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ATOMIC ENERGY
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L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

HEALTH OF RADIATION WORKERS

La santé des travailleurs radiologiques

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Chalk River, Ontario

November 1979 novembre

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by

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Résumé

Les travailleurs radiologiques sont en meilleure santé que la moyenne des gens dans l'ensemble de la population et ils semblent être en aussi bonne santé que les travailleurs des autres industries "sûres". On part, cependant, de l'hypothèse qu'il n'existe pas de dose sûre de rayonnement et que toute exposition aux rayonnements accroîtra l'incidence du cancer dans une mesure directement proportionnelle à la dose totale de rayonnement. Sur la base des estimations de risque données par CIPR (Commission internationale de protection radiologique) des expositions aux rayonnements allant jusqu'à 1 rem par an pendant 47 ans devraient causer moins de décès attribuables au travail que les conditions dans lesquelles travaille la moyenne des ouvriers dans l'industrie canadienne. Des expositions à 5 rems par an de l'âge de 18 ans à l'âge de 65 ans donneraient lieu à un risque quatre fois plus élevé que celui encouru par la plupart des travailleurs au Canada et ils pourraient accroître la probabilité d'un décès avant l'âge de 75 ans, ce qui correspondrait à peu près à l'espérance de vie moyenne du grand public.

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ABSTRACT

Radiation workers are healthier than the average person in the general population and appear to be as healthy as workers in other "safe" industries. It is, however, assumed that there is no safe dose of radiation and that any exposure to radiation will cause a small increase in the incidence of cancer, this increase being directly proportional to the total radiation dose. On the basis of the risk estimates given by ICRP, radiation exposures up to 1 rem per year for 47 years are predicted to cause fewer work-related deaths than expected for the average worker in Canadian industry. Radiation exposures of 5 rem per year from age 18 to age 65 would result in a predicted risk which is about four times higher than that for most workers in Canada and might increase the chances of death before age 75 to nearly the same level as for the average member of the general public.

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Introduction

This paper represents the text of a talk on health of radiation workers that was given at the Chalk River Nuclear Laboratories on 1979 August 22.

To introduce the general topic, the impact of modern technology on our general health and life span was considered briefly. Primitive people living under natural conditions, such as those that prevailed near Canada a thousand years ago, lived to be about 20 years old on the average (1). This value, i.e., 20 years of age, is used as the base line in Figure 1. Today the average person in Canada is expected to lived a little over 70 years (1). Most of this increase in our life span has occurred within the past 100 years (1) (Figure 1). In other words, our accumulated technology has added 30 to 50 years to our average life expectancy.

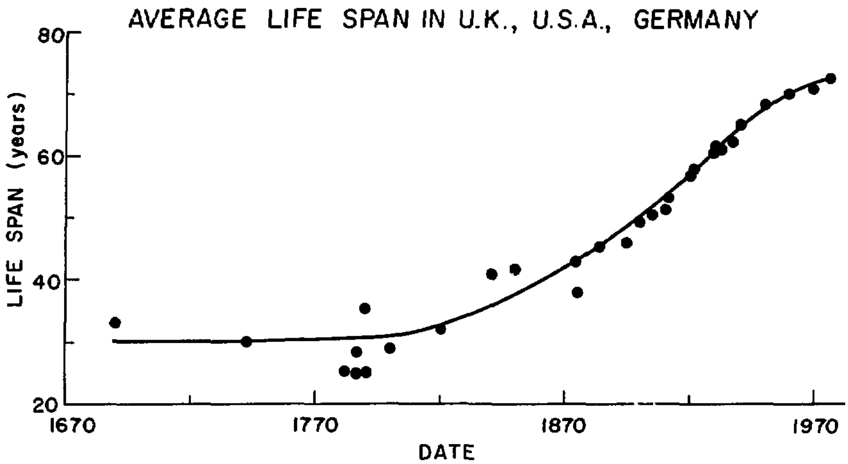

Figure 1

Cheap and safe supplies of energy are required for the complex technology which has made all of this possible. As most of us probably know, nuclear power is one such source of cheap and safe energy. The possible adverse effects of nuclear power on the health of the general public are known to be extremely small in comparison with those of most other sources of energy. But what about the health of the people working in a nuclear power station? This question will be the theme of the remainder of the present talk.

General Causes of Death between Ages 18 and 65

The main topic of this paper will be causes of death and how these are affected by working in a nuclear power station. For this purpose, it is assumed that the employee commences work at age 18 and continues working for 47 years to age 65. Any of the data presented can of course be adapted to shorter periods of employment if desired.

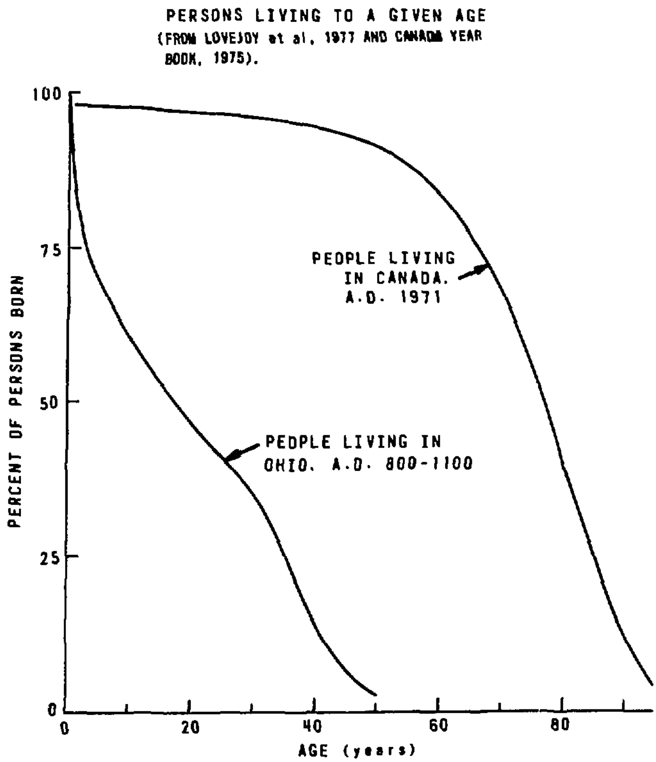

Figure 2

At age 18, the average Canadian is expected to live to 75 years of age (Figure 2), the average for males being about age 72 and for females age 78 (1). That is to say, one out of every two people age 18 will normally live to reach age 75. The chance of death before age 65 is about one in five (Figure 3), with the risk for males being again considerably higher than for females. The chance of death from cancer between age 18 and 65 is roughly the same for males and females, but females are less susceptible than males to fatal accidents, fatal circulatory diseases and other causes of death before age 65 (2).

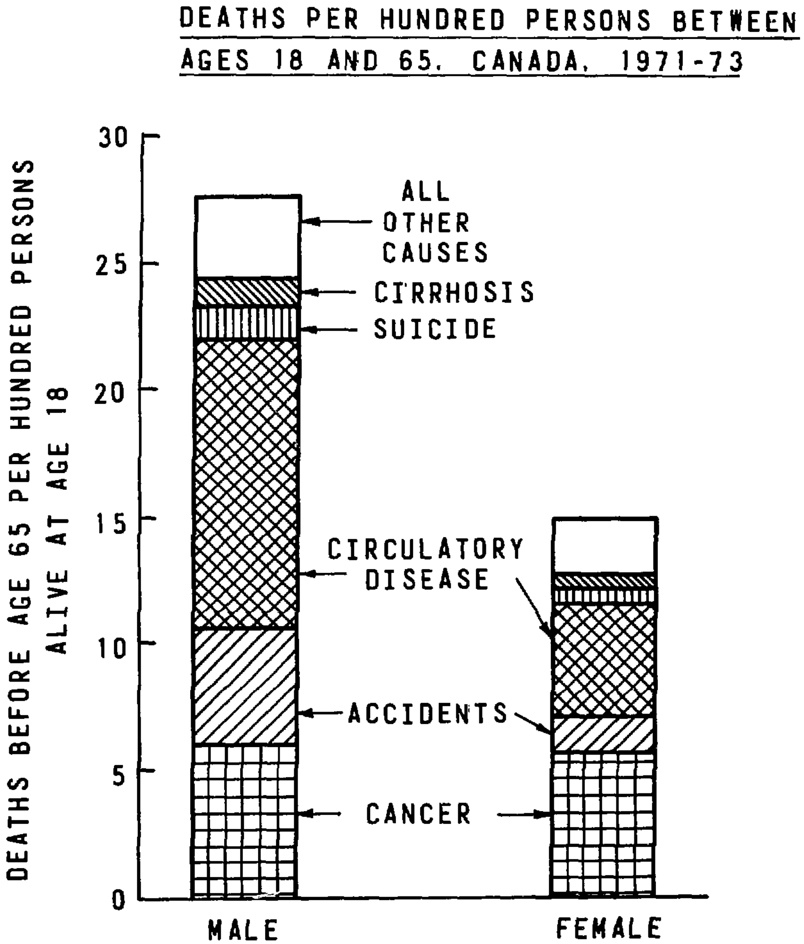

Figure 3

In the nuclear industry, we are particularly concerned with fatal accidents and fatal cancers: accidents because they happen to people in every industry (as well as during off-work hours) and we want to be certain that the nuclear industry is at least as safe as any other industry; cancers because we do have international estimates of risk of fatal cancers per unit of radiation exposure and because we do have accurate methods of measuring the radiation exposure of each radiation worker. By way of comparison, it should be noted that there are no internationally accepted estimates of the risk of cancer caused by most other environmental agents (such as chemicals) and there are no convenient, reliable methods of recording the cumulative exposures of individual workers to most other agents.

Types of fatal accidents are shown in Figure 4. Only employed persons are considered, and U.S. data (3) are used since a similar breakdown is not available for Canadian workers. The incidence per year in 1977 (3) was simply multiplied by 47 years to provide the average values given in Figure 4. Roughly one in every four fatal accidents occurs at work and three out of four during off-work hours. The major cause of fatal accidents to workers is motor vehicle accidents during off-work hours.

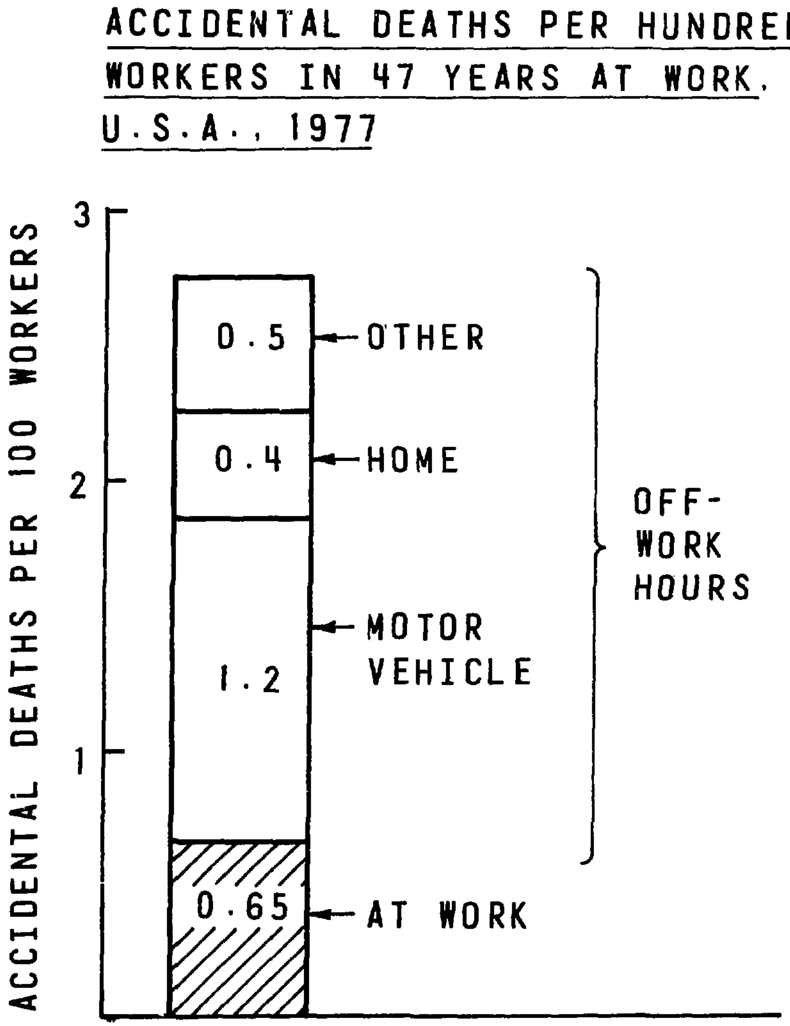

Figure 4

Fatalities in different occupations are shown in Figure 5, using recent data from Labour Canada (4). Approximately 80% of workers in Canada are employed in industries with a casualty rate equal to or less than one death per 10,000 workers per year. A smaller number of people are employed in industries with a two- to ten-fold greater risk.

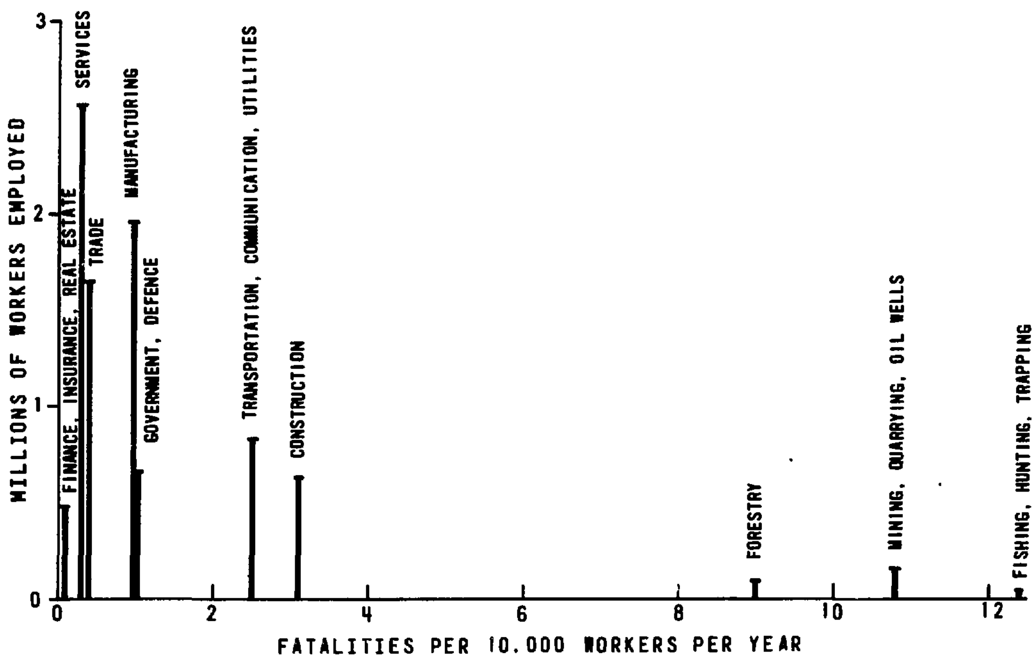

Figure 5

The most recent recommendations (5) of the International Commission on Radiological Protection (ICRP) have suggested that one death per 10,000 workers per year be regarded as the upper limit for a safe industry. When multiplied by 47 years at work, this means that one out of every 200 workers who start work at age 18 will be killed at work between ages 18 and 65. The ICRP recommendations suggest that the average worker in the nuclear power industry should receive a similar degree of protection as a minimum. The ICRP report (5) uses words such as "acceptable risk" and "adequate protection" which are open to personal interpretation. Some persons suggest that the only acceptable risk is zero and this can certainly be considered to be a laudable goal. At present, the ICRP recommendations are usually interpreted to mean that the average risk of fatalities caused by working in a nuclear power plant should not exceed the risk of working in other safe industries and that the more the risks can be reduced within reason, the better it will be for everyone concerned. This latter statement is otherwise known as the ALARA principle; in other words, risks should be "as low as reasonably achievable".

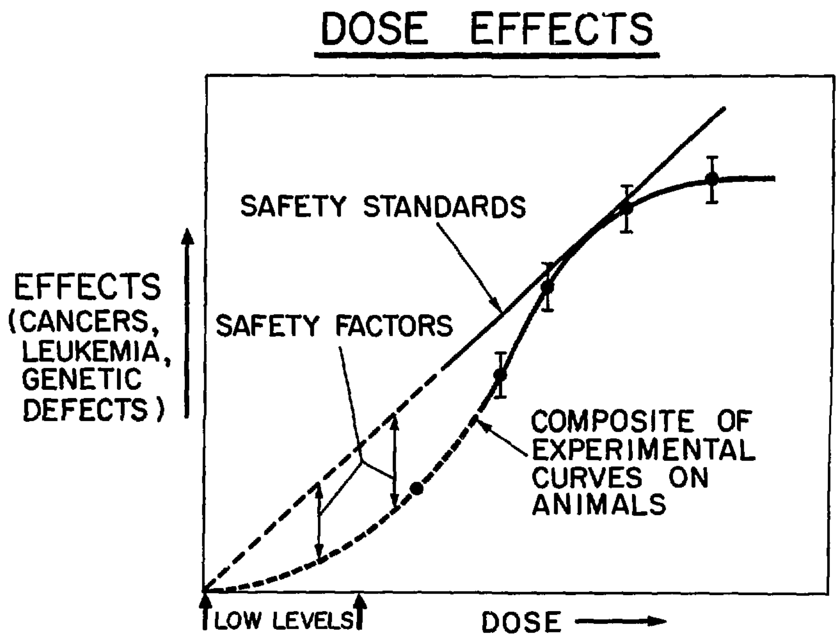

Figure 6

Radiation hazards are calculated on the basis of the assumption that effects are directly proportional to total accumulated dose and that there is no safe dose of radiation (Figure 6). Even the small amount of radiation from natural sources to which we are all inevitably exposed is assumed to have a proportional effect. Most radiation biologists agree that this linear dose-effect curve over-estimates the hazards of low level radiation to some extent and that there is a modest safety factor built in to all of the currently accepted risk estimates (Figure 6). However, this potential safety factor is ignored in all of the subsequent data.

Predicted Hazards to Radiation Workers

Figure 7 compares predictions of work-related deaths resulting from 47 years employment in a nuclear power station with the average for all industries in Canada and for manufacturing industries in Canada, 1975-77. In general, most of the fatalities in other industries are due to accidents,

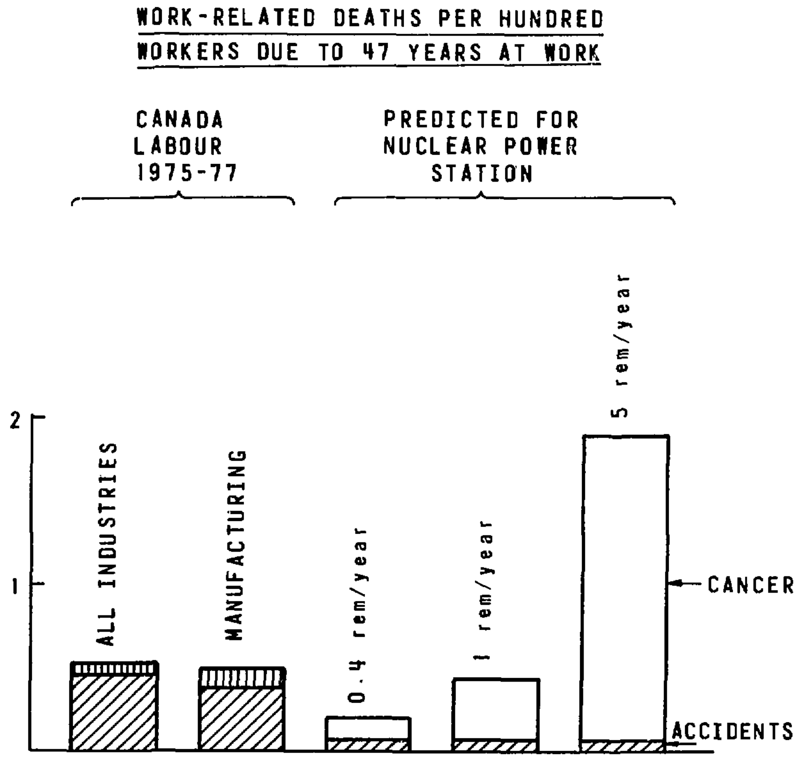

Figure 7

(<u>Note</u>: The diagonally hatched areas in all rectangles represent deaths due to immediately fatal accidents; the vertically hatched areas in the first two rectangles indicate deaths due to occupational diseases recognized by workers compensation boards; the open areas in the last three rectangles on the right indicate maximum predicted numbers of deaths due to fatal cancers induced by radiation exposures at three different levels. Maximum predicted deaths due to radiation-induced cancers were calculated on the basis of the following assumptions:

(a) The risk of induced cancers is directly proportional to the radiation dose and is equal to a maximum of 1.25 fatal cancers per 10,000 persons exposed to one rem each (5).

(b) The average time between radiation exposure and death (g) is about 10 years in the case of leukemia and about 25 years for any other induced cancers.)

with a small contribution from occupational diseases as recognized by workers compensation boards (4). The predictions for the nuclear power industry show a low incidence of fatal accidents and a larger contribution from radiation-induced cancers (Figure 7).

The data on fatal accidents in nuclear power stations are derived from the more extensive U.K. experience (6). There have not yet been any fatal accidents during operation of nuclear power stations by Ontario Hydro (7) and the limited data available for CRNL (two fatal accidents, neither of these associated with radiation, since the late 1940's) are in reasonable agreement with the information from the U.K.

The major predicted occupational hazard for workers in nuclear power stations is radiation-induced cancers. The numbers shown in Figure 7 include all predicted cancers, both during employment and after retirement at age 65.

Perhaps it should be noted at this point that the average radiation exposure of people in North America is about 0.2 rem per year, half of this from natural sources and half from medical X-rays (8). The numbers given in Figure 7 are occupational exposures in addition to those to which the average person is exposed.

With an average occupational exposure of 0.4 rem per year, which is roughly the average increment in radiation exposure for all persons working at CRNL (most employees receive less than 0.4 rem per year and a small number receive considerably more) (9), the total occupational risk is well below the suggested limit for safe industries. At 1.0 rem per year, which is roughly the average for employees at the Pickering station (7), the potential risk is approaching the limit for safe industries. At 5.0 rem each year for 47 years, which is currently the maximum permissible exposure, the potential risk is about four times the limit chosen for safe industries. Most of the induced cancers would appear late in life; the average predicted decrease in life expectancy resulting from 5 rem per year for 47 years can be calculated to be about 0.3-0.4 years (10). That is to say, a worker exposed to 5 rem each year for 47 years might be expected to live to 74 years and 7 months on the average rather than to 75 years if all other factors except the radiation exposure were equal. This is roughly equivalent to the effect of smoking one to two cigarettes per day for 47 years (cf. 11, 12). At 0.4 rem per year for 47 years, the maximum predicted decrease in life span is about 0.03 years or 11 days.

Table 1 provides a more detailed breakdown of the normal incidence of various types of fatal cancer in Canada and of the potential effects of exposure to 1 rem per year from age 18 to 65. The latter numbers are calculated in the same way as described for Figure 7. A simpler calculation, ignoring life expectancy, latent periods and based on the assumption of an average of about one fatal cancer per 10,000 persons exposed to one rem each (5), would indicate a total of 0.47 fatal cancers per hundred workers, rather than the total of 0.36 given in Table 1. The numbers are similar, but those given in Table 1 are thought to be somewhat more realistic.

Table 1

Causes of Death After Age 18

Cause of death	Normal chance of death	Predicted increase due to 1 rem per year for 47 years
Thyroid cancer	0.06/100	0.013/100
Bone cancer	0.09 "	0.013 "
Leukemia	0.07 "	0.08 "
Breast cancer	1.9* "	0.07* "
Lung cancer	3.8 "	0.05 "
Other cancers	14.8 "	0.13 "
All cancers	21.3/100	0.36/100
All other causes	78.7 "	0.0 "

* All values are averages for males and females. Breast cancers are largely restricted to females; both the normal incidence and the increase due to radiation are two times the above values when females only are considered.

Data on the Health of Radiation Workers

The predicted health hazards of radiation (Figure 7 and Table 1) are based on risk estimates given by ICRP (5); these estimates agree with those published in a recent and more extensive review of data by the United Nations Scientific Committee (13). The news media have sometimes drawn attention to suggestions that these estimates are incorrect and that low level radiation (whether from nuclear reactors, natural background or medical X-rays) is much more hazardous to health than most scientists think it is. For example, in 1977 Mancuso, Stewart and Kneale published a scientific paper (14) with some rather extravagant claims of radiation hazards based on a preliminary study of the health of radiation workers at Hanford; the initial analysis was further extended and the initial conclusions were modified in 1978 (15). These papers have been severely criticized by other scientists (16,17), and the original authors have now indicated that they "did not claim that cancer was a major hazard of the nuclear industry or even that the cancer mortality of Hanford workers was significantly raised" (18).

Rather than get involved in the intricacies of this scientific discussion, it may be more useful to look at the basic data relating to the health of three groups of radiation workers. These particular data are not in dispute. Figure 8 indicates the relative incidence of deaths from all causes for workers at Windscale, U.K. (19), Hanford, U.S.A. (17) and for Ontario Hydro (20). The total number of deaths involved in each case is indicated on the graph; the data which involve large numbers are fairly reliable. The Windscale data have not been changed appreciably by a more recent update in 1976 (21). The Hanford data, which are the most extensive, involve nearly 21,000 persons who have been employed there at various times since 1945; of these, only 2800 received total accumulated doses in excess of 5 rem (17). The total cumulative dose for all employees is roughly 60,000 person·rem. About 6 extra fatal cancers might be predicted on the basis of ICRP risk estimates. The total number of spontaneous fatal cancers in a group of 21,000 persons will eventually reach about 4,000: of these, some 700 have been observed to date. The ratio of observed to expected deaths to date is about 82% both for persons under 65 and for persons over 65 who were employed at Windscale (21).

The general conclusion from these data is simple. Radiation workers in general appear to be healthier than the average person of the same age in the general public (Figure 8). This is also true for workers in other safe industries, but radiation workers do seem to be at least as healthy as other workers. This "healthy worker" effect is probably due to selection of relatively healthy persons at the time of employment, to emphasis on accident prevention and safety programs, and to the extra medical attention provided in many safe industries.

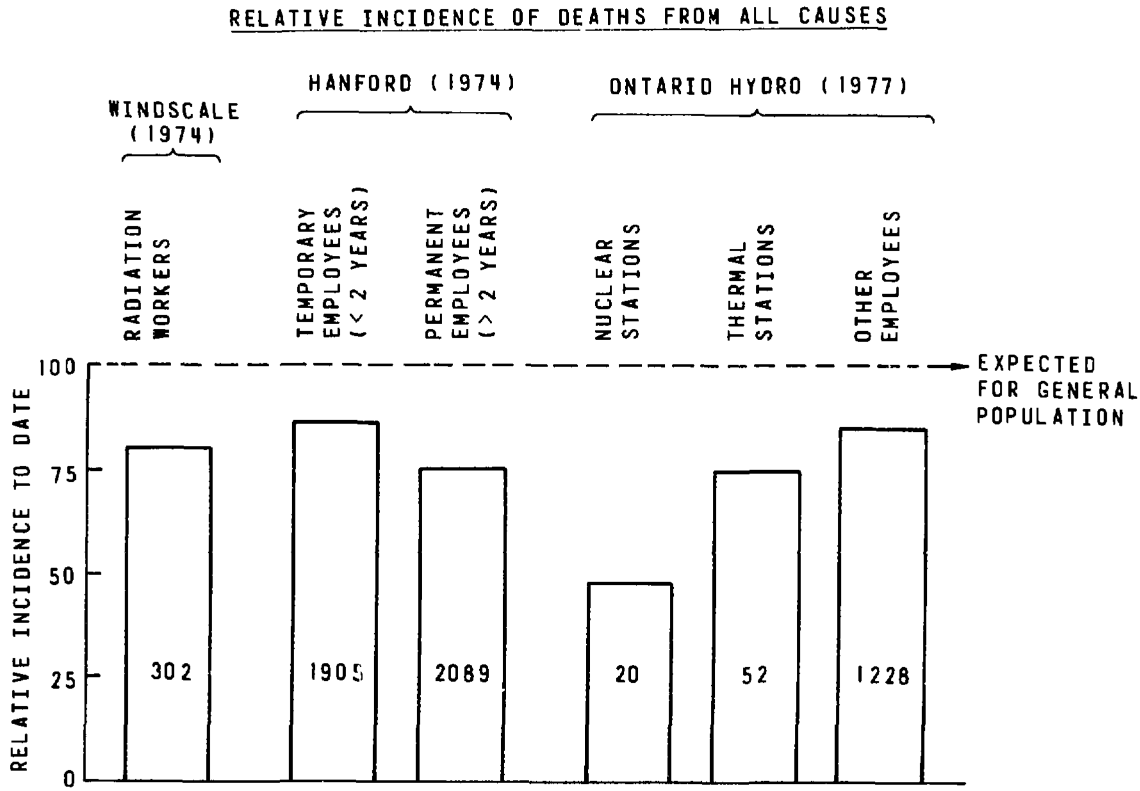

Figure 8

(<u>Note</u>: The vertical bars represent "standard mortality ratios" which are corrected for the age of the persons in each group. The actual numbers of deaths in each group are indicated inside each vertical bar.)

Figure 9 indicates the relative incidence of deaths from cancer for the same groups. Again, the incidence of fatal cancers to date is less for radiation workers than for the average person of the same age in the general public. The follow-up of these groups is continuing, but there is no reason to expect any appreciable change in the standard mortality ratios at Windscale and Hanford. Data for cancer incidence among workers at thermal power stations (mainly coal-fired stations) have not been reported elsewhere and it is much too early to say whether the apparent increase for workers at thermal power stations at Ontario Hydro (Figure 9) is real or not.

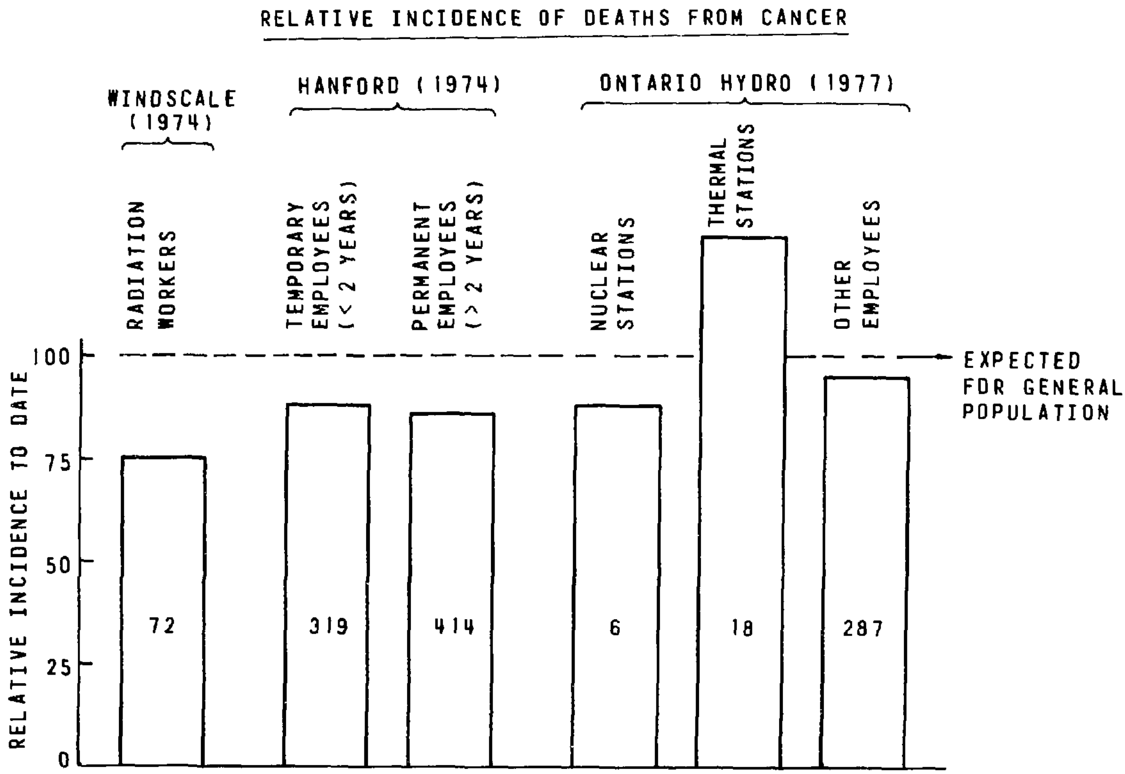

Figure 9

(Note: The vertical bars represent "standard mortality ratios" which are corrected for the age of the persons in each group. The actual numbers of deaths in each group are indicated inside each vertical bar.)

The conclusions to be drawn from all of the above information are summarized in the tables. About 21 out of every hundred deaths after age 18 is normally caused by cancer. Occupational exposures to radiation are predicted to cause a small increase in this normal risk of cancer with zero increase in the risk of death from other causes (Table 1).

The increase in risk of cancer is assumed to be directly proportional to total radiation dose. Thus it is possible that cancer mortality among Chalk River workers could be increased by about 1% from 21.3 to 21.5 per hundred (Table 2). This increase would in theory be about 2% for Ontario Hydro workers at Pickering who are exposed to 1 rem/year on the average, and could be as much as 10% for persons who were exposed to the maximum limit of 5 rem per year for 47 years (Table 2). The predicted increases have, as noted earlier, not yet been observed in studies of the health of radiation workers.

Table 2

Deaths from Cancer After Age 18

General population	21.3/100
Radiation workers (predicted)	
- 0.4 rem/year	21.5/100
- 1 rem/year	21.7/100
- 5 rem/year	23.3/100

Table 3

Probability of Death Between Ages 18 and 65

All Causes:	
general population	20/100
radiation workers (low exposures)	16/100
Work Related Causes:	
average industry	0.5/100
radiation workers (predicted, all ages)	
- 0.4 rem/year	0.2/100
- 1 rem/year	0.4/100
- 5 rem/year	2/100

In the general population, 20 persons out of every 100 die between age 18 and 65; radiation workers exposed to low radiation doses (and workers in other safe, healthy industries) have about 16 chances in 100 of dying during the same years (Table 3). Only a small portion of these deaths are work-related. When all fatal cancers including those which might appear after age 65 are counted, an average exposure of 1 rem per year for 47 years is predicted to result in less than 1 in 200 work-related chances of death. At 5 rem per year for 47 years, the predicted chances increase to a maximum of about 2 in 100 (Table 3). The general increase in health of radiation workers (Figure 8) and the predicted deleterious effects of 5 rem per year (Figure 7) are of a similar order of magnitude and might therefore be expected to cancel out. In other words, the chances of death before age 75 should be nearly the same for a radiation worker exposed to 5 rem per year for 47 years as for an average person in the general public (see Table 3).

Children of Radiation Workers

The only other health hazard of low levels of radiation, apart from induction of cancer, is induction of genetic defects in the children of irradiated parents. The numbers are summarized in Table 4.

It is useful, however, to indicate first what we mean by genetic defects. We are all genetically different to some extent; sometimes these genetic differences are detrimental to our health and are termed "defects". Radiation does not produce new types of genetic defects; what it may do is increase slightly the numbers that occur normally in human populations. What we are considering thus are the normal hereditary or partially hereditary conditions that result in some more or less serious trouble at some time in a person's lifetime. Certain cases of deafness late in life fall into this category, as do certain cases of childhood blindness. The hemophilia which afflicted some of the Hapsburg and other royal families in Europe also falls into this category.

There is one chance in ten, i.e. ten in one hundred, that the average child in Canada will be born with some genetic abnormality requiring medical attention at some time in say 70 years of life (Table 4). For radiation workers commencing work at age 18 and exposed to an average of 1 rem per year, the chance that a child or a grandchild will be born with some genetic defect is thought to be increased by about 1%, i.e., from 10 to 10.1 per hundred children. As noted above, most radiation workers at CRNL receive less than 0.4 rem per year from occupational exposures. For these persons, the chances that a genetic defect in the children or grandchildren is due to occupational exposures is less than 1 in 200 (Table 4).

Table 4

Genetic Defects in our Children and Grandchildren

General population	10/100
Radiation workers (predicted)	
- 0.4 rem/year	10.05/100
- 1 rem/year	10.1 /100
- 5 rem/year	10.6 /100

These numbers are again based on ICRP risk estimates (5), which are in reasonable agreement with those published by the United Nations Scientific Committee (13). There is no direct proof of this prediction. There is no detectable increase in the incidence of genetic defects among the children exposed to high radiation doses at Hiroshima and Nagasaki (13). Moreover, animals whose parents were repeatedly exposed to high radiation doses (either from natural sources or in the laboratory) over many generations do not show any change in general health or fitness (22, 23), despite cumulative doses up to 4800 rem over 15 generations. As in the case of cancers, it is however considered prudent to assume that lower levels of radiation will produce some increment in numbers of genetic defects (Table 4).

Genetic defects have been taken into account by ICRP in their recommendations concerning radiation exposures (5). The chances of increased genetic defects resulting from employment in other industries have never been estimated, even though it is fairly certain that certain chemical agents in our environment must have effects similar to those of radiation (cf. 24). All that one can really say at present is that 99% or more of all genetic defects in the general population are due to causes other than radiation (Figure 10), and that the increases predicted for the children and grandchildren of radiation workers are small but not zero.

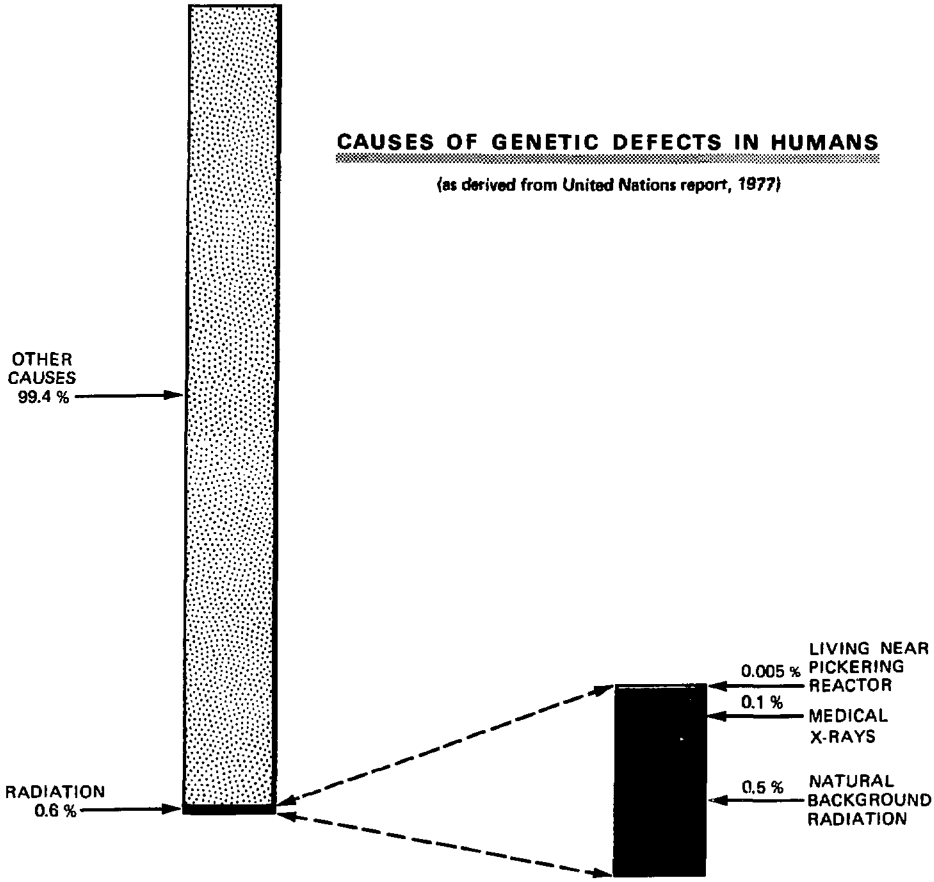
CAUSES OF GENETIC DEFECTS IN HUMANS
(as derived from United Nations report, 1977)
OTHER CAUSES 99.4 %
RADIATION 0.6 %
0.005 % LIVING NEAR PICKERING REACTOR
0.1 % MEDICAL X-RAYS
0.5 % NATURAL BACKGROUND RADIATION

Figure 10

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DISCUSSION

A verbal discussion period followed the verbal presentation of this paper at CRNL. During this discussion, participants were provided with a sheet of paper on which to write their question. All written questions that were received are included in the following text, together with a written answer.

Question: I find it curious that you say that radiation causes cancer and that radiation workers have fewer cancers than the general population. I do not understand this anomaly.

Answer: The predicted radiation effects referred to in Fig.7 and in the tables are theoretical values based on the known effects of radiation in humans exposed in the past to high radiation doses in a short period of time; for example, persons who survived the atomic bomb explosions at Hiroshima and Nagasaki or persons who were exposed to high doses of medical X-rays for the treatment of certain diseases. It is assumed that the effects of smaller radiation exposures will be directly proportional to total radiation dose and that we can therefore predict the maximum potential harmful effects of these lower radiation exposures with some accuracy. (As noted, there may well be safety factors involved which have been ignored for these calculations.) These effects cannot be demonstrated directly because they are too small relative to other factors in our life that affect our chances of death from cancer and other causes.

The radiation workers referred to in Fig.9 were in general exposed to low radiation doses and did in fact exhibit a lower incidence of fatal cancer than is observed for persons of the same age and sex in the general population. Some possible reasons for this "fact of life" (which, as noted, is not restricted to radiation workers but is also a fact of life for healthy workers in other safe industries) were mentioned in the text. Another factor influencing cancer mortality is "socio-economic status". In general, persons who are better educated, earn a good wage, eat a well-balanced diet and who do not indulge in excessive consumption of tobacco and strong spirits do have a somewhat lower risk of death from cancer before age 65 than does the average person in the general population. This factor may also contribute to the modest decrease in cancer mortality among the radiation workers referred to in Fig.9.

The type of data shown in Fig.7 and Tables 1-3 are necessarily predictions and not fact, but they are believed to be reasonably accurate predictions of maximum potential risk. If these predictions were grossly under-estimated, we would not see the healthy-worker effect for employees at Windscale and Hanford (Figs. 8 & 9), which establishments have, as noted earlier, been in operation for more than 30 years.

Question: In view of the inherent time lag on life expectancy data (up to 50 years) and the long induction period for cancers (about 25 years), our information must be predictions rather than facts. Since the nuclear industry has developed appreciably in the last 25 years, presumably significant cancer information will start appearing in the next ten to twenty years. Please comment.

Answer: There is no appreciable time lag on the life expectancy data. These data can be calculated for any given calendar year from Canadian vital statistics. These show, for example, that 98 of every hundred babies born alive survived to age 5 in 1971, that 97.7 out of every 98 persons age 5 survived to age 10 in 1971, and so on. From this information, one constructs the type of graph shown in Fig.2. Although the calculation can be carried out for any given calendar year, we tend to rely on the official values given for 1971, the year of the last actual census of numbers of persons of any given age alive in that year.

The data on health of radiation workers (Figs.8 & 9) are in any case quite independent of life expectancy data. We are in this case concerned only with known death rates, in immediate past years, of two age-matched groups differing only in their occupational history. No deleterious effect on the health of the radiation workers was observed.

The induction period for most cancers is indeed long, although an excess of leukemia can be detected 5 to 15 years after exposure to high doses of radiation or certain other carcinogenic agents. Because of this fact, because the radiation exposures are moderately low, and because radiation is not a major cause of cancer or of any other fatal disease even among persons exposed to high doses, it is expected that many decades of accurate record-keeping will be required before any harmful effects of radiation exposure could be detected among the persons who work in nuclear power plants.

To clarify this point, it might be noted that 5172 of about 21,000 persons who survived the atomic bomb exposions at Hiroshima and Nagasaki died from various diseases including cancer during the period 1950-1972; of these 5,000 deaths due to disease, approximately 200 have been attributed to the effects of roughly 200 rem radiation received by these 21,000 persons in 1945. That corresponds to 4 out of every 100 deaths due to disease; some very accurate record-keeping is necessary in order to detect this excess, let alone to calculate radiation hazards from these data. The increase in incidence of leukemia is relatively easy to measure in this group of Hiroshima/Nagasaki survivors; 84 leukemia deaths were observed, when only about 20 were expected in the absence of the radiation exposure in 1945. Data on other causes of death are not as clear but are necessarily utilized to calculate risk estimates.

Question: Is an exposure to part of the body factored into the overall exposure calculations?

Answer: Yes. Careful attention has been paid by the International Commission to the effects of exposing parts of the body to radiation. For example, exposure of the lung only or exposure of the bone marrow only is estimated to carry 12 percent of the hazard of exposing the whole body to a given dose of radiation. Some radionuclides (for example, tritium) are uniformly distributed in the whole body whenever they get into the body; radiation doses from tritium are thus whole body doses. Other radionuclides tend to concentrate in certain tissues when they get into the body; for example, most of the radium in the body is retained in the bone. All of these factors are taken into account in calculating the biological effect of radiation exposure from any source.

Question: I'm not at all sure about the statistical significance of the data shown in Fig.8. For example, the low "relative incidence to date" for Ontario Hydro nuclear stations would be meaningless if the age distribution was different from that of the general population. This, of course, would also apply to other rectangles in Fig.8. Even if the age distributions are comparable, one would then have to ask if the differences are significant. Have statistical tests been applied to demonstrate significant difference?

Question: Workers at Hydro "thermal" ie. fossil fuel stations seem to be less healthy than those at nuclear stations (Fig.9). Could this be an age effect?

Answer: All of the data on relative incidence of death in Figs.8 & 9 are corrected for age effects. Let me explain how this is done. Statistics Canada publishes each year vital statistics on numbers of persons dying from various causes. From this we know that 506 out of every 100,000 males age 60-64 in Canada died of cancer, for example, in 1974. If the employees in a given industry included 100 males age 60-64 in 1974, it would therefore be expected that 0.5 of these particular persons would die of cancer in 1974. This type of comparison is repeated for each age group and each sex and for each of the calendar years involved. By comparing the observed deaths for employees in a given industry with the averages expected from the vital statistics for the general population, one arrives at the type of data shown in Figs.8 & 9. The data for Hanford and Windscale workers are statistically different from those expected for persons of the same age and the same sex in the general population. Not all of the differences observed for Ontario Hydro workers are statistically significant; the numbers involved are too small.

Question: Fig.8 is clear; so is Fig.9, but it might be clearer if an aside or footnote in the text explained the importance of using real numbers (as you do) rather than percentage of deaths from different causes. For example, the value 21.3/100 would go up sharply for a hypothetical population with a reduced rate from "all other causes" (Table 1), say, a 10% reduction in cardiovascular deaths. If we eliminate all other causes of death, we'll all die of cancer at a very old age. If one takes the numbers in each bar of Fig.9 and divides them by the corresponding numbers in Fig.8 one gets, approximately

24%, 17%, 20%, 30%, 35% and 23%.

The high cancer risk in working in Ontario Hydro stations (especially thermal!) can be "proved" by such numerology! But some readers could draw this conclusion unless the fallacy is explicitly noted.

Answer: Thank you for the comment, which is quite correct. Prof. T. Anderson has pointed out the same fallacy very clearly in his paper in Health Physics (1978) and elsewhere. It is essential to compare the observed number of cancer deaths in a given group of persons with the number of cancer deaths in another group of the same age in order to see whether cancer incidence is the same or different. Percent deaths due to cancer can vary greatly depending on how successful society has been in prevention of deaths due to other causes.

Let us consider another example. The number of persons dying of cancer increased from 64 to 176 per 100,000 persons per year in the U.S.A. between 1900 and 1976. This has led some persons to suggest that the incidence of cancer (and of various other ailments) has increased dramatically in western countries since, say 1900. Of course the percentage of deaths due to cancer has increased since 1900 because many persons died of influenza, pneumonia and other infectious diseases at that time and did not live long enough to develop cancer. Cancer is a complicated disease with many potential causes; however, like circulatory and heart diseases, cancer is and always has been primarily a disease of old age (Fig.11). The average life-expectancy of the U.S. white population was about 50 years and of the coloured population 34 years in 1900; in 1976 the life expectancies had increased to 73 and 68 years respectively. If a large number of people die of pneumonia at age 50, they will not die of cancer (or of heart failure) at age 70. If one eliminates most other causes of death at an early age, as our society has done over the past century, then of course a larger percentage of people die of cancer and a larger percentage die of heart disease. When this factor is taken into account, it becomes clear that cancer mortality, that is to say, risk per year of dying of cancer at any specified age, has not increased appreciably since 1900 (despite the truly remkarable increase in incidence of lung cancer due to cigarette smoking, which has been offset by a major decrease in stomach cancer). I mention these additional details in an attempt to further clarify your comment and to indicate that it is relevant to other areas besides that of radiation hazards.

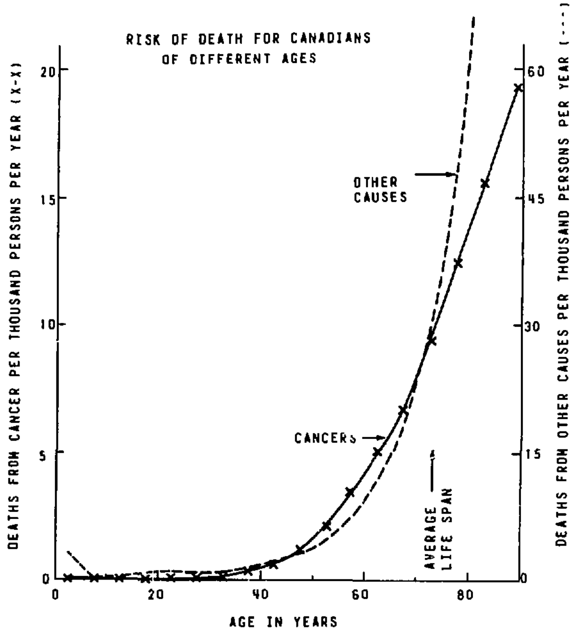

Figure 11

Question: Is there any increase in cancer fatalities in persons exposed to naturally occurring high levels of radiation?

Answer: An area along the coast of India near Kerala involves about 70,000 persons exposed to an average of about 0.4 rem per year from thorium-rich sands; six percent of these people are exposed to natural radiation levels in excess of 1 rem per year. No increase in cancer fatalities has been noted; however, the people in this area, as in many other parts of India, have other major health problems caused by their poverty and most of them do not live long enough to develop cancer. Another study by Frigerio and Stowe involved some six million people in the Colorado area of the U.S.A. who are exposed to about 0.09 rem per year more than are most persons in the U.S.A. These persons do not show any increase in incidence of leukemia or other fatal cancers; in fact, they seem to be somewhat healthier than the average citizen of the U.S.A.

Question: What group in the general population is chosen for the control in studies on the health of radiation workers?

Answer: The primary control group is always persons of the same age and same sex in the whole of the general population of a country or a province. The Ontario Hydro study also used as control group those persons employed at fossil-fuel plants and all other persons employed by Ontario Hydro. The Hanford study included a comparison of persons who worked at Hanford for a short period of time with more permanent employees who worked there for more than two years. Persons exposed to lower radiation doses can also be compared to persons exposed to higher radiation doses. A variety of other control groups can be used in an effort to eliminate the healthy worker effect, but the comparison with the general population must always be included since the general population provides the largest numbers and therefore the most reliable statistics.

Question: What are the statistics on the health of radiation workers in the medical field and health sciences (radiologists, nurses, technicians)?

Answer: Leukemias and other cancers were in fact first noted in research workers and radiologists who were exposed to high radiation doses in the early portion of this century. Fairly massive radiation doses were involved. Awareness of the hazards of radiation to medical radiologists led to the formation of the first international committee on radiological protection by the International Congress of Radiology in 1928. The limited data available on excess incidence of leukemia in early radiologists have been taken into account by ICRP, UNSCEAR and the BEIR committees in their reviews of radiation hazards. There have not been any reports of increased cancer incidence among medical radiologists and technologists employed in recent years since precautions to minimize radiation exposures have been invoked.

Question: Are there people within AECL and Ontario Hydro who regularly receive exposures of about 5 rem?

Question: Is there any information on distribution of exposure for all employees and for particular trades at AECL and at Ontario Hydro?

Question: How is 0.4 rem average at CRNL distributed? Are a small fraction of staff at greater risk and is the average artificially lowered by taking too big a group in calculating risk for a radiation worker?

Question: Are there, in fact, people who accumulate several rem per year for many years? At CRNL? At Hydro? How are lifetime doses distributed?

Question: Most of your figures were based on all workers receiving an average dose of radiation. How would these be modified by considering those workers who are exposed to more than this average?

Answer: All CRNL personnel are monitored and indeed a small fraction of the staff receive much higher doses than do the majority of CRNL employees. The average value of 0.4 rem quoted above is the 1977 average for all 2255 employees. Based on the values for all 4175 AECL personnel who were monitored in 1977, it appears that 85 percent or six out of every seven AECL employees received less than 0.5 rem, that most of the remaining employees received between 0.5 and 3.0 rem and that a small number of employees (38) received between 3.0 and 5.0 rem. The average radiation exposure of all employees receiving more than 0.5 rem in 1977 was close to 1.5 rem.

A small number of employees at CRNL do accumulate a few rem per year for many years. The predictions of potential risk given in Fig.7 were designed to cover the whole spectrum from an average of 0.4 rem per year (where the potential hazard is considerably less than that for the average worker in Canada) up to a maximum of 5 rem per year (where potential risk is in the same region as that of a construction worker), and were moreover calculated on the assumption that the employee accumulated the stated exposure every year for 47 years from age 18 to age 65. The values thus cover a range from a large number of employees at low risk to a small number of employees at higher risk. The same is true in other industries, as has been noted by ICRP.

Ontario Hydro has gone into these questions in considerable detail. It appears that about 50 percent of Ontario Hydro radiation workers (as compared to 15 percent of AECL radiation workers) are exposed to appreciable radiation doses. The following values are quoted in a recent paper by R. Wilson and K.E. Donnelly ("ICRP-26, Its Applicability in a Nuclear Power Program", IAEA SM-242/43):

	Annual average dose (rem)	
	All Nuclear Generation Division workers	Exposed workers
Ontario Hydro (1975-77)		
Operators	1.0	2.1
Mechanical maintainers	1.3	2.8
Control technicians	0.8	2.3
Service maintainers	0.2	0.4
Other staff	0.2	0.8
Average for all groups	0.8	1.7

Expected lifetime doses have also been estimated in detail for Ontario Hydro employees. These data, together with similar estimates for radiation workers in other countries, have been summarized in the 1977 report of the United Nations Scientific Committee. Based on workers employed for 10-14 years, estimated lifetime doses at Ontario Hydro are as follows:

Operators	49 rem
Mechanical maintainers	90 rem
Control technicians	35 rem

Question: The risk data for people receiving 5 rem per year for 47 years show that this group is at relatively high risk. Is there an argument for a lifetime dose limit of, say, 50 rem, to equalize the burden?

Answer: Suggestions similar to this have in fact been made by some scientists. It is, however, useful to note that the potential hazard of exposure to 5 rem per year is approximately equivalent to the actual hazard of driving 30,000 miles per year on the highway, of flying 200,000 miles per year by air, of working for one year in the construction industry or of working for 4 months in an underground mine. A travelling salesman, an airplane pilot, or an underground miner are also in higher risk occupations. Perhaps all members of our society should be rotating their jobs in order to equalize the burden; I have no real answer to this suggestion, which is a matter for further discussion and consultation. The International Commission on Radiological Protection has not made any specific recommendations on total lifetime exposures, preferring to emphasize the principle that all exposures should be kept as low as reasonably achievable.

Question: Have any studies been done on a specific group of radiation workers, example: pipefitters or operators in one of the reactors?

You say the average yearly radiation dose is 0.4 R. Many of us in the reactors get 4 R+ yearly, yet the plant average is 0.4 yearly.

A study should be done on persons receiving high radiation to see if we are getting a higher risk.

Question: Were any records kept of the health of the workers involved in the 1952 accident in NRX, ie. incidence of cancer in later life?

Question: Are there any statistics showing how many atomic workers at CRNL employed or retired have died of cancer or cancer related diseases over the past 25 to 30 years?

Question: How does AECL keep track of cause of death for former employees?

Answer: No studies on the causes of death of past CRNL employees have yet been carried out. We do intend to do this. The methods by which this could be done were first outlined in detail by Dr. H.B. Newcombe in 1976. The topic was taken up and reconsidered by Dr. J.L. Weeks of the Whiteshell Nuclear Research Establishment, who has received a promise of financial support for this study. A number of persons at CRNL are already involved, getting the records into shape so that this study can be carried out. The cooperation of all personnel would be invaluable in assisting us to carry out this study, which would be similar to those already carried out at Windscale and at Hanford.

We had not thought of looking at the health of those workers specifically involved in the 1952 accident, since the total radiation exposures were too small to be expected to produce any measurable effects. However, it is an interesting suggestion and one which is relatively easy to incorporate into the overall study once we have all the past records organized into a compact and machine-readable form. The comparison between AECL employees receiving higher radiation doses with those receiving lower radiation doses will certainly be carried out, even though it is doubtful whether any effects will be detected. The main problem with this or any other proposed study on small groups of persons is that the numbers will probably be too small to be statistically reliable, but we certainly intend to find out what the numbers are.

Question: With reference to Windscale reprocessing plant, would workers be subjected to a higher background radiation and if so, after thirty years of operations, are there any statistics related to higher cancer rates in workers working with radioactive substances, not percentages of employees which would include office workers.

I was interested in Windscale because of the so-called "Windscale incident", when radioactivity was released to the atmosphere in the immediate area.

Answer: The Windscale employees receive an average of about 1.2 rem per year (1971-1976). This is broken down into various groups as follows:

Operations	3.7
Mechanical maintenance	2.9
Health physics	1.7
Electrical and instrument maintenance	1.1
Laboratory services	0.6

The problem is the same as that encountered in the suggested study of persons involved in the 1952 accident at Chalk River. The total radiation exposures are too small to produce any measurable effects and the predominant effect observed among Windscale workers is the healthy worker effect.

Question: Is the ICRP considering lowering the maximum dose rate for radiation workers from 5 rem/year to something lower, eg. 1 rem/year?

Answer: The most recent recommendations of the ICRP in 1977 suggest that the maximum permissible dose for any given radiation worker should be 5 rem per year. However, it is pointed out that the average dose for a group of radiation workers is usually about one-tenth of this value (i.e. is about 0.5 rem per year) when the maximum to any individual is set at 5 rem per year. A similar distribution of risks occurs in all industries, that is to say, some workers are exposed to greater risk than the average for that industry while others are exposed to less risk than average. The ICRP considers an average exposure of 0.5 rem per year to be well within the limits for a safe industry. The report recommends that a careful analysis of the situation and proper justification should be required for any station that proposes to expose most or all of its employees to doses approaching 5 rem per year.

Question: What is the radiation level at which the controversy between the linear/super-linear effects begins?

Answer: If I understand the question correctly, it might be suggested that the proper question would be "what is the radiation level at which the controversy between the linear and SUB-linear (not supra-linear) effects begins". There is relatively little controversy about supra-linear effects except in the non-scientific press. The scientific discussion concerns the extent to which the linear dose-response model has or has not over-estimated (not under-estimated) hazards of low-level radiation. To illustrate this point, I might quote two sentences from page 2 of the Summary and Conclusions of the draft of the BEIR report in May 1979: "For most calculations of estimated cancer risk at low doses, the Committee has used the linear no-threshold hypothesis (effect proportional to dose). The Committee recognizes that some experimental and human data, as well as theoretical considerations, suggest that, for exposure to low-LET radiation (X-rays, gamma rays) at low doses, most cancer risk estimates based on the linear hypothesis are high and should not be regarded as more than upper limits of risk". These sentences, which were presumably accepted by the whole of the BEIR committee, are in complete agreement with similar qualifying sentences in the 1977 reports from UNSCEAR and ICRP.

To the best of my knowledge, any recent data suggesting a supra-linear response at low radiation doses were carefully reviewed by the BEIR III committee. These data include chain reactions which occur in non-living systems, the reports of Mancuso and colleagues on the Hanford workers, and reports by Bross and colleagues on the tri-state leukemia study.

The May 1979 draft of the BEIR III 1979 report did include a "dissenting" minority report; as a result, the draft was not accepted by the president of the U.S. National Academy of Sciences and was returned to the BEIR committee for resolution of this controversy. However, the conclusions of the dissenting scientists indicated that the risk estimates given in this draft report and based on the linear hypothesis over-estimated (not under-estimated) the hazards of low levels of X- and gamma-radiation by a factor of ten-fold or more. In this case, low levels mean anything in the region of 5 rem per year or less.

<u>Question</u>: There has been conflicting testimony before the Ontario Select Committee on the biological risks due to low level radiation. Prof.Radford has claimed that the BEIR Committee will be publishing a report which indicates that previous estimates of risk are too low. What <u>will</u> the BEIR Committee recommend and what would their recommendations, if accepted, do to <u>your</u> estimates of cancer deaths and genetic defects in radiation workers?

<u>Answer</u>: The risk estimates given in various reports are listed below:

Report	Maximum predicted effect when 10,000 persons from the general population are exposed to one rem per person.		
	Fatal cancers	Non-fatal cancers	Genetic defects in first generation
BEIR 1972	0.85-4.5	not estimated	0.05-0.8
UNSCEAR 1977	1	~1	0.24
ICRP 1977	1.25	~1.25	<0.4
Draft of BEIR III 1979	0.7-3.5	1.9-6.8	0.02-0.26

All these values apply to the general population. The values for genetic defects are calculated on the assumption that 40 percent of the general population is less than the average reproductive age of 30 years; radiation workers do not commence work before age 18 and the genetic risks will be considerably smaller in this case.

The main change in the risk estimates given in the draft of the BEIR III document released in May 1979 is an increase in the estimated number of non-fatal cancers induced by radiation. The risk estimates for fatal cancers and for genetic defects, which are considered more important than non-fatal cancers for radiation protection purposes, are reduced slightly but are essentially unchanged. Both of the BEIR reports have used an "absolute risk model" and a "relative risk model" for calculating the total number of radiation-induced cancers, while UNSCEAR and ICRP use only the absolute risk model. The values given in the BEIR III draft for fatal cancers based on an absolute risk model (0.7 - 1.2 per 10,000 person·rem) are similar to those derived by UNSCEAR. The relative risk model gives higher numbers (1.5 - 3.5 fatal cancers per 10,000 person·rem) but predicts that most of these fatal cancers will occur later in life; the average loss of life expectancy is about the same with either model. Perhaps we should concentrate on loss of life expectancy rather than numbers of fatal cancers in order to clarify this situation for all of us.

The short answer to your question on what these risk estimates will do to the estimates of cancer deaths and genetic defects given in the present paper is: nothing. Data on non-fatal cancers (eg. thyroid cancers) will require further consideration.

Question: Please comment on the reported higher incidence of leukemia in military personnel involved with U.S. nuclear tests.

Answer: I know very little more about this than does anyone else at the moment. We are all waiting for the published results of the scientific study of this possibility. Reports in Nucleonics Week and similar magazines suggest that the study is complicated by the lack of good records of the identity of the military personnel who participated in this exercise.

I can, however, make some general comments on this situation. First, the current study will require a reasonably accurate estimate both of the radiation doses and of the fate of all of persons involved; neither of these numbers has been published in a scientific journal. Second, when the numbers have been published and have been subjected to critical review by other scientists who also publish their analyses of the data in a scientific journal, one can be sure that the data will be carefully considered by the various national and international committees appointed to review the scientific literature on radiation hazards. Third, we have in the past been exposed to various ad hoc suggestions that radiation hazards have been grossly underestimated. Suggestions that infant mortality in the neighbourhood of nuclear reactors is increased, and that cancer incidence (oddly enough not leukemia incidence) was increased among Hanford workers have proven to be incorrect once the data were published in scientific journals and exposed to the normal process of peer review.

It may be difficult to accept the recommendation of patience while waiting for the publication of the data on the military personnel to which you referred, but there is no other method to arrive at an accurate assessment of the facts.

Question: How do the average exposure levels of nuclear workers compare with that received by airline pilots and crew?

Answer: The average occupational exposure received by aircrew who spend about 1000 hours per year flying at an altitude of 10-12 kilometers is estimated to be 0.3-0.5 rem per year. This is similar to the average occupational exposure of all CRNL employees.

Question: You have presented your information on radiation hazards in terms of workers at nuclear powerplants. Could you comment on the hazard to uranium miners.

Answer: Underground uranium mining, like any other form of underground mining, is a relatively hazardous occupation (Fig.5). The death rate due to immediately fatal accidents is 10-12 times the maximum limit suggested for safe industries, is similar to that involved in the development and supply of off-shore oil, and is roughly 100 times that expected in nuclear power plants. Provided that radiation exposure levels are kept below the maximum recommended by the International Commission in 1959, immediately fatal accidents are the major occupational hazard to uranium miners.

Radiation exposures of uranium miners have only been kept below ICRP maximum recommended limits since 1975. The ICRP makes recommendations, not laws, and the provincial authorities in charge of the uranium mines in Ontario, like those in the U.S.A., apparently felt the ICRP recommendations were too restrictive in the earlier years. The ICRP recommendations on radiation exposures of uranium miners have now been given legal status under the Atomic Energy Control Act and can therefore now be enforced by the Control Board. Uranium miners who were exposed to high levels (up to twenty times the current maximum recommended limit) of radon daughters during the 1950's have developed a higher than average incidence of lung cancer. When exposures are kept relatively low, as they are at present, the cancer hazard is expected to be similar to that of radiation workers in a nuclear power plant.

The increase in lung cancer among uranium miners is attributed mainly to inhalation of radon daughters in the mine air. The data in the Ham report of 1976 are based on a total of 15 thousand persons who worked in uranium mines at Elliot Lake or Bancroft between 1955 and 1974; 10-11 thousand were employed at the peak period in 1958-59. The following health effects have been observed among these persons:

Cases of silicosis	90+
Excess deaths due to all respiratory diseases (including silicosis) other than cancer	0
Excess deaths due to lung cancer	36
Excess deaths due to violent causes (mainly occupational accidents) other than motor vehicle accidents or suicide	174
Deficiency of deaths due to all other causes	-148
Total excess deaths	62
Total deaths	956

Of these 956 deaths, 47 were due to suicide; this was 1.5 less than expected. This particular item is mentioned here because Sister Rosalie Bertell is now claiming that radiation is largely responsible for many of the woes of the world including suicide; the data on Ontario uranium miners do not support her suggestion and I do not know of any other data that do.

Question: Compare effects on uranium miners from inhaled dust remaining in the lungs to that for, say, coal miners.

Answer: Inhaled dust is a major health concern in coal mines as well as in certain uranium mines, and the effects on the lungs of the miners are rather similar. In one case, the effects are called "black lung" disease and in the other case "silicosis", but in both cases the lungs become clogged by the accumulation of dust. Previously miners died of these diseases. At present the miners are in essence "pensioned off" and receive workers' compensation when there is any significant evidence of the disease developing. Neither black lung disease nor silicosis are as common as they once were among miners. Among the ten thousand or more Elliot Lake miners who were exposed to higher dust levels in the early years, 90-100 had developed silicosis by 1974. Apparently none of these cases has proved fatal; nevertheless this is a serious health problem. Recent dust levels in the uranium mines in Ontario are somewhat lower than in gold and nickel mines. The problem is endemic to all underground mining activities.

There is no evidence that inhalation of silica dust or of coal dust produces a measurable increase in risk of lung cancer. The situation for asbestos mining and milling can be considered more serious because inhalation of asbestos dust has been directly linked to lung cancer.

Basically the health hazards to uranium miners are very similar to those of coal miners. The average risk to society as a whole will be greater for coal mining than for uranium mining since a ton of coal contains roughly ten times less useable energy than a ton of low grade uranium ore such as that currently being mined at Elliot Lake; therefore, society as a whole requires about ten times as many coal miners as uranium miners in order to obtain the same amount of useable energy. However, the risks to the miners themselves are high compared to the risks in most other industries in our society.

Question: To what extent is the better health of radiation workers related to the geographical location of nuclear stations? For example, CRNL is located remote from industrial pollutants.

Answer: This is an interesting question to which we do not really have any complete answer. It is known that the incidence of certain specific types of cancer is increased in heavily industrialized portions of the U.S.A. It is unlikely that the decreased incidence of fatal cancers and of deaths from all causes at Hanford and Windscale (Fig.9) can be totally explained on this basis, but someone needs to do more research on this question before the answer can be properly substantiated. It can, however, be noted that the "healthy worker" effect (that is to say, a reduced rate of deaths from all causes) is also observed in safe industries which are located in industrialized areas.

Question: (a) The exposure limit for beta radiation is set at 30 rem/year; 15 rem/3 months; 1.6 rem/2 weeks. Since it is recognized that beta radiation may cause cataracts, what acute dose, as opposed to >30 rem chronic dose, is likely to result in eye damage? (b) Is any information available on the incidence of eye damage (or lack of damage) to radiation workers employed before beta radiation was recognized as a hazard?

Answer: Beta radiation doses below 200 rem in a few minutes do not cause any cataracts at all, either in humans or in experimental animals; cataracts only became probable with beta radiation doses approaching several thousand rem in a few minutes. There is no information in the published literature to suggest increased incidence of cataracts among radiation workers.

Question: Are there any diseases other than cancer that might be traced to radiation exposure?

Answer: For low-level radiation, by which is meant 5 rem per year or less, only cancers and genetic defects are predicted. High doses of radiation in a short period of time, for example much more than 200 rem to the whole body in a few minutes, can produce a variety of unpleasant health effects. When the total radiation dose and the dose-rate are reduced to 5 rem spread out over a year, none of these other effects are observed either in humans or in experimental animals, even after many years of exposure. The various committees who have considered the biological effects of radiation are all agreed that low levels of radiation do not increase the incidence of heart attacks, do not reduce our resistance to diseases, and do not cause more rapid ageing, for example.

Question: Are some persons more susceptible than the average person to the effects of radiation?

Answer: An active research program on this topic is currently in progress at CRNL, with the support both from AECL and from the U.S. National Cancer Institute. There is at least one very rare hereditary disease in which the patients appear to be considerably more susceptible than average to radiation effects, just as there is at least one very rare hereditary disease in which the afflicted person is highly susceptible to harmful effects produced by sunlight. These diseases are so extremely rare that they do not represent a serious public health problem. However, research in this area suggests that perhaps one to five percent of the total population is somewhat more sensitive than average to radiation and also to certain chemical agents. The differences in sensitivity are not very large and we do not have any simple method tc determine who these people are. However, this whole area is one which is being actively investigated.

Question: What is the data base for the genetic effects of radiation?

Answer: The main data base for estimation of the genetic effects of radiation is a measurement of heritable changes in coat colour in specially bred strains of mice. A wide variety of other evidence from various experimental organisms such as fruit flies and yeast is also considered in arriving at this estimate.

In order to estimate the genetic effects of radiation in human populations, it is necessary to determine, first, how many persons suffer from some genetic defect, second, how many of these defects are inherited from the grandparents and how many arise as a result of new mutations in the parents in each generation, and third, what dose of radiation to the parents would double the number of new mutations in each generation.

The first two numbers have been estimated from direct observation of human populations; the third number is estimated primarily from the results of a multi-million dollar study of heritable changes in coat colour of mice. A theoretical but reasonable number is derived in this way. No excess of genetic defects could be detected in the children of humans who were exposed to high radiation doses at Hiroshima and Nagasaki. This fact provides an upper limit to the numbers of genetic defects that could be caused in humans by radiation, and substantiates the conclusion that the currently accepted estimates for genetic risks are not grossly under-estimated.

Question: If the activity from Three Mile Island reactor had escaped to the atmosphere, are the estimates of 10,000-20,000 deaths in the general population valid?

Answer: If it were possible to disperse the entire core of the reactor into the atmosphere in such a way as to expose the surrounding population, the suggested estimate seems reasonable. I am not sure this dispersal is possible. The actual releases from the Three Mile Island accident are expected to result in less than one cancer death at some time over the next several decades in a population of two million persons who lived within 50 miles of the reactor at the time of the accident. The total average increment in radiation exposure of this population due to the Three Mile Island accident was estimated to be about 0.0015 rem, as compared with the normal exposure from natural sources of 0.1 rem each year or 7 rem in a lifetime of 70 years.

Question: The second slide showed something like % survival versus age. It seemed to show that the gain in life expectancy at age 30 (and up) was greater for primitives than it is for us. Is this true?

Answer: A decrease in infant mortality has played an important role in the increase in life span, as has the large decrease in premature deaths due to malnutrition, to pneumonia and other infectious diseases, etc. However, the average life expectancy of those persons who survived to one year of age under primitive conditions was approximately 23 years; most of those who survived to age 30 were dead before age 50. Persons who survive to age 30 at present can expect to live to an age of 75 years on the average.

Question: It doesn't necessarily follow, as you suggested in your opening remarks, that longevity is the result of an energy intensive society, although it certainly is a characteristic of such societies. My own perceptions tell me that improved medical knowledge, the advent of vaccines and antibiotics and improved social hygiene, such as adequate water-treatment and sewage systems, are the paramount factors contributing to increased life expectancy. The per capita energy required to do these things is relatively small. Perhaps the real clue is that energy releases labour and makes it available to do other things, such as build sewage systems, etc.

Answer: I agree most heartily with these remarks but the answer to the question, "how much energy do we need to maintain our current life span" is not quite that simple. Our current longevity is dependent upon a highly complex society which provides adequate housing, food, public health facilities, education and medical attention, to name only some of the most important factors, and the functions of this society are in turn highly dependent upon cheap and safe supplies of energy. Adequate nutrition is certainly essential, and our society uses a lot of energy in the production and supply of food-stuffs. Adequate housing requires energy, particularly in cold climates. A considerable amount of energy is utilized for the care of the aged and infirm. A few other items do seem relevant to these comments.

First, if we plot the rate of infant mortality in a given country against average energy consumption per person in the same country at the present time, we find that infant mortality is low and similar in all countries with an average energy consumption down to about one-third of that which we are currently using in Canada (Fig.12). Assuming that other health factors follow the same general trend, this fact suggests that we might be just as healthy as we are at present if we used one-half or one-third of the amount of energy that we do at present. Below about one-third of our current energy consumption, the general health of the population begins to deteriorate, as judged from this comparison of infant mortality in one country with another at present.

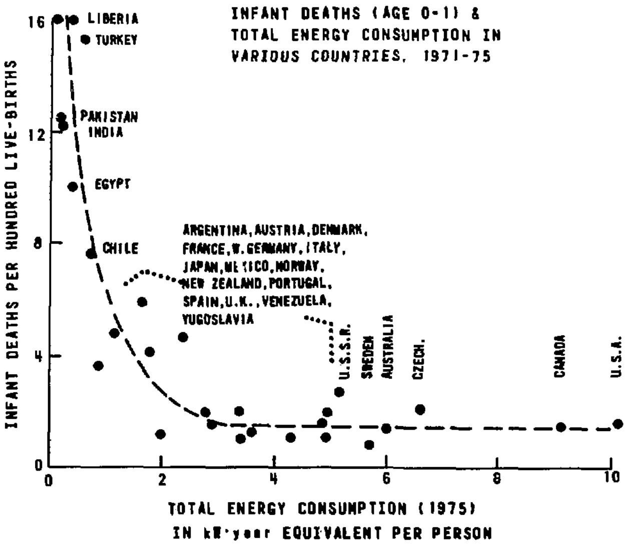

Figure 12

Second, if we look at average life span in certain under-developed countries over the past few decades, we find that their life expectancy is increasing moderately rapidly without correspondingly rapid increases in energy consumption. This appears to be due to communication of public health information from the countries that have consumed a lot of energy per person, and have learned certain health principles, to the countries that are still learning these particular facts of life. It is probably true that some of our public health measures (but not food and housing) could be maintained without large amounts of energy once they are established; but probably we would never have discovered what many of these measures (eg. vaccines, antibiotics) were if our society had not had the wealth and leisure time to discover these apparent "luxuries" and to educate us about their usefulness.

Third, some peculiar facts concerning the relationship between socio-economic status and health within any given country at present should be noted. For example, the death rate from cervical cancer is much smaller for U.K. females with a high socio-economic status than for those with a lower status; on the other hand, the death rate from breast cancer shows a directly opposite trend. Various explanations have been postulated; I would simply like to note that there are health hazards in both directions. However, if one looks only at overall risk of death, one finds that the risk of death (whether from cancer or all other causes) below age 65 is lower for persons of high socio-economic status than for persons of low status. This is equally true for the U.K. and for the U.S.A. In other words, people who are wealthy and better educated tend to live about six years longer on the average within the technologically advanced countries.

In general, cheap and safe supplies of energy are required to create a wealthy society and part of this wealth is used to increase life-expectancy as much as possible. One might perhaps conclude from these considerations that, within certain limits, longevity is not only a characteristic but is a direct result of human ingenuity in an "energy-intensive" society. The same human ingenuity has not been able to provide solutions to famine and disease in societies which do not have abundant energy supplies.

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