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RESEARCH IN RADIATION BIOLOGY, IN THE ENVIRONMENT AND IN RADIATION PROTECTION AT CRNL

by

A.M. MARKO, D.K. MYERS, I.L. OPHEL,
G. COWPER and H.B. NEWCOMBE

Chalk River Nuclear Laboratories
Chalk River, Ontario
January 1978

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Recherches en radiobiologie dans l'environnement et dans la radioprotection à Chalk River

par

La Division de biologie et de radioprotection

Résumé

Les recherches en radiobiologie à Chalk River concernent:

- l'évaluation des effets des faibles doses de rayonnement sur les êtres humains et autres organismes vivants
- le développement de nouvelles méthodes pour détecter les effets de l'exposition aux rayonnements dans les grandes populations
- le développement continu de méthodes améliorées permettant de mesurer les niveaux de rayonnement de façon précise et sûre
- l'évaluation des effets de l'emploi de l'énergie nucléaire sur l'environnement.

Le présent rapport résume nos connaissances acquises dans le domaine des risques de rayonnement et il décrit les activités actuelles de recherche à la Division de biologie et de radioprotection de Chalk River.

L'Energie Atomique du Canada, Limitée
Laboratoires Nucléaires de Chalk River
Chalk River, Ontario

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RESEARCH IN RADIATION BIOLOGY, IN THE ENVIRONMENT AND IN RADIATION PROTECTION AT CRNL

by

Biology and Health Physics Division

ABSTRACT

Research in radiation biology at CRNL is concerned with:

- evaluation of the effects of low doses of radiation upon humans and other living organisms
- the development of new methods for detecting the effects of radiation exposure in large populations,
- the continued development of improved methods by which radiation levels can be measured accurately and reliably,
- evaluation of the effects of nuclear power use upon the environment.

The present report summarizes our background knowledge of radiation hazards and describes current research activities in Biology and Health Physics Division at CRNL.

Chalk River Nuclear Laboratories

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RESEARCH IN RADIATION BIOLOGY, IN THE ENVIRONMENT AND IN RADIATION PROTECTION AT CRNL

INTRODUCTION

The nuclear power industry in Canada has an outstanding history of continued safety. This safety record is due in large part to a persistent emphasis on protecting humans against exposure to excess radiation and avoiding radioactive contamination of the environment. In order to maintain a body of expertise on radiation levels and the biological effects of radiation, research in this area has been supported at the Chalk River Nuclear Laboratories (CRNL) since 1945. This activity of course involves familiarity with international publications on radiation, in relation to humans and their environment. The present brochure will describe briefly, first, our present understanding of the biological hazards of low levels of radiation and second, current research activities at CRNL on the biological consequences of exposure to radiation, the measurement of radiation, and environmental radiation levels.

The radiations of importance in the nuclear power industry are ionizing radiations, i.e. radiations with enough energy to break up atoms into electrons and ions. Such ionization can lead to chemical changes that will harm living systems. Examples of ionizing radiations are X-rays and the α-, β-and γ-rays emitted in radioactive decay. Neutrons, which are emitted in the fission process, also produce ionization. Lower energy radiations such as the ultraviolet component of sunlight do not produce ionization but they can also be dangerous in large amounts, again because of the chemical changes they can cause.

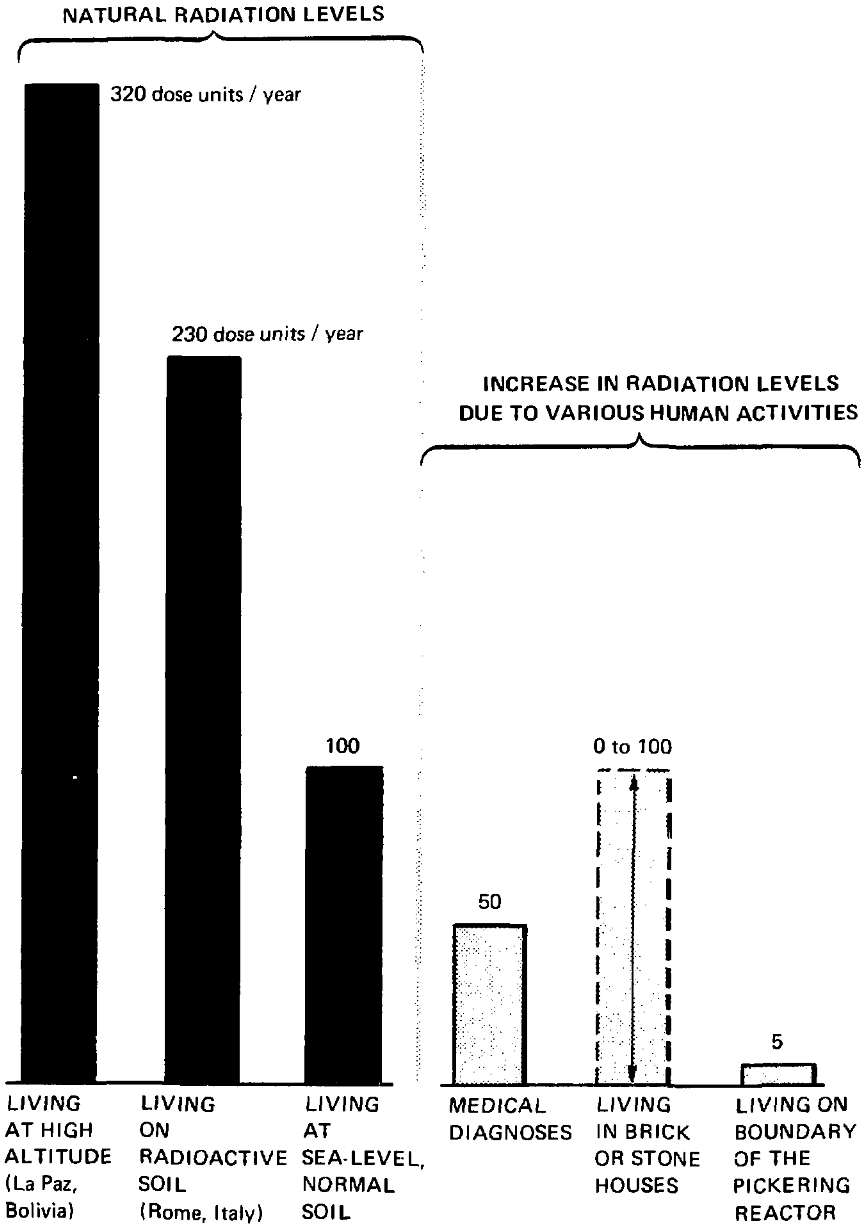
RADIATION LEVELS

All living things are exposed to low levels of radiation because the universe itself is naturally radioactive. We receive radiation from cosmic rays, rocks, soil, food and the constituents of our own body. The natural level for most persons amounts to about 100 dose units per year (1 dose unit = 1 millirem). The amount of radiation received is not constant, but depends on where you live on the earth's surface. People in Denver, Colorado, or Rome, Italy, for example, receive about 200 dose units per year. A few isolated areas in India and Brazil have a natural radiation level of more than 500 dose units per year.

X-rays for medical diagnosis are the major source of additional radiation dose to the human body. A single chest X-ray contributes between 15 to 500 dose units to part of the body, depending on the type of equipment used. A complete dental X-ray may contribute between 1,000 to 20,000 dose units to a small part of the body. If these X-ray doses are averaged over the whole body for the entire North American population, they add 30 to 70 dose units to the 100 already received from natural sources. Other man-made additions are relatively small; for example, a ten-hour jet flight (Vancouver to Toronto return) adds 3 dose units due to greater cosmic radiation at higher altitudes.

By comparison the nuclear power industry currently contributes less than 0.01 dose units per year to persons living in North America. In other words, the nuclear power industry's contribution to the average radiation dose received by the general public is very small, i.e. less than one ten-thousandth (1/10,000) of the dose received from natural radiation.

There are legal limits to the doses persons may receive. Canada and many other countries have given the force of law to recommendations made, after consideration of biological


NATURAL RADIATION LEVELS
320 dose units / year
230 dose units / year
100
INCREASE IN RADIATION LEVELS DUE TO VARIOUS HUMAN ACTIVITIES
50
0 to 100
5
LIVING AT HIGH ALTITUDE (La Paz, Bolivia)
LIVING ON RADIOACTIVE SOIL (Rome, Italy)
LIVING AT SEA-LEVEL, NORMAL SOIL
MEDICAL DIAGNOSES
LIVING IN BRICK OR STONE HOUSES
LIVING ON BOUNDARY OF THE PICKERING REACTOR

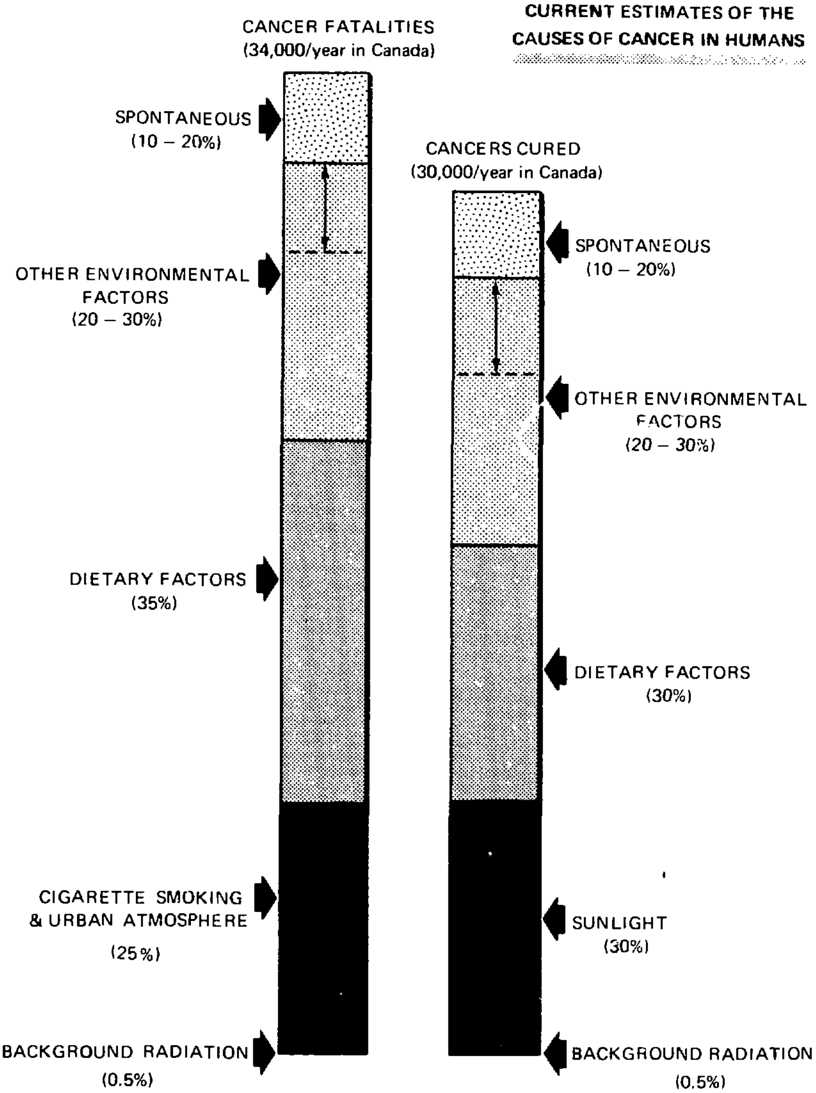
effects, by an independent international commission. Nuclear industry workers, whose exposures are carefully controlled and permanently documented, are permitted by law to receive up to 5,000 dose units per year, although few of them actually do. The commission's recommendation is that the general public should not receive more than 500 dose units per year in addition to natural background radiation. But the design target for radiation levels for people living at nuclear power plant boundaries -- a level which is routinely achieved at the Pickering Nuclear Power Station -- is five dose units per year, only one per cent of the legal limit. (Of course, no one lives right at the boundary of the Pickering or any other Canadian nuclear power plant.)

RADIATION HAZARDS

When X-rays were discovered by Roentgen in 1895, they were not known to be dangerous and people working with them took no safety precautions. The first cancers caused by X-rays were reported in 1902. Thus radiation was added to the growing list of agents already known to cause cancer, a list which started in 1775 with chimney soot, followed by arsenic in 1822, paraffin oil and coal tar in 1876, sunlight in 1894, and chemical dyestuffs in 1895. This list has since been extended to include more than 1,500 different cancer-producing agents. The most important single agents in North America today are probably dietary factors, cigarette smoke and sunlight.

With the discovery that large doses of radiation could cause cancer the question arose: "How dangerous are small amounts?".

The effects of low radiation doses spread over a long period of time are much too small to be measured directly. To be safe, the assumption is made that all radiation is harmful and that the number of cancers, or other ill-effects, produced



CURRENT ESTIMATES OF THE CAUSES OF CANCER IN HUMANS

These estimates are derived from comparisons of the incidence of various types of cancer in different countries with different life-styles. Persons from other countries who live in North America for many years tend to develop the patterns of cancer incidence typical of North America.

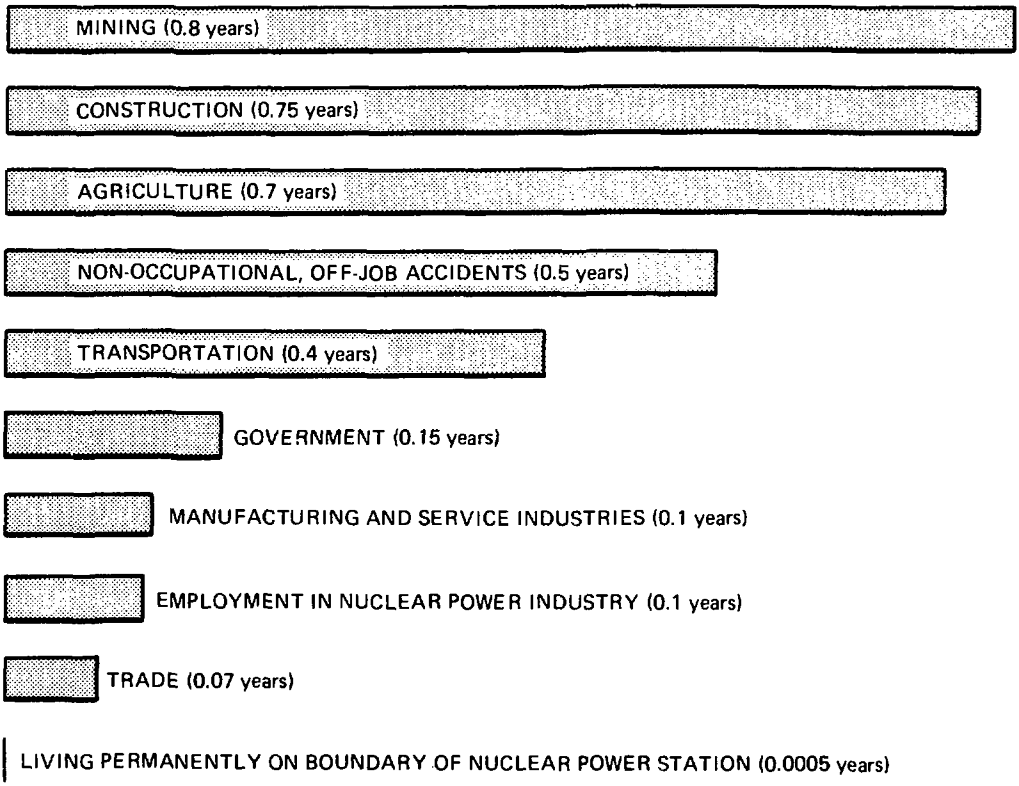
The prevalent types of cancer which can be cured at present include most skin cancers, most thyroid cancers, and about half of the cancers of the large intestine, bladder, uterus and female breast.

by it is proportional to the total dose. Internationally accepted estimates state that 10 to 15 cancer deaths per million people might be caused by a radiation dose of 100 units per person. We also know that two out of every ten persons die of cancer in North America, on the average at about age 70. In other words, less than one per cent of all fatal cancers could be attributed to the natural radiation level of 100 dose units per year.

What then is the cause of the other 99% of deaths from cancer? We already know some of the most important causes, e.g. tobacco tar and diet, but not all of them are known. The World Health Organization estimates that 75% or more of all fatal cancers are caused by environmental factors other than natural radiation. The causes of cancer are being explored by many laboratories including CRNL.

What risk is the nuclear power plant worker taking by working at radiation levels higher than the natural level? In practice, workers in Canadian nuclear power plants will receive about 50,000 dose units (millirem) over their entire working lifetime. Allowing for age at time of exposure, and also for the time taken for cancer to develop, it can be calculated from risk estimates that the average lifespan would be reduced from 73.0 to 72.9 years, a loss of 0.1 year in lifespan as a result of additional cancers caused by the higher radiation dose. This risk is similar to that in many other occupations in North America which are considered relatively safe, and is considerably smaller than the risks involved in an occupation such as farming.

Apart from cancer, radiation has another known biological effect -- the production of hereditary defects in offspring of irradiated persons. Almost all our knowledge of this effect is derived from laboratory experiments using mice and lower organisms. From the results obtained in these experiments, Average *shortening of life-span* due to immediately fatal accidents incurred as a result of employment in various industries, compared with that predicted as a result of cancers caused by radiation in the nuclear power industry.



international committees have estimated that about one per cent of all hereditary diseases in humans could be caused by the natural radiation level of 100 dose units per year. However, there is as yet no evidence even from survivors of the Hiroshima and Nagasaki bombs of any increase in hereditary defects in the children of humans exposed to high radiation doses.

As with cancer, the question may again be asked, "What is the cause of the remaining hereditary defects, if natural radiation is responsible for only one per cent of them?". This area is also part of our research interest at CRNL.

BIOLOGICAL RESEARCH AT CRNL

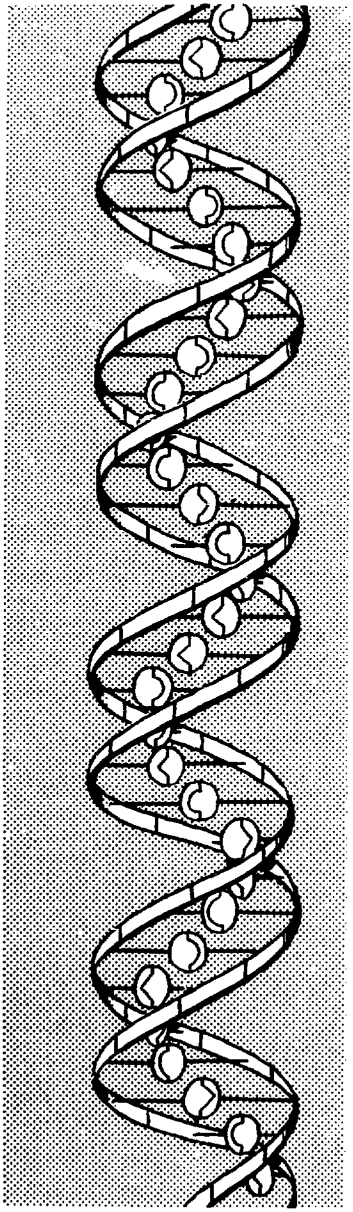
Basic research in radiation biology is directed towards a detailed understanding of the long-term biological effects of low levels of radiation. Present risk estimates are based largely on results at high radiation doses and high dose rates where measurable effects of radiation can be observed. The appropriateness of the standards of radiation exposure which have been set for protection of the health of radiation workers and of the general public depends upon the reliability of the estimates of biological effects. There are some uncertainties involved in the extrapolation of estimates from high doses down to very low radiation doses at low dose rates. A continuing program in basic research is therefore being carried out at CRNL to make certain that we do in fact know what the long-term biological effects of low radiation doses are. For this purpose we have concentrated on radiation damage to DNA in the living organism.

About 25 years ago biologists discovered that the information for all life processes is contained in a long threadlike molecule called deoxyribonucleic acid (DNA). The DNA molecule is the blueprint for the construction and function of living things; it stores all the genetic information that is passed from one generation to the next and in this manner ensures that the major characteristics of living things remain constant over many generations.

Cancers and hereditary defects are both believed to be caused by changes in the DNA coding. Numerous changes do occur spontaneously because DNA is not completely stable and is subject to slow breakdown. Current data suggest that up to 50 alterations per minute (or several million a year) may occur spontaneously in the DNA of each living cell in the human body. Changes in DNA structures may also be broughtabout by radiation, ultraviolet light, viruses and many environmental chemical agents. In these circumstances, life as we know it would be impossible if the organism did not contain built-in mechanisms which repair the DNA molecule. The instructions for the repair mechanisms are also included in the DNA as part of the information necessary for life processes.

These repair systems identify and correct changes in DNA, whether these changes arise spontaneously or as a result of environmental agents. In fact, almost all changes in DNA coding are corrected unless the exposure to radiation or chemical agents becomes so high that the system is unable to cope. The cancers and hereditary defects which do occur naturally are believed to be the result of a small number of errors which are overlooked and therefore not repaired, or are repaired incorrectly.

Part of our research program is concerned with the exact nature of the kinds of errors introduced into the DNA by radiation and an understanding of the mechanisms by which this damage is repaired. Radiation effects are studied with a wide variety of living organisms using advanced techniques in molecular biology, in order to be certain that we understand the effects upon other living things in our environment as well as the effects upon humans.



DNA - The Genetic Material

DNA carries the hereditary information for all life processes

*

Approximately 100,000 separate instructions are encoded in the DNA of each human cell.

*

Errors in these instructions can lead to cancers and hereditary changes.

*

Errors are introduced into the DNA by spontaneous events, by environmental chemicals, by certain viruses, by sunlight (skin only) and by ionizing radiations such as X-rays.

*

Natural radiation levels are responsible for less than 1% of the errors which result in cancers or hereditary diseases in human populations.

Attempts are also being made to identify any rare individuals in the human population who might be more susceptible than normal humans to radiation. We have shown that patients with an extremely rare hereditary disease (ataxia telangiectasia) which makes them abnormally sensitive to radiation do in fact suffer from a hereditary defect in DNA repair mechanisms.

Other research programs are concerned with the interaction between radiation and environmental chemicals such as tobacco tar, caffeine, etc. The object of this research is to improve our knowledge of the basic mechanisms that cause cancer and hereditary defects, and to continue to ensure that radiation standards for the protection of health are in fact safely derived.

DETECTION OF HARMFUL EFFECTS IN MAN

Appropriate safety standards must be based to a large degree on knowledge of the risks to man at various exposure levels. This is true not only for radiation but more generally for chemical agents that cause cancer or other harmful effects. It is difficult to obtain accurate information in cases where the possible harm may not appear until many years later. For this reason, investigators at CRNL have taken a special interest in the potential value of existing routine health records (e.g. death registrations, hospital discharge summaries, and registers of special diseases) which contain diagnoses of cancers and of hereditary conditions.

These records exist in the form of magnetic tape, which could be used to determine whether or not members of an "exposed" group suffer delayed harm from their exposure. Computer methods developed by CRNL staff enable the records of populations exposed to various working environments, or to medical X-rays, to be searched for medical information concerning subsequent harm. All names are converted into code and strict precautions are taken so that no personal identification and no breach of privacy is possible. Currently our computer methods are being used by the National Cancer Institute of Canada, in collaboration with Statistics Canada, to follow up large populations of employees in various Canadian industries, and large numbers of persons who received repeated fluoroscopic examinations some decades ago in the course of treatment for tuberculosis.

By using these computer methods to reduce the costs and increase the sizes of the populations that can be followed up, it is expected that much better human risk data can be obtained on which future safety standards in many industries may be based. Thus, an emphasis on radiation safety has led to methods for obtaining information on the hazards of less well-understood industrial chemicals.

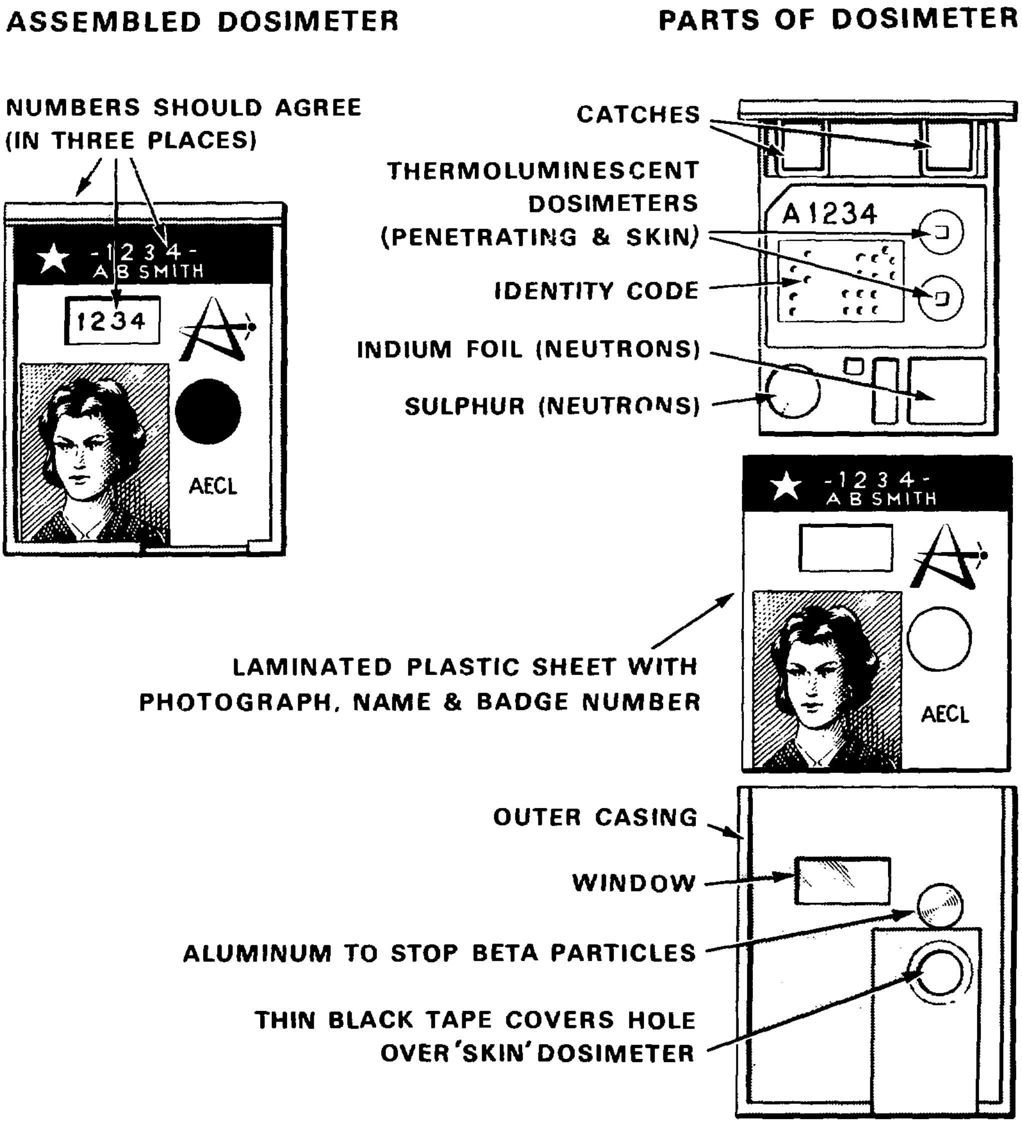
HEALTH PHYSICS RESEARCH AT CRNL

The effects of radiation exposure on biological systems can only be evaluated if we have the means of measuring quantities of radiation accurately. To work with radioactive materials, accelerators and nuclear reactors, we must also be able to measure radiation levels precisely so that the exposure of people at work can be kept within acceptable limits. Similar measurements are essential for the medical uses of radiation. To meet these requirements, health physicists at CRNL have a continuing program in radiation dosimetry and the development of radiation measuring techniques.

Radiation detectors are devices in which radiation produces a physical effect which can then be measured with sensitive electronic techniques. When gamma radiation interacts with a gas, neutral atoms are separated into positively and negatively charged bodies. These charges can be collected in an electric field and measured either as a very small current or as a series of electrical pulses. Certain solid materials have the capability of absorbing the energy in a radiation field and converting it into visible light. The light flashes emitted can be detected with sensitive photoelectric cells. Some liquids also display this property of radiation-induced luminescence and can be used to measure quantities of radioactive substances in liquids. Certain semiconductor materials, similar to those used in "solid state" radio and television receivers, also have the property of producing electrical signals when exposed to radiation. Some of the semiconductor radiation detectors are similar to devices used to convert solar energy to electricity. Yet another kind of radiation detector operates by the phenomenon of thermoluminescence. A crystal of lithium fluoride, for example, when exposed to radiation absorbs and stores some of the radiation energy. Subsequently, if the crystal is heated to a particular temperature the stored energy is released as a flash of light proportional to the amount of radiation exposure it has received. Thus the accumulated radiation exposure received throughout a work period can be determined. All of these devices are used to measure radiation.

The extent to which radiation interacts with any matter depends strongly on its atomic composition. To estimate the significance of the radiation exposure upon biological material or a person, it is desirable to make the detector out of tissue-equivalent materials. In the case of exposure to X-rays or gamma rays, this is a comparatively simple problem; detectors are selected whose average atomic weight is near that of human tissue. An air-filled ionization chamber with plastic walls can measure the dose received in a field of gamma radiation. Luminescent solids and liquids made from organic compounds can also be used.

THE AECL PERSONAL DOSIMETER



However, not all of the most sensitive detectors are conveniently similar to tissue in their composition; their response must be modified to represent the physical impact of radiation upon people. This is currently one of the principal objectives of radiation dosimetry. For this purpose, techniques have been borrowed from other fields of study. For example, processing of signals and modification of response functions of detectors uses many electronic techniques from computer science. The development of miniature devices with complex functions uses techniques developed for space programs.

The end products of this work can be seen in any visit to a nuclear power plant or a research laboratory like Chalk River. Each visitor is given a badge containing a crystal of thermoluminescent lithium fluoride which will register any radiation exposure he has received during the visit.

When a person enters an area where radioactive materials are processed, there is a small chance that he may pick up traces of radioactivity which has been spilled in the process. To ensure that this contamination is detected and is not carried on the person beyond the boundaries of the processing area, the visitor or worker is required, before leaving, to check his hands and shoes with sensitive radiation detectors to ensure that they are free of radioactivity.

In locations where large radiation sources are handled, other instruments will sound an alarm if the intensity of the radiation fields exceeds an acceptable level. For those who work with nuclear energy, radiation monitoring procedures and methods such as these ensure that acceptable safety standards are maintained.

ENVIRONMENTAL RESEARCH AT CRNL

Canadian nuclear reactors have been designed so that they have a minimal effect on the environment. There are at least threedifferent barriers designed into the CANDU* reactor system to prevent release of radioactivity to the environment. Only extremely small amounts of radioactive elements (radionuclides), in low concentrations, are released into the environment where they mix with other naturally present radionuclides.

Radioactive elements in the environment behave in the same way as other chemical elements, i.e. they are dispersed in air, soil and water and some are subject to biological concentration in plants and animals. This means that there are a large number of potential environmental pathways by which radioactivity can reach humans. At CRNL a considerable part of the research work involves a study of how radionuclides behave in the environment, particularly those that are important for the nuclear power industry in Canada.

We are fortunate to have at CRNL a wide range of fresh-water and forest habitats suitable for environmental field research. One such habitat is Perch Lake, a small fresh-water lake within the boundaries of CRNL. It contains several species of fish, snapping turtles, as well as many different micro-organisms and aquatic plants. The lake also contains low levels of radioactivity and for this reason it has become a valuable asset to environmental research. The uptake and concentration of radionuclides from the lake water by organisms, from the smallest plants and animals up to the top predatory animals such as carnivorous fish, have been investigated.

The dependence of higher animals on lower forms of life for food is a fact of nature. This can be simply illustrated by a food chain for a man eating range-fed beef: GRASS → STEER → MAN. In other words, the grass is eaten by the steer and the steer is eaten by the man. Not all food chains are as simple as the above illustration and those existing in fresh-water lakes are often extremely complex. A typical

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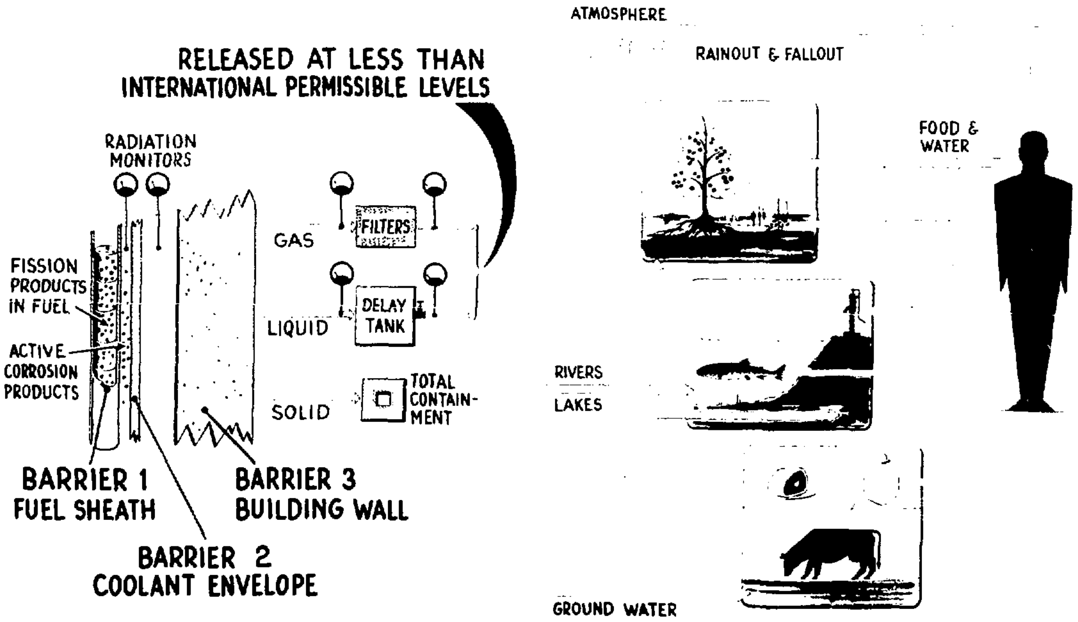
*CANDU - Canada Deuterium Uranium

RADIOACTIVITY IN FOOD-CHAIN OF MAN



fresh-water food chain found in Perch Lake is:

WATER SEDIMENT	→	BACTERIA ALGAE PLANTS	→	INSECTS ZOOPLANKTON SNAILS CLAMS	→	FROGS SMALL FISH BULLHEAD SMALL PERCH	→	SNAPPING TURTLES ADULT PERCH

Our research on aquatic food chains has been concerned with two important radionuclides, cobalt-60 and strontium-90. We have found a progressive decline in the concentrations of both these radionuclides as they move along the food chain. This means that top predators, such as large carnivorous fish, assimilate less radioactive cobalt and strontium per unit body weight than do the plants and smaller fish on which they feed.

The movement, dispersion and concentration of a radionuclide in the environment is identical to that of its stable counterpart; for example, radioactive strontium behaves like stable strontium. By studying the distribution of existing stable nuclides, environmental scientists can therefore obtain useful information about the behaviour of radionuclides. Many environmental transport processes have extremely long time-scales when compared to the observation time periods in field and laboratory studies. For some radionuclides, time-scales of up to 100,000 years are not unreasonable and the long-term implications for the exposure of future generations from long-lived radionuclides must therefore be considered. By studying the distribution of the stable chemical elements that have already existed for many thousands of years in the environment, information can be obtained on the probable behaviour of radioclides in the distant future. For this reason there is a considerable amount of research work at CRNL into the hydrological and geochemical characteristics of the environment.

Water and nutrient "budgets" of lakes, chemical analysis and physical chemistry of water, soil, air, rock and lake sediments are all part of a program designed to yield as much information as possible about the nature of the environmental compartments through which the radionuclides move. Some of this work is done in collaboration with scientists from the Department of Fisheries and Environment and from Canadian universities (Queen's, Waterloo, Toronto) who find the facilities at CRNL provide suitable conditions for carrying out research work of mutual interest.

To ensure that discharged radionuclides do behave as expected and that people are not exposed to significant amounts of radiation it is necessary to monitor the environment for radioactivity. We are routinely carrying out extensive surveillance within the CRNL area. Environmental monitoring in public areas is independently done by another authority, the Department of National Health and Welfare, in cooperation with the Ontario Ministry of Health and the Ontario Ministry of the Environment. Results of environmental monitoring are available to the general public in a publication entitled "Environmental Radiation Surveillance" obtainable from the Department of National Health and Welfare. CRNL's contribution to this work is in the development of improved methods of environmental monitoring, training of staff from the agencies, and in acting as consultants to the environmental monitoring group.

Another aspect of environmental research at CRNL that relates to the Canadian nuclear power program concerns the use of low-grade heat. At the present time heat produced in cooling water used by Canadian nuclear power stations is wasted because the temperature is too low to be economically useful. This low-grade heat, as it is called, could be used to increase food production. The research approach at CRNL is to use this heat to increase the growth rate of small plant cells known as algae. An increase in small plant cells would mean a greater abundance of natural food for the fish, hence the growth rate of the fish would also be increased. Research on low-grade heat continues throughout the year at a CRNL field facility, namely Maskinonge Lake. The selection of suitable species of algae is determined by experimentation and their response to increased temperature, nutrient requirements and ability to grow in Canadian environments is tested.

In environmental research precise analysis of the samples obtained from field work is needed before meaningful results can be obtained. This means the measurement of not only radioactivity in the samples but also their stable nuclide content, physical characteristics, etc. For this reason the laboratories at CRNL are equipped with modern analytical instrumentation capable of carrying out these analyses. Extremely small amounts, as low as one part per billion in some cases, of stable trace elements such as zinc, cobalt, manganese, arsenic, strontium, etc. are routinely measured by environmental chemists. In the analysis of radioactivity, instruments in use in the environmental research laboratories are able to detect, in the samples, minute amounts of radioactivity above background levels.

The protection of people requires continuing assessment of the effects of the nuclear industry on the environment. It is the responsibility of the environmental scientists at CRNL to analyse and publish the data obtained from research so that proper environmental assessments can be made.

SUMMARY

Mankind and all other living things have always been exposed to low levels of naturally occurring radiation. In this century, small additional exposures have resulted from the use of X-radiation for medical purposes and from the use of nuclear power. All radiation exposures resulting from the nuclear power industry are carefully monitored and strict precautions are taken to ensure that the general public is not exposed to any major increases over and above the natural background level of radiation.

Research in radiation biology at CRNL is concerned with:

- evaluation of the effects of low doses of radiation upon humans and other living organisms,
- the development of new methods for detecting the effects of radiation exposure in large populations,
- the continued development of improved methods by which radiation levels can be measured accurately and reliably,
- evaluation of the effects of nuclear power use upon the environment.

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