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AUSTRALIAN ATOMIC ENERGY COMMISSION

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ABSTRACT

This paper examines the claim of the nuclear industry to have an excellent safety record, in terms of health and accident records of workers in the industry. It does not consider accidents which have not resulted in harm to the workers' health.

The nuclear industry is considered to include all work with ionising radiations and radioactive materials, in education, research, medicine and industry.

Since 'safety' is not an absolute concept, comparisons are made with the published records of other industries, and a study is made of the performance of the nuclear industry in relation to its own safety criteria.

Data are presented on the radiation exposure of nuclear workers in Europe, America, India and Australia, in relation to the internationally recommended limits, and there is some discussion of the risks involved in these limits.

The death rate in parts of the nuclear industry in America, the United Kingdom, and Australia is presented and compared with the death rate for other industries in those countries, and a listing is made of deaths caused by radiation in the period 1945 to 1968. Injury rates for the US and Australian nuclear industries are also compared with the

(continued)

injury rates for other industries in these countries.

Consideration is given to the safety record of individual components of the nuclear industry (using the wide definition of this industry given above), special attention being given to health records of uranium miners, plutonium workers and radiologists.

Although there are difficulties in obtaining sufficiently detailed information of this kind it is considered that the data presented, relative to any reasonable standard, demonstrate that the nuclear industry has a safety record to be proud of.

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COMPARATIVE EVALUATIONS; NUCLEAR INDUSTRY; PERSONNEL; PERSONNEL MONITORING; RADIATION DOSES; RADIATION HAZARDS; SAFETY; WORKING CONDITIONS

HEALTH AND SAFETY RECORD OF THE NUCLEAR INDUSTRY

The nuclear industry, which is world-wide, claims to have an excellent safety record. Even Lord Ritchie-Calder in his foreword to 'Poisoned Power - The Case Against Nuclear Power Plants' [Goffman & Tamplin 1973] says 'Indeed, radiological protection of the individuals has been so scrupulously maintained that the nuclear industry, throughout the world, is entitled to claim that its record of industrial health and industrial accidents is far better than for any other industry... It may even be true that, in the light of now-considerable experience, the safeguards may be excessive.' (Lord Ritchie-Calder is a science writer and university professor who is not noted for his advocacy of nuclear power.)

In this paper, the safety record of the nuclear industry is examined in relation to the safety of the workers in the industry, dealing as far as possible with recorded facts rather than calculations or predictions. The paper does not examine the industry's performance in terms of engineering and plant failures, safety of the public or consequences of possible major accidents; these are discussed elsewhere.

'Is it safe to work in the nuclear industry?' is not a simple question for several reasons. Two main points have to be clarified; first, what is the 'nuclear industry' and secondly, what is 'safe'?

The nuclear industry may be taken to include any or all of the following:

- uranium mining and processing;
- nuclear fuel production;
- operation of nuclear reactors for research, radioisotope production or power production;
- fuel reprocessing and waste disposal; and
- the use of radioisotopes and X-rays in industry, medicine and research.

Clearly, although the 'industry' has in common ionising radiations and radioactive materials, it is very varied and multi-disciplinary. One can expect, therefore, some variations in degrees of 'safety' within the industry.

Safety, also, requires an extended definition. Safety in industry cannot be defined in absolute terms since it depends strongly on social and economic factors and standards, for these have changed with time. For example, some practices that were regarded as 'safe' in the industries of a century ago are totally unacceptable today. Thus, when we talk about safety in industry we are really talking about relative safety.

Relative to what? Since, for complete safety, there would be no industry at all and other human activities would be severely curtailed, industrial safety can only be related to the day-to-day risks accepted by mankind. The safety record or the risks of the nuclear industry can be compared with the safety record or risks of other industries (particularly those found to have a good safety record), or with the risks involved in natural events such as earthquakes and lightning strikes, and with man-made disasters such as automobile and aircraft accidents. Comparisons with the latter are valid, since travelling by automobile or aircraft is a voluntary action, as is working in any specific industry. If the nuclear industry presents special hazards, then we should examine to what extent they cause accidents and injuries within the industry.

The special hazard of the nuclear industry, radiation, can be measured and compared with safety criteria in the form of the Recommendations of the International Commission on Radiological Protection (ICRP). This body was set up in 1928 by the Second International Congress of Radiology and considers all the available data relevant to human exposure to ionising radiations. The unit of radiation exposure dose, the roentgen introduced in 1928, is a measure of X- or gamma-radiation in air. The unit of absorbed dose (energy deposited per unit mass) is the rad*, which measures the effect of any radiation in any material. Equal rad doses of different kinds of radiation may not produce an equal biological effect; this difficulty is overcome by using another unit of dose, the rem, which is the quantity of any type of radiation that produces the same effect as one rad of X-radiation. The ICRP's primary recommendations of upper limits to the radiation doses that may be incurred by radiation workers and members of the public are given in terms of the rem. Most countries have incorporated these limiting doses into legislation and, in Australia, similar limits have been recommended by the National Health and Medical Research Council.

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* In SI units, 10^{-2} joules per kilogram.

The ICRP recommends that the dose to the whole body of a radiation worker should not exceed 5 rem per year averaged over his working life, and there are other figures for different organs of the body. These limits govern a radiation worker's occupational exposure although some latitude, under defined conditions, is allowed in the dose incurred in any one year. The ICRP does not suggest that doses in excess of the recommendations will necessarily cause injury, but does suggest, on the cautious assumption that even small doses may carry some risk, that radiation dose should be kept 'as low as is readily achievable, economic and social conditions being taken into account' (ICRP 1966).

Does the nuclear industry comply with its own safety recommendations? Table 1 indicates, for a number of organisations, data relating their staffs to the 5 rem per year limit. In general, we see that less than 0.1% of all radiation workers have exceeded the 5 rem limit at any time and we may consider that this constitutes a good safety record.

A world survey made by the International Labour Office [Hellen 1972] indicated that out of more than 298 000 radiation workers, approximately 44% worked in the medical field and the great majority of all workers received radiation doses of less than 0.5 rem per year. These dose levels can be compared with the natural background radiation level of about 0.1 rem per year in many parts of the world (a few areas, such as parts of India and Brazil, have background radiation levels more than ten times higher).

Unfortunately, non-nuclear industries do not have comparable records of the exposure of their work forces to hazardous materials, so no direct comparison is possible in these terms.

If the above indicates that the nuclear industry has a satisfactory record in relation to its own radiation safety recommendations, can we still ask if these recommendations are safe enough? This question can only be answered in a negative way; since we are now talking about the small probabilities of injury from low levels of radiation exposure. For example, it has been said [Sagan & Thomas 1974] that to find an accurate probability of a person contracting leukaemia after receiving a radiation exposure of 5 rem per year, the records of 6 million man-years of exposure at this level would be needed before any change in the natural occurrence of this disease could be detected. (Leukaemia is a form of cancer and can arise from radiation exposure.)

An occupational exposure of 5 rem per year has been estimated to produce, at most, 500 extra cancer deaths per million radiation workers

Continued p.5.

TABLE 1

RADIATION EXPOSURE OF NUCLEAR WORKERS

[After Hellen 1972; Duncan & Howell 1970; USAEC 1971; Pepper & Carter 1972]

Organisation or Country	Survey Data			Percentage exceeding annual limit
	A No. of years	B Man-years' experience	C No. of times 5 rem/y exceeded	$D = \frac{100C}{B}$ %
USAEC	28 (1943-70)	1 663 852	1971	0.12
UKAEA	3 (1965-67)	53 815	249	0.46
CEGB	9 (1962-70)	19 500	0	0 (less than about 0.005)
AAEC	9 (1966-74)	9016	1	0.01
Canada	1 (1969)	28 643	17	0.06
France	1 (1969)	19 595	0	0 (less than about 0.005)
Germany (Federal Republic)	1 (1969)	22 550	18	0.08
India	1 (1969)	26 391	between 100 & 250*	from 0.03 (Nuclear Energy) to 1.95 (Industry)

** Not directly reported, inferred from other reported data.*

USAEC - United States Atomic Energy Commission and its Contractors (now part of ERDA - the Energy Research & Development Administration)

UKAEA - United Kingdom Atomic Energy Authority.

CEGB - Central Electricity Generating Board (England & Wales).

AAEC - Australian Atomic Energy Commission.

per year [Lave & Freeburg 1973]. The same report estimates that deaths from exposure to the US Environmental Protection Agency's primary standards for non-radioactive airborne particulates and sulphur dioxide (produced for example by burning coal) would be, respectively, about 600 and about 300 extra deaths per million persons per year. Thus, the recommended radiation exposure limits appear to be at least as 'safe' as currently recommended 'safe' levels for other potential health hazards. As a atter of record, during the London 'smog' of 1952 an estimated 4000 people died from bronchial illness [Ministry of Health, UK 1954]; during a 15-day period of intense air pollution in New York City in 1963, 809 deaths were noted in excess of the average for the same period in other years; the effect of air pollution is estimated to have caused between about 200 and 400 of these excess deaths [Greenburg et al. 1967]. The record of deaths from radiation exposures is indicated later (Table 4).

The 'natural' rate of death from cancer is about 1500 per million population per year. Thus, if a worker in the nuclear industry were exposed to 5 rem per year, the chance of that individual worker dying of cancer would increase from about one in 670 to about one in 500. At the more typical exposure of 0.5 rem per year, the chance of a radiation worker dying from cancer increases from about one in 670 to about one in 640.

Those are calculations; what records are available for people exposed continuously to similar radiation levels? Surveys have been carried out on residents of some of the high radiation background areas on the Kerala Coast of India [Gopal-Ayengar et al. 1972] where the natural doses to the population range from 0.1 rem per year to over 2.0 rem per year. Results on the fertility index, sex ratio among offspring, infant mortality rates, pregnancy terminations, multiple births and gross abnormalities among these peoples have been published; no statistically significant differences in the average mean values of the data for differently exposed groups were reported. However, the authors suggested that the total loss of offspring (low fertility index and high infant mortality rates) in one group of nine couples receiving over 2.0 rem per year from natural background radiation was somewhat higher than in other groups. These data tend to confirm that the whole body radiation doses received by radiation workers throughout the world represent a low degree of risk.

How does the nuclear industry compare with other industries? To substantiate its claim to have a good safety record, it must be seen to be good in relation to other industries. Let us now examine the overall safety record of the nuclear industry by comparison with the safety record of other industries.

Figure 1 compares the death rates of staff of the USAEC with the US National Safety Council (USNSC) figures for industry in the USA for the years 1943 to 1970. During 1943-1969, the USAEC death rate averaged only about 43% of the rate for industry as a whole. Thus a worker in the USAEC had only half the chance of accidental death that his colleague had in other industries. (Note also that 98% of the USAEC deaths were brought about by non-nuclear occurrences.)

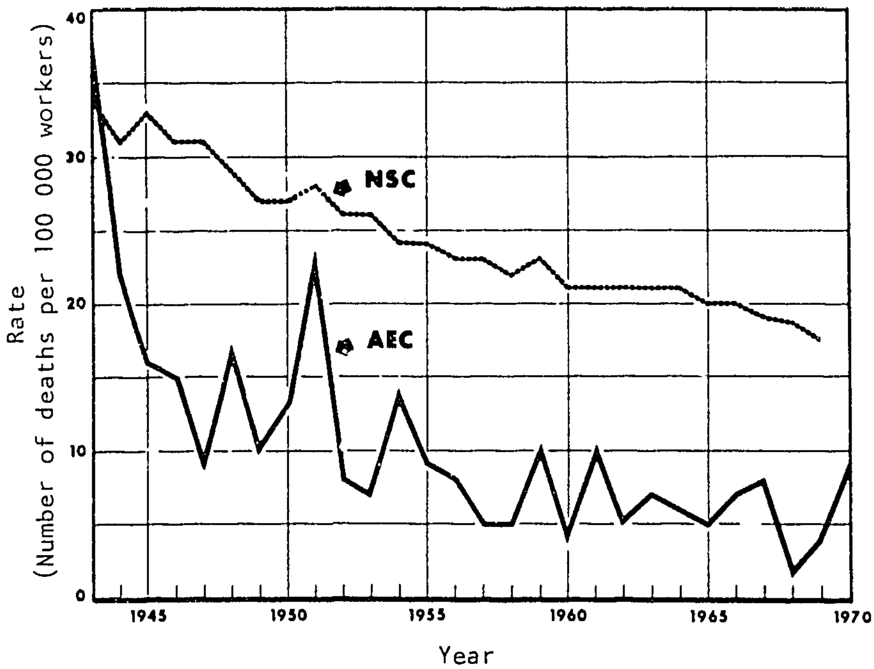

FIGURE 1
DEATH RATES USAEC v.USNSC 1943-1970 (After USAEC 1971)

A survey made in 1968 of deaths of workers in the UKAEA [Duncan & Howell 1970] showed that there were 1235 deaths in the period 1962 to 1968 compared with the statistically 'expected' number of deaths totalling 1963. The causes of death, studied in detail, showed 331 deaths from alignant neoplasms (cancers) instead of the 'expected' 438 deaths from the same cause. Although these data may indicate primarily that the group studied was not a statistically 'average' group, they also indicate that the health of nuclear industry workers is at least as good as the health of the general population.

Corresponding Australian figures are as follows: between 1960 and 1974, there were 31 deaths from all causes in the AAEC work force of about 1100 persons (say, 2 per thousand per year). None of the deaths were attributed to the working environment. The only accidental death in the same period was that of a contractor's employee, during construction work. In comparison, Australian deaths from all causes for the years 1969-1970 in the age group 20 to 65 were about five per thousand population per year, and those from accidents other than motor vehicle accidents were about 0.17 per thousand population per year. Table 2 gives data for a number of industries in the United Kingdom.

TABLE 2

FATAL ACCIDENTS IN UK INDUSTRY

Industry	1959-1968		1963-1972	
	Total fatalities	Average annual incidence*	Total fatalities	Average annual incidence*
Coke ovens & manufactured fuel	37	29.0	26	21.0
Construction	2539	20.0	2358	19.2
Iron & steel (general)	454	18.1	409	17.8
Shipbuilding & repairing & marine engineering	323	16.5	249	14.9
Bricks, fireclay & refractory goods	78	13.2	73	13.4
Abrasives & building materials (not elsewhere specified)	78	8.9	117	13.0
Iron castings	145	13.8	123	12.5
Cement	23	24.0	14	11.7
Paper & board	84	10.5	86	11.7
Grain & milling	30	12.0	26	10.9
General chemicals	162	10.0	146	10.7
Sugar	14	9.9	13	10.6
Timber	92	12.0	71	8.7

** per 100 000 workers. Source: 1972 Annual Report of HM Chief Inspector of Factories.*

How does the nuclear industry worker fare in regard to non-fatal injuries? Figures 2 and 3 show the frequency rate (number of injuries per million man-hours) and severity rate (number of days lost per million man-hours) for the USAEC compared with USNSC figures for US industry as a whole. Clearly, in all its activities the USAEC has a better safety record than other industries.

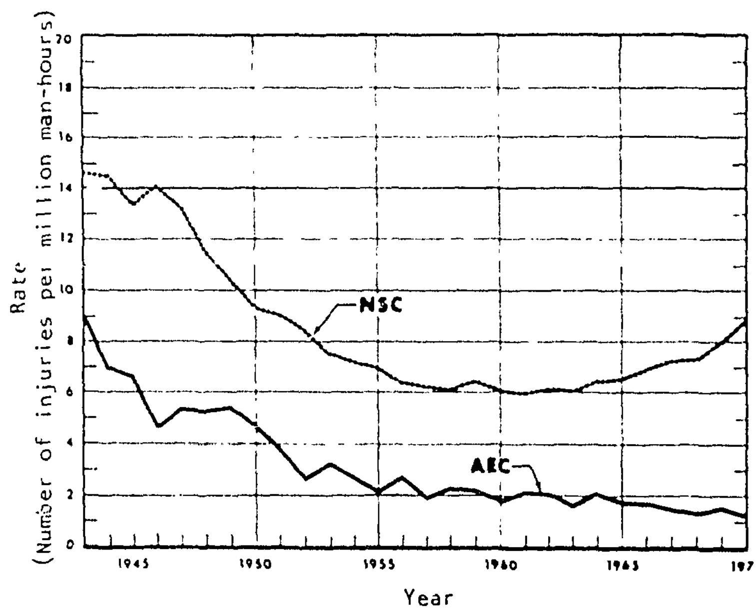

FIGURE 2
INJURY FREQUENCY RATES USAEC v. USNSC
1943-1970 (After USAEC 1971)

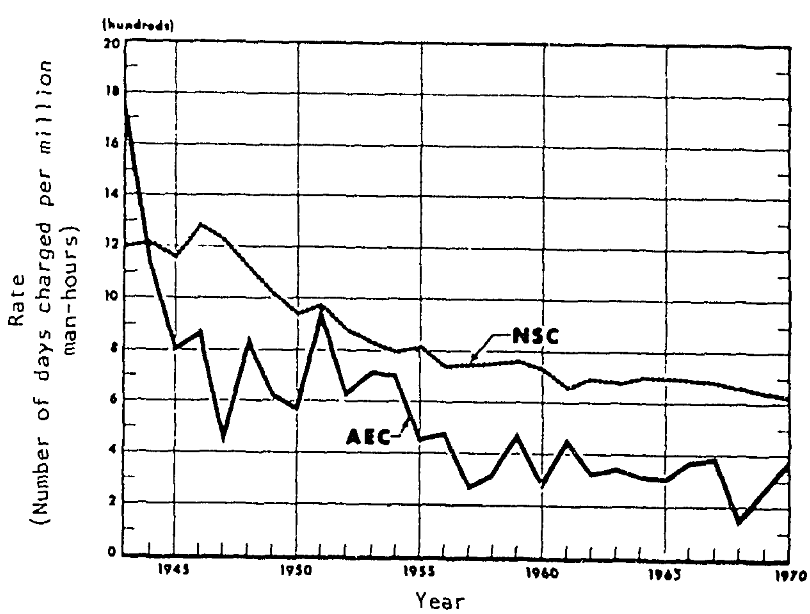

FIGURE 3
INJURY SEVERITY RATES, USAEC v. USNSC
1943-1970 (After USAEC 1971)

From what we have seen so far, the nuclear industry has a good safety record. Let us now look at the safety records of separate parts of the industry starting, logically, in the uranium mines.

Has uranium mining a better record than the rest of the mining industry? The industrial safety record of the mining industry as a whole is not particularly good. We have only to look at the record of coal mining to realise this. Table 3 gives some comparative figures for the USA for the years 1965 to 1969.

TABLE 3

USA MINING ACCIDENT DATA 1965-1969

[After Lave & Freeburg 1973]

Process	Accidents per year		Disability days per million man-hours
	Fatal	Non-fatal	
Coal mining	246	10 251	8441
Uranium mining	8	272	8702
Uranium milling	0.2	59	1091
Uranium mining + uranium milling	8.2	331	6299 (see below)

From the final column, the safety of uranium mining taken alone appears to be comparable to that of coal mining, but if uranium milling is included, the uranium industry's record is better than that of coal mining, (the man-hours spent milling is roughly half the man-hours spent mining).

Underground uranium miners in Europe and North America have shown an excessive incidence of lung cancer. An excess of lung cancer has also been reported in miners from some other, but not all, types of underground mines. For example, miners of fluorspar in Newfoundland suffer a lung cancer rate 20 or more times greater than that of the non-mining male population of Newfoundland [Donaldson 1969]. The common factor in all these mines has been the presence of radon (the radioactive gas to which radium decays) at higher than normal levels in their atmospheres, and a clear relationship has been established between lung cancer incidence and exposure to radon, and its radioactive daughter products, in mine air. Underground uranium miners who smoke have a considerably higher incidence of lung cancer than those who do not, but smoking itself can be responsible for only a minor part of the increase observed [Archer et al. 1973]. The major effect of smoking may be to lessen the time between a miner's first exposure to radioactive mine atmospheres and the appearance of lung cancer; the time lag may be as long as 20 years.

The increase, in recent years, of lung cancer in underground uranium miners must be set against the development of the nuclear industry, but it should be seen in perspective. First, the most important cause of excess mortality in uranium miners has not been lung cancer but accidental death, which is shared with other forms of underground mining. Secondly, the lung cancers now occurring in uranium miners have arisen because the lessons of history were not learnt, and because the special hazards were not recognised and controlled. These lessons have now been learnt and lung cancer should cease to be a significant hazard for underground uranium miners.

And what of nuclear fuel manufacture? The nuclear industry enriches the uranium and makes it into reactor fuel. The processes used to make reactor fuel are similar to those used in the metal refining and ceramics industries. One significant radiological hazard in these processes is the handling of small quantities of highly enriched uranium used as fuel in experimental and research reactors. Such materials could cause a 'criticality accident' but so far there have been none in enrichment plants. (In a criticality accident, fissile material fortuitously gets into a situation where a nuclear chain reaction takes place in an uncontrolled manner with the emission of very high levels of gamma and neutron radiation. Since such events are unplanned, there will often be no radiation shielding of personnel.)

Criticality accidents are comparable to explosions in the chemical industry, i.e. owing to a failure of safeguards, hazardous material is in the wrong place at the wrong time. In 1967 in the USA, 7423 people were killed by 'fire and explosion' and 42 by 'explosion of pressure vessel' [Meleis & Erdmann 1972]. In 1974 28 people were killed by an explosion at the Nypro chemical works, Flixborough, UK [UK Department of Employment 1975]. The worst criticality accident to date killed three people (see Table 4). We should also note that of the six deaths caused by criticality accidents, three occurred in research situations, and three during refuelling work on a military training reactor. There have been no criticality accidents at commerical power reactors.

Uranium enrichment and nuclear fuel manufacture can also present a hazard to the workers, arising from the daughter products of uranium. The same standards of safety and radiological protection are applied to these parts of the industry as to the other parts, and the relevant statistics are included in the data presented in this paper.

TABLE 4

RADIATION-CAUSED DEATHS 1945-1968*

[After Sutra-Fourcade 1969]

Date	Location	Type of accident	No. of deaths
21.8.45	Los Alamos, USA	Criticality accident (assembly)	1
21.5.46	Los Alamos, USA	Criticality accident (assembly)	1
1952	Rhineland-Pfalz, Germany	25 years of work with X-rays	1
1953	Berlin, Germany	14 years of luminous paint preparation	1
1954	Marshall Islands	Japanese fisherman contaminated with weapons test fallout	1
1956	Brookhaven, USA	Inhalation of radioactive material 1946-1948	1
1957	Berkeley, USA	Work with radioactive material	1
18.10.58	Vinca, Yugoslavia	Criticality accident (reactor)	1
30.12.58	Los Alamos, USA	Criticality accident (chemical plant)	1
8.6.60	USSR	Suicide (radioactive source)	1
3.1.61	Idaho Falls, USA	Criticality accident (reactor)	3
1961	Germany	Medical over-exposure	1
1962	Mexico	Radioactive source left in a house	4
24.7.64	Wood River Junction, USA	Criticality accident (chemical plant)	1

* *Excluding lung cancers of uranium miners.*

The fuel is used in nuclear reactors, which range from small experimental devices to very large commercial power reactors. In the years 1945 to 1968, reported deaths from radiation or radioactive materials within the nuclear industry totalled 19 (Table 4), of which 6 were associated with reactors or critical assemblies (a special kind of very low power reactor) and were caused by criticality accidents. The only reported deaths caused by radiation accidents since 1968 have been in the medical field.

Used nuclear fuel is reprocessed to recover valuable uranium (which can be used as fuel again) and plutonium (which is another nuclear fuel) and radioactive waste materials have to be stored and handled. Plutonium has been described as one of the most toxic materials known to man, so any shortcomings in safety precautions would surely show up in the health records of plutonium workers. As an emitter of alpha-particles, plutonium presents its greatest hazard to man if it gets inside the human body.

What are the risks from radioactive material in the body? Here again, ICRP recommendations provide the basic standards of radiation safety. For each different radioactive nuclide, the ICRP has recommended a maximum permissible body burden (mpbb) for radiation workers. The mpbb is the amount of a radioactive nuclide that, if left in the body, will irradiate either the whole body or a particular organ to the primary dose limits. Therefore, exposure to an mpbb is considered safe, though with the same proviso as for radiation dose - exposure should be minimised. Harmful effects are unlikely to follow intake of radionuclides into the body unless in quantities very considerably greater than the mpbb.

In the years 1957 to 1970, plutonium was ingested by 203 USAEC personnel, in amounts between 0.25 and 10 times the mpbb, as shown in Table 5. Medical observations showed that none of them have suffered health injuries as a result of their exposure. A more important group (because any biological effects of radiation exposure take time to develop) are three groups of persons who were exposed about 30 years ago. Twenty-five persons were exposed during the very early development of atomic weapons, resulting in plutonium body burdens between about 0.15 and 10 mpbb; they have had periodic biomedical checks since 1945.

TABLE 5

INTERNAL PLUTONIUM DEPOSITIONS EXCEEDING 25% OF THE OCCUPATIONAL PERMISSIBLE BODY BURDEN AMONG USAEC PERSONNEL 1957-1970

[After Richmond 1974]

No. of persons	Year	No. of persons	Year
12	1957	22	1965
6	1958	27	1966
10	1959	10	1967
10	1960	8	1968
16	1961	6	1969
20	1962	3	1970
9	1963	15	? *

No. of persons	Route of entry	No. of persons	Percentage of permissible body burden
131	Inhalation	118	25 to 50
48	Wound	35	50 to 75
8	Both	13	75 to 100
16	Unknown	15	100 to 200
		15	200 to 500
		7	500 to 1000

* *The query is not explained in the reference; presumably the year of intake is not known for these 15 persons.*

second group of 42 persons was also exposed during weapons development, 25 of whom are now being studied. A different group of 18 persons, regarded as being hopelessly ill in 1945-46, were injected with doses of from 7.5 to 150 mpbb; 15 of them were over 45 years of age at the time - 4 of them are still alive and 3 are still under study. Not a single person in these three groups has experienced any observable amage to health that can be attributed to their exposure to plutonium [Richmond 1974].

Large quantities of radioactive materials, including several tonnes of plutonium, are handled annually at the Windscale works of British Nuclear Fuels Limited (BNFL) in the UK. A recent report [Schofield & Dolphin 1974] shows that the occupational health record at Windscale is at least as good as the record at a similar BNFL plant where smaller quantities of radioactive materials are processed. As we have seen earlier, the record can be favourably compared with that of other industries. Between the years 1967-72, there were 23 deaths from cancer in the Windscale work force, compared with an 'expected' 37 cancer deaths from age-adjusted national statistics. Schofield [1975] has also pointed out that, in a 24-year period, there have been five known cases of leukaemia among Windscale employees, ex-employees and pensioners, whereas natural incidence in the staff of 300 radiation workers in the period would be about four cases, and double that number if retired persons and those moved to other jobs were taken into account.

Two conclusions can be drawn from these data on plutonium exposure. First, the total number of persons who have exceeded the recommended limits is small (just as in the case of the 5 rem per year radiation limit); secondly, the evidence shows that exceeding these limits by up to ten times does not produce observable effects, which suggests that the recommended limits are conservative ones.

Of course the total number of persons involved is comparatively small, and the most-feared consequence of plutonium exposure, cancer of the lung, may not appear until twenty years or more after exposure begins, so there is still some uncertainty. However, an industry that can handle large quantities of such a highly toxic substance as plutonium, for some thirty years, without apparent harm to its own work force can reasonably claim to have an excellent safety record.

Much has been written about the long-term storage and handling of radioactive waste materials but, from the workers' safety viewpoint, there are no safety problems different to those already discussed. The record of this part of the industry is included in the general safety statistics presented above.

Are the medical and industrial users of radiation safe? Radioactive materials, produced in reactors, are used in medicine (radiotherapy or radio-diagnosis), in industry (radiography and various devices such as level gauges), and in research.

At least one of the deaths listed in Table 4 is associated with the medical use of radiations and radioactive materials and, of more recent date, at least two patients have died from ionising radiation. Doctors and paramedical personnel are also at risk working in nuclear medicine. Since they have been at risk for longer than other workers in the nuclear industry, studies carried out in the USA and the UK compare the death rates of radiologists with other groups of doctors; one USA study, from 1945 to 1954, indicated that radiologists had higher death rates from cancer, cardiovascular disease and all other causes than the other medical practitioners [Sagan 1974]. Unfortunately, there are no records of their lifetime radiation exposures, which are believed to lie in the range of hundreds to possibly thousands of rem. The UK study and a study of younger radiologists in the USA showed no life shortening effect, and the studies summarised in Table 6 indicate a relative reduction of leukaemia in more recent years, which may indicate that the adoption of improved methods and practices by radiologists has been effective in reducing the risks. Here again, the data tend to confirm that the limits recommended by the ICRP present low degrees of risk.

TABLE 6

COMPARATIVE DEATH RATES FOR US MEDICAL PRACTITIONERS

[After Schwartz & Upston 1958]

Years	Ratio of leukaemic/total deaths for radiologists compared with physicians in the USA
1929-1943	10.3 : 1
1944-1948	6.7 : 1
1952-1955	3.6 : 1

Radioactive materials have a very wide range of industrial uses, from small amounts used in, for example, fire detectors, to very large amounts used in, for example, radiation sterilisation of surgical products. There have been a number of accidents with radioactive sources used for industrial radiography. If these sources are left out of their shielding cases (or fall out accidentally), they can give extremely high radiation doses to any person handling them. They can cause radiation burns, and can possibly lead to the eventual amputation of affected limbs. In 1955, a man in Melbourne carried a source in his trouser pocket; he subsequently had to have his right leg amputated. In Argentina, a man had to have both legs amputated after a similar accident. The Russian suicide cited in Table 4 also used a radioactive source.

In the International Labour Office survey of radiation exposures to worldwide nuclear industry workers [Hellen 1972], India gave results for separate parts of the industry; these are shown in Table 7.

TABLE 7

RADIATION EXPOSURE IN THE INDIAN NUCLEAR INDUSTRY, 1969

	Percentage of workers with exposures in the given range, 1969			
	0-0.5 rem	0.5-1.5 rem	1.5-5.0 rem	over 5 rem
Industry	77.6	15.75	4.7	1.95
Medicine	92.06	5.38	2.14	0.38
Research, Education	97.44	1.79	0.58	0.19
Nuclear energy	83.80	10.04	6.12	0.03

To draw conclusions from figures for one year would be unwise, but they do indicate that, for exposures greater than 5 rem per year, industry and medicine had a poorer performance than research, education and nuclear energy.

And what is Australia's record? As we have already seen, the exposure of AAEC personnel to radiation is satisfactorily low when ompared with overseas organisations or the ICRP recommendations. A survey of radiation incidents in New South Wales (NSW) in the years 1956 to 1964 [Fleischmann 1965] reported 12 accidents, 11 of which occurred luring the industrial use of radioactive materials (the twelfth was in the medical field). Fifteen persons were involved in these accidents, f whom 11 were known to have received radiation doses greater than the appropriate recommended limit. The NSW survey reinforces the impression given by the overseas surveys that the industrial use of radioactive materials has the least satisfactory safety record in the nuclear industry; but even these failures of safety generally involve infringement of ICRP recommendations rather than actual damage to health.

Table 8 shows the AAEC's general safety record compared with other industries in NSW for the year 1973.

TABLE 8

COMPARISON OF SAFETY RECORDS IN NSW INDUSTRY, 1973

[Private communications - National Safety Council of Australia; AAEC]

Industry	No. of employees	Disabling injuries*	Frequency rate
Agriculture & forestry	2417	428	97.2
Mining	13 739	2581	104.5
Manufacturing	129 041	8013	31.0
Electricity, gas water supply	14 498	1696	65.1
Construction	3819	960	122.6
Wholesale & retail	5890	320	25.7
Transport & storage	2740	463	192.3
Communications	3810	144	20.5
Public administration	373	24	28.6
Community services	5684	396	35.0
AAEC	1117	40	20.6

* *The total number of disabling injuries per million man-hours worked, where a 'disabling injury' results in 'death or permanent disability or inability to work for at least one full day or shift any time after the day or shift on which the injury occurred' (Australian Standard CZ6-1966 - Recording and measuring work injury experience).*

Can we now answer our first question? To demonstrate that any human endeavour is safe, we have to show that unacceptable hazards are absent. It is easier to show that an unsafe industry is unsafe, than it is to show that a safe one is safe. This paper is based on published accident data, and we have failed to find evidence of a large number of accidents or injuries to the work forces of the nuclear industry. Where we have found accidents recorded, a comparison with other industries indicates that the nuclear industry has a good safety record; this endorses Lord Ritchie-Calder's comment that the nuclear industry's record is better than that of any other industry. In particular, very few of the accidents that do occur in the nuclear industry are attributable to the industry's special hazards.

Earlier, we said that safety in industry is a relative matter; we believe that the facts presented here amply demonstrate that it is safe to work in the nuclear industry.

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GLOSSARY

The following definitions are provided for the reader not familiar h some nuclear and other terms used in this paper. The explanations drawn from standard glossaries.*

ha-particle	A helium 4 nucleus emitted during a nuclear transformation. *Alpha-decay* is radioactive decay in which an alpha-particle is emitted; whence *alpha-radioactivity, alpha-activity, alpha-emitter, alpha-radiation.*
a-particle	An electron of either sign which has been emitted by an atomic nucleus or *neutron* in the process of a transformation; whence *beta-emitter, beta-gamma-activity, beta-radiation.*
diovascular isease	Disease of the heart and blood vessel system.
ghter product	Any *nuclide* which follows a specified *radionuclide* in a decay series.
ich	To increase the abundance of a particular *isotope* in a mixture of the isotopes of an element; whence *enrichment, isotope enrichment.*
ssile	See *fissionable.*
ssionable	Capable of undergoing fission by any process. In British usage it is equivalent to *fissile* but in US usage, *fissile* is restricted to interaction with slow neutrons.
ma radiation	Electromagnetic radiation emitted by the nuclei of radioactive substances during decay; whence *gamma-activity, gamma emitter. Gamma-rays* are similar to Xrays.
ising radiation	Radiation which knocks electrons from atoms during its passage, thereby leaving electrically charged particles (ions) in its path; whence *ionisation.*
tron	A nuclear particle having no electric charge and the approximate mass of a hydrogen nucleus; whence *neutron absorption, neutron activation, neutron capture.*

nuclide	A species of atom characterised by its mass number, atomic number and nuclear energy state.
particulate	Having particle form. Can be used to describe matter (in powder form) or radioactive particles.
rad	A unit of *absorbed ionising radiation dose*; whence *millirad*, *megarad*, etc.
radioisotope	An *isotope* which is radioactive.
radiography	The examination of objects by passing X, *gamma* or *neutron radiation* through them and photographing the shadows cast.
radiology	The application of penetrating *ionising radiation* in medicine; whence *radiologist*, *radiological*.
radiotherapy	Treatment of disease by use of *ionising radiation*.
radon	A gaseous product of the disintegration of radium.
rem	A unit of radiation dose equivalent, the product of absorbed dose, quality factor and other modifying factors necessary to obtain an evaluation of the effects of irradiation received by exposed persons, so that the different characteristics of the exposur are taken into account; whence *millirem*, etc.
roentgen (röntgen)	The unit of exposure to X or *gamma radiation*, based on the capacity of the radiation to produce ionisation in air.

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