deaths per million per year	Calendar days lost due to accidents	Calendar years per death
Laminoirs	170	202	3 172 463	51
Cokeries	12	257	104 114	24
Service Auxiliaires	339	279	2 937 475	24
Aciéries	189	558	1 652 235	24
Hauts-fourneaux	101	560	627 957	17
B. U.S. Department of Labor				
Trade	700	72	4 706 000	34
Manufacturing	1 400	93	11 481 000	41
Services	500	121	2 573 000	26
Transportation	1 100	378	2 663 000	12
Construction	1 500	736	2 640 000	9
C. U.K. Industries				
14 factory occupations	166	32	5 180 000	106
Manufacturing metal, bricks & shipbuilding	112	110	2 220 000	63
Construction	204	146	1 450 000	23

Time lost owing to industrial accidents in different occupations, and average time lost (in calendar years) per accidental death in each occupation. "Calendar years" are estimated according to whether "days lost" are quoted as working days or calendar period.

TABLE 6. ACCIDENTAL MORTALITY AND ESTIMATE OF TIME LOST PER LIFE LOST IN EUROPEAN STEEL INDUSTRIES (EUROSTAT 1970)

Year	Accidental mortality (per million per year)	Time lost per life lost (calendar years)
1960	401	24.0
1961	336	28.6
1962	409	22.5
1963	319	29.7
1964	323	28.7
1965	363	24.5
1966	260	32.4
1967	251	30.9
1968	325	24.4
1969	321	26.7
1970	307	28.6
1971	269	34.1
1972	221	41.2
Mean	316	29.0
Rate of change (%/y)	-3.3	+2.7
Correlation with year $r=$	-0.73	+0.60

per million per year, it is seen (Fig. 2) that there is considerable regularity in the data within each survey, and even to some extent between surveys in different countries. Moreover, the improvement with time in the safety of European steel industries, with an accidental mortality falling by 3.3% per year from about 400 to about 200 10^{-6} y^{-1}, is associated with a parallel rise by 2.7% per year in the estimate of time lost per life lost (Table 6 and Fig. 3).

(23) This finding clearly needs to be examined on a much wider basis. Essentially, however, it seems to follow simply from two observations. Firstly, as already noted, the annual frequency of accidental deaths (D) increases more rapidly than that of accidents (A) with increasing hazard. Secondly, the length of time off work per accident (C) is remarkably constant for occupations of varying hazard in any given country. Thus, for sixty-two U.S. industrial groups,[12] the mean period was 14±3.5 (S.D.) days with

only a small regression on accident rate given by $C = 12 + 7 \times 10^{-5}A$, and a range of only 12–16 days for main groups.

Similarly, for six major types of employment in France,[13] the mean period was 24.9 days, with $C = 20.9 + 5 \times 10^{-5}A$, with a range of 23–30 days for the main groups. Other studies have given values for C in different occupations with coefficients of variation round the mean value in the region of 25%.

If therefore $A = KD^n$, the loss of time L per unit loss of life will approximate simply to a function of D, given by

$$L = AC/D = CK/D^{1-n}$$

which for values of n between 0.5 and 0.8, will decrease slowly with increasing D.

(24) If any consistent relationship of this type is found to hold for a range of occupations within any country and even, despite differences in notification procedure, between countries, some tentative comparisons become worth considering between the occupational harm from accidental deaths and that from non-fatal accidents. It was shown above that the mean loss of life from an accidental death from occupational causes was about 30 years. If it were to be assumed that loss of a period of time through being dead was "worse" than an equal loss of time off work as the result of accident, accidental deaths would make the major contribution to harm in conditions in which the "time lost per life lost" exceeded 30 years (Fig. 2).

(25) This assumption is, of course, not self-evident. To the worker, death might sometimes appear preferable to prolonged and painful disability. To his family also, the anxiety, nursing problems and financial stress of repeated or prolonged periods off work might occasionally seem to be the worse alternative. In general, however, the great majority of periods off work involve short spells of less than 2 months. Thus, for one typical survey,[11] 75% of all spells off work were of less than 7 weeks duration, and 50% were of less than 3½ weeks.

(26) Clearly, however, accidents causing permanent disability need to be taken into account in assessing the time off work from non-fatal injuries, and their frequency relative to other accidents is likely to vary considerably in different occupations. For a wide range of occupations in Japan, permanent *total* disability appeared to be caused with only about 5% the rate of accidental deaths from industrial causes. Permanent partial disability in the same groups had about twice the frequencies (of new cases per year) of accidental deaths.

(27) In general it would seem reasonable to assume that loss of years through death are as bad as, or worse than, and probably considerably worse than, loss of years off work following non-fatal accidents. If so, the occupational fatality rate would measure the majority of accidental harm for occupations with fatality rates of over about 200 10^{-6} y^{-1} (Fig. 2).

Before considering a possible "index" of harm based on this type of criterion however, the contributions from industrial diseases and from genetic and foetal damage require consideration.

OCCUPATIONAL DISEASES

(28) Inclusion of the harm (including death) due to occupational diseases involves two major difficulties. Firstly, the range of diseases attributable to occupational causes is difficult to define comprehensively. Some conditions may be merely exacerbated by these causes; some, such as those due to chemical carcinogens in the working environment, are only slowly becoming recognized. Death certificates may name an occupational disease as the cause of death when in fact it may only have been present at the time of

a death due to a non-occupational cause. Moreover, lists and records of occupational diseases relate primarily to administrative arrangements for compensation and not necessarily to biological causation.

The second difficulty is due to the very variable contribution of occupational diseases to harm in different industries, making a major contribution in some (for example in coal mining) and probably a trivial one only in others (as for example in many engineering occupations).

(29) In principle, however, the same type of analysis could be carried out as for accidental injuries and deaths, taking account of the frequency of illnesses and average time off work involved by each, and of the frequency of deaths and the mean age at death. Allowance would need to be made by some sort of weighting factor for illnesses only partly attributable to the occupation, but such weighting factors are widely used and accepted in deciding upon compensation or pension, and such factors might legitimately be used.

In fact, however, for most industries, occupational disease appears to make much smaller contributions, at least on the basis of time off work, than do occupational injuries. On statistics obtained in the U.K.,[11] the working days lost in one year owing to non-fatal industrial accidents were 20.2 million, and those lost owing to prescribed occupational diseases were 0.70 million, or 3.5% of the total loss.

The same proportion, with occupational illness having only a few per cent of the impact of industrial accidents, emerges from analyses of types of hospital or other treatment required (Table 7).

(30) If an index of harm is being based on days lost, therefore, this evidence suggests that, except in occupations with recognized high rates of occupational disease, such diseases normally make a trivial contribution to the index. Records from four groups of industries in the Federal Republic of Germany[14] indicated that just less than 8% of deaths from occupational diseases and occupational accidents were due to the former, much of this percentage being due to relatively high rates in mining (Table 8). In work in factories, the U.K. Chief Inspector of Factories[15] recorded only three deaths (and 324 cases) of poisoning and ten deaths (304 cases) from gassing accidents, as compared with 251 accidental deaths and 204 935 accidents within the same occupations. Death certificates recorded the presence of asbestosis in seventy-seven cases and byssinosis in twenty-one, pneumoconiosis appearing in 228 cases from occupations other than mining or quarrying. In mining or quarrying, pneumoconiosis appeared on the death certificate in 838 cases and this compares with about 160 deaths in the year from fatal accidents in mines and quarries, and about 144 000 accidents recorded in these occupations.

TABLE 7. FREQUENCY OF SPELLS OF TIME OFF WORK (UK, JUNE 1969/MAY 1970)

No. of spells of	From industrial accidents	From occupational diseases	Ratio of frequencies: Spells from diseases / Total spells
In-patient treatment	50 500	2 720	0.051
Out-patient treatment (of 25d. or more)	166 600	9 140	0.052
Lesser disabilities	623 200	15 380	0.024
All spells	840 300	27 240	0.031

Frequency of spells off work from industrial accidents and from occupational diseases[11] per year, and ratio of frequencies.

TABLE 8. DEATHS FROM OCCUPATIONAL ACCIDENTS AND DISEASES (GERMAN FEDERAL REPUBLIC, 1970)

Group of industries	Number of deaths from occupational Accidents	Diseases	Ratio of frequencies: From diseases / Total	
Mining	160	75	0.32	
Iron & Metal	417	17	0.04	0.03
Chemical	90	11	0.11	
Construction	675	7	0.01	
Total	1 342	110	0.08	

Number of deaths from occupational accidents and from occupational diseases in different industries,[14] and ratio of frequencies.

It seems likely, therefore, that in the majority of industries and for the great majority of workers, industrial diseases increase by only a few per cent the estimate of harm based on mean period of disability or loss of life from accidents. In certain occupations, however, such as mining or quarrying and in some sections of chemical industries,[1] high incidences of occupational disease require this component to be taken into account.

RADIATION-INDUCED SOMATIC EFFECTS

(31) Radiation may cause "somatic" effects, which are expressed in the exposed individual, and "genetic" effects expressed in his descendants. The somatic effects are classed as "non-stochastic" (which occur only if a substantial threshold dose is exceeded) and "stochastic". For the latter, the frequency is related to the dose—ordinarily without evidence of a threshold—and the induction of malignant disease is likely to be the only significant component, except in the developing embryo, at dose levels received occupationally.

(32) Non-stochastic effects are most unlikely to result from exposures within present permissible limits, and thus should make no contribution to harm from occupational exposure. The present section therefore deals with the induction of malignant disease as constituting the main somatic effects induced in the adult. The importance of effects upon an embryo or foetus is described in paragraphs 51–64, and that of genetic effects in paragraphs 43–50.

(33) The average risk factor for fatal malignancies is taken as about 10^{-4} rem^{-1}, as the average for both sexes and all ages, in *ICRP Publication 26*. As discussed below (paragraph 38) this value appears consistent with the estimates given for individual organs or tissues, as the total risks of fatal cancers of various types, derived from human epidemiological surveys. In deriving such estimates, allowance is made for the duration of the survey, and the additional deaths that might occur during the lifetime of the exposed individuals beyond the period surveyed.

(34) For a population exposed at constant average rate during a working lifetime of from 18–65, however, a proportion of all potentially fatal induced cancers will fail to develop or cause death since deaths will occur from natural causes before all induced cancers develop. No exact value for this reduction in estimated risk can be obtained, owing mainly to uncertainty as to the distribution of "latent intervals" between exposure and death from induced cancers, but the average reduction appears unlikely to be greater than about 25%. The mean latency for leukaemia is in the region of 10–13 years, and for this malignancy the distribution of intervals from exposure to death can now be approximately estimated.[16] The mean latency for cancers is likely to be about twice as large and the distribution of latencies for cancers is assumed to be twice as extended in time as for leukaemia.

TABLE 9. VARIATION WITH AGE AND SEX OF THE INDUCTION OF A FATAL MALIGNANCY

Average risk in age group (10^{-6} rem^{-1})	Age Groups 18-	20-	25-	30-	35-	40-	45-	50-	55-	60-	Total
Males											
Leukaemia	20	20	20	20	20	20	20	17	14	8	
Cancer	80	78	75	70	64	56	45	32	22	10	
Total	100	98	95	90	84	76	65	49	36	18	
% in age group	7.1	12.2	10.8	10.1	9.7	10.3	11.0	9.4	10.0	9.4	
Product	710	1 200	1 030	910	810	780	720	460	360	170	7 150
									7 150/(100 × 100) = 0.72		
Females											
Leukaemia	20	20	20	20	20	20	20	20	17	14	
Cancer	130	130	127	122	113	104	91	73	52	35	
Total	150	150	147	142	133	124	111	93	69	49	
% in age group	17.2	22.7	10.5	6.3	6.4	7.5	8.9	7.6	8.2	4.7	
Product	2 580	3 410	1 540	890	850	930	990	710	570	230	12 700
									12 700/(150 × 100) = 0.85		

Risk of death from radiation-induced malignancy (per million per rem) with age at which exposure occurs (see paragraphs 37 and 38). Average risk, for populations with age distributions as in working populations, 0.72 (males) or 0.85 (females) times that calculated on the assumption of a full expression of all induced cancers.

(35) Table 9 gives estimates made on this basis for the numbers of malignancies that would be expressed as a result of exposure at constant rate during the period of working life, as compared with the numbers that would result from exposure early in life with full expression of the risks of the exposure. Assuming mean ages of death from natural causes of 72½ and 77½ years in males and females respectively, the risk of death from radiation-induced leukaemia starts to fall from its maximum value, taken as 20 10^{-6} rem^{-1},[18] for exposures received after the age of 50 in males and 55 in females.

(36) For other radiation-induced malignancies, *ICRP Publication 26* derives maximum risk rates, per million exposed per rem, for fatal cancers of lung as 20, for bone cells as 5, for thyroid as 5, for breast as 25 (as an average of 50 in females and 0 in males) and for all other organs together as 50. The average maximum risk rate for all malignancies other than leukaemia would thus be 105 10^{-6} rem^{-1}.

(37) Assuming a distribution of latencies (from exposure to death) for all such cancers to be twice that for leukaemia, Table 9 indicates that the risk rate starts to fall slowly from the maximum values, for exposures received after the age of 20 in males and 25 in females.

(38) The age distribution of working populations assumed in Table 9 is that for all U.K. male and female workers (registered as employed, June 1969–May 1970[11]). For these populations, the average risk rate for fatal induced malignancies would have a value of 100 10^{-6} rem^{-1}, or about 80% of the maximum rate for exposure at an age allowing full expression of all induced malignancies.

	Risk of all fatal malignancies (per million per rem)		
	Assumed for full expression	For exposures during working life	Percentage expressed
Males	100	72	72
Females	150	127	85
Average	125	99	78

(39) The percentage of the full risk that is expressed as a result of exposures during working ages will vary considerably with the age and sex distribution of the working population, and is clearly estimated here on a very tentative basis. Comparable values (71% for males and 87% for females) were however obtained for the age distribution of employees