 EA-90-01

ENVIRONMENTAL ASSESSMENT BOARD

ONTARIO HYDRO DEMAND/SUPPLY PLAN HEARINGS

IN THE MATTER OF the Environmental Assessment Act, R.S.O. 1980, c.140 as amended, and Regulations thereunder;

AND IN THE MATTER OF an undertaking by Ontario Hydro consisting of a program in respect of activities associated with meeting future electricity requirements in Ontario.

REPORT OF THE PUBLIC HEALTH COALITION: ONTARIO PUBLIC HEALTH ASSOCIATION/ INTERNATIONAL INSTITUTE OF CONCERN FOR PUBLIC HEALTH RESPECTING THE HEALTH EFFECTS OF ONTARIO HYDRO'S DEMAND/SUPPLY PLAN (HEALTH EFFECTS REPORT)

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"... conservation is the best strategy for minimizing environmental and health impacts, at least in the medium term until the more benign technologies become available."

> [The Report of the Royal Commission on Electric Power Planning; Chairman: Arthur Porter; Volume 6; Environmental and Health Implications of Electric Energy in Ontario; p.xv]

"... no technologies are risk free, including those employing ionizing radiation. Some level of risk is invariably necessary if the benefits of technologies are to be enjoyed by individuals and society at large."

> [From an editorial in the Journal of the American Medical Association entitled "There's No Free Lunch: The Benefits and Risks of Technologies"; Vol.265, No.11; March 20, 1991, pp.1437-8]

Foreword

The Public Health Coalition wishes to acknowledge the experts and consultants who contributed reports and advice: R. Bertell [International Institute for Concern on Public Health], H.J. Boermans [University of Guelph], R. Brecher [GlobalTox International Consultants Inc.], D.C. Cole [L.A.M.P. Occupational Health Program], P. Coyte [University of Toronto], M. Goldberg [GlobalTox International Consultants Inc.], S.F. Hall [Energy Consultant], T. Hancock [Public Health Consultant], J.G. Heller [James G. Heller Consulting Inc.], R. Honsberger [MacViro Consultants], R. Labonté [Public Health Consultant], P.Lane [Victoria Hospital, Trauma Services], A.J. Orkin [McGill University], K.Z.Morgan [Emeritus member of E.C.I.P.], L.D. Pengelly [McMaster University], W.E. Rees [University of British Columbia], P.Rosenberg [Head of Emergency Medicine, Etobicoke General Hospital], H.D. Sharma [University of Waterloo], and A. Stewart [University of Birmingham]. Reviewers of expert materials included E. Cardis [International Agency for Research on Cancer], R.E. Dales [University of Ottawa], K.G. McNeill [University of Toronto], D.C.F.Muir [McMaster University] and G. Torrance [McMaster University].

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Overview

The Public Health Coalition [PHC], composed of the Ontario Public Health Association and the International Institute of Concern for Public Health, presents this report to the Environmental Assessment Board [Board] as a framework document for performing a health effects assessment of Ontario Hydro's [Hydro] Demand Supply Plan [DSP].

For each of three major supply options (hydraulic, fossil fuel and nuclear), the energy efficiency improvement option and the electricity transmission/distribution grid, selected public and worker health issues known to be associated with the operation of these components of Hydro as a utility are reviewed to develop estimates where possible of their real cost to Hydro customers.

The PHC has also attempted to quantify the real health cost of these options and to identify and quantify the range of uncertainties associated with the estimates.

Preliminary PHC estimates of the health costs of the two major supply options, the nuclear and coal fired electricity generation options, show them to have the largest normalized health costs of all alternative demand and supply options. This document provides the first estimates of these costs and identifies and quantifies the range of uncertainties associated with the estimates.

With respect to the nuclear option, the PHC also examines Hydro's regulatory environment and its relationship to health and safety issues and the state of emergency and medical preparedness for nuclear accidents.

The PHC recommends the conserver society option as an alternative to Hydro's undertaking. While there are significant public health consequences no matter which option is selected, the conservation option is the least harmful of the several supply options in the short term.

Explanatory Note Respecting Conclusions

The PHC will make three different types of recommendations.

First, the PHC will make a series of recommendations respecting the undertaking, the environmental assessment material submitted by Hydro and other parties, in support of its position that Hydro's environmental assessment is inadequate and that the conserver society is the best alternative to Hydro's undertaking.

Second, should the Board find that Hydro's assessment is adequate and that the undertaking should be approved, the PHC recommends a number of terms and conditions which it submits should be imposed to mitigate the worst effects of the undertaking.

Third, in the course of this review the PHC has identified a number of concerns and made recommendations on issues to which the solutions are, strictly speaking, beyond the jurisdiction of the Board. The PHC will invite the Board to comment on these recommendations in its decision. An example is the PHC recommendation that the government of Ontario create an agency to monitor and evaluate environmental and health effects of Hydro's operations.

Chapter 1
Introduction

1.1 Definition of Health

Representatives from three national and international health organizations (World Health Organization, Health and Welfare Canada and Canadian Public Health Association) met in Ottawa in 1986 to forge a document entitled the "Ottawa Charter for Health Promotion" (at the First International Conference on Health Promotion; November 17-21, 1986; Ottawa, Canada). The charter is instructive in shifting the definition of health from a passive state of freedom from illness to a broader, more active context called "health promotion". Quoting from that Charter:

> Health promotion is the process of enabling people to increase control over, and to improve, their health. To reach a state of complete physical, mental and social well-being, an individual or group must be able to identify and to realize aspirations, to satisfy needs, and to change or cope with the environment. Health is, therefore, seen as a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources, as well as physical capabilities. Therefore, health promotion is not just the responsibility of the health sector, but goes beyond healthy life-styles to well-being.
>
> The fundamental conditions and resources for health are peace, shelter, education, food, income, a stable eco-system, sustainable resources, social justice and equity. Improvement in health requires a secure foundation in these basic prerequisites.
>
> Good health is a major resource for social, economic and personal development and an important dimension of quality of life. Political, economic, social, cultural, environmental, behavioural and biological factors can all favour health or be harmful to it. Health promotion action aims at making these conditions favourable through **advocacy** for health.
>
> Health promotion focuses on achieving equity in health. Health promotion action aims at reducing differences in current health status and ensuring equal opportunities and resources to **enable** all people to achieve their fullest health potential. This includes a secure foundation in a supportive environment, access to information, life skills and opportunities for making healthy choices. People cannot achieve their fullest health potential unless they are able to take control of those things which determine their health. This must apply equally to women and men.
>
> The prerequisites and prospects for health cannot be ensured by the health sector alone. More importantly, health promotion demands coordinated action by all concerned: by governments, by health and other social and economic sectors, by non-governmental and voluntary organizations, by local authorities, by industry and by the media. People in all walks of life are involved as individuals, families and communities. Professional and social groups and health personnel have a major responsibility to **mediate** between differing interests in society for the pursuit of health.

> Health promotion strategies and programmes should be adapted to the local needs and possibilities of individual countries and regions to take into account differing social, cultural and economic systems.

Health is, therefore, a multidimensional construct, involving subjective states of wellbeing and quality of life, and objective states relating to freedom from disease or infirmity. For the purposes of this submission the PHC wishes to note three key dimensions of health:

1. Physiological integrity (an objective determinant of health based on the absence of disease, disability or infirmity);
2. Wellbeing (an individually determined subjective construct of health which is more common in people free from disease); and
3. Quality of life (a socially determined subjective construct of health which includes physiological integrity and wellbeing, and is quantified by health economists into usable social indicators).

The PHC contends that these three dimensions of health must be considered together in a comprehensive evaluation of the costs to society of alternative demand/supply options proposed by Hydro. In this respect, the PHC's approach to health differs from Hydro's, which restricts its analysis and discussion of health impacts to infirmity, morbidity and mortality.

"Wellbeing" and "Quality of life" as dimensions of health are often combined when examining the psychosocial determinants of poor health. The literature is ambiguous on this point. Some researchers separate the two dimensions by suggesting that quality of life "relates both to the adequacy of material circumstances and to people's feelings about these circumstances", thus distinguishing between the two concepts by their degree of reference to socioeconomic conditions external to the individual. Other researchers combine the notions by defining quality of life as "the sense of satisfaction and wellbeing that an individual feels about his or her life".

Wellbeing and quality of life are regarded by many researchers and policy makers as representative of societal and institutional goals. Subjective evaluations of wellbeing are more representative of quality of life than are objective indicators such as demographics, income, employment, economic growth, etc.

There is also a need for qualitative studies evaluating experiences of health (wellbeing, quality of life) relative to electricity generating options. These studies may be particularly relevant to people living near generating or transmission line sites, and should form part of a social impact assessment.

Although quality of life is often used synonymously with wellbeing, some researchers argue that it compromises the relationship between states of wellbeing and particular social structures or conditions. For example, quality of life might be considered to apply to social as distinct from personal wellbeing.

Social indicators are generally used to measure social wellbeing. However, most social indicators reflect administrative goals of institutions and are not strongly correlated with measures of personal wellbeing. For the purposes of this submission, the PHC will combine these subjective dimensions of health. Please see the PHC expert reports by R.Labonté et al. (August 25, 1992) for a more complete discussion of this subject.

1.2 A Brief History of Public Health

The material for this history of public health has been drawn from a report by PHC expert T. Hancock (The Public Health Approach; September, 1992).

Public health has a long history, dating back to the Mosaic food laws of the Hebrews, the teachings of the Greek "father of medicine", Hippocrates, and to the Roman health laws and public engineering works. In Renaissance Italy, Boards of Health were established in most of the major cities in the 15th century. They had broad powers to regulate public gatherings, enforce quarantine laws, issue health passes, and carry out inspections. By the 16th century, their responsibilities included such diverse areas as hygiene, sanitation, food quality, burials, the regulation of hospitals, physicians and apothecaries, and the control of prostitutes and vagrants.

The nineteenth-century public health movement proved to be remarkably effective in increasing life expectancy (a common measure of overall health). In examining the evidence concerning the causes of this dramatic increase in life expectancy, a startling conclusion was reached: the major causes of improvement in health came not from specific medical interventions but from general social and public health measures including a rising standard of living; improved nutrition; sanitary reform, especially the development of clean water supplies and waste disposal systems and improved food and general hygiene; a decline in the virulence of some organisms and to a lesser extent specific immunization and therapy measures. It is clear that many of the infectious diseases which were the major killers in the nineteenth century were well on the way to being controlled before specific vaccines or antibiotics were available.

Public health reached its golden age between 1890 and 1910. During that period, there were dramatic declines in mortality from infectious diseases as a result of the sanitary activities of the public health movement complemented by the discovery of specific microbial agents and the development of specific vaccines.

In the 1930s, however, the first antibiotics became available and the clinical and therapeutic model slowly came to dominate the health scene. After the Second World War, the introduction of a National Health Service in Britain in 1948, public hospital insurance (1958) and national medical insurance (1968) in Canada cemented in place the therapeutic model as the main instrument for improving the health of Canadians. However, a Canadian reappraisal in the early 1970s of the best means to ensure health has resulted in a significant public health renaissance.

Canadian thinking about and practice of public health has undergone important shifts in the past fifteen years. The first of those shifts was the federal government's report "A New Perspective on the Health of Canadians", commonly referred to as the Lalonde Report (Health and Welfare Canada, 1974). That report noted that health was not the product of our system of health care, but rather of our environment, our lifestyle and our biological makeup and inheritance. The report stressed, moreover, that "future improvements in the level of health of Canadians lie mainly in improving the environment, moderating self-imposed risks and adding to our knowledge of human biology."

The first fruits of this breakthrough were in the area of "lifestyle", which the Lalonde Report defined as "the aggregation of decisions by individuals which affect their health and over which they more or less have control." The message was clear: the health of Canadians would be greatly improved if they would only make changes in their self-imposed risks and personal behaviour. Indeed, the focus on individual responsibility in the report was even extended to making people collectively responsible for any of their health problems that arose from problems in the wider environment.

The immediate effects of this emphasis on personal responsibility for self-imposed risks was an emphasis on personal behavioural change as the way to improve health. Canadians were urged to change their eating, drinking, smoking, exercise and other behaviours in a way which almost completely ignored the influence of the social environment on behaviour and thus on health. Indeed, this approach became known as "victim blaming", since it was seen to ignore the extent to which people's behaviour was moulded by their environment, and thus ignored the extent to which they are victims of their circumstances.

As Dr. Carol Buck, a Canadian epidemiologist and former president of the International Epidemiologic Association, commented in her 1984 review of the report:

> Both the report and subsequent policy decisions failed to deal adequately with the element of the environment. I shall argue that this is the most important of the four elements in Lalonde's health field concept. If the environment is wrong, the elements of human biology, lifestyle and health care organization will be wrong too (see PHC commissioned paper by T.Hancock on "The Public Health Approach").

Buck suggested that we must continually and constructively challenge the unhealthy environment.

This more complex understanding of health behaviour has led to the approach to public health known as health promotion. Health promotion is based upon a multivariate, holistic and interactive model of health which integrates environmental and social factors in the context of culture and the biosphere. Five spheres of health promotion activity have been identified by the World Health Organization [WHO]:

1. Healthy public policy, which is the development of health-enhancing policies in non-health policy areas.
2. Creating physical and social environments supportive of health.

3. Strengthening community action, including fostering public participation and mutual aid.
4. Developing personal skills and coping mechanisms.
5. Re-orienting health services toward disease prevention and community-based care.

In short, the "new" public health recognizes the need for comprehensive, long term public policy initiatives, together with environmental, community, personal and health service system changes, if the health of the public is to be enhanced.

The PHC maintains that cheap electrical power is a source of wealth production in our society and, by raising the standard of living, leads to better social conditions and overall improvements in the health of the public in the broadest sense.

While there is good evidence that a certain level of energy use is related to physical, mental and social well-being, there is also evidence that energy production and utilization has adverse health consequences. At what point do further increases in energy use (including electrical energy use) fail to have any significant beneficial effects and may in fact begin to have adverse health effects that outweigh the benefits? It is clear that other countries have been able to attain high levels of health with substantially lower per capita energy use, including electrical energy use. Moreover, there is evidence that some countries have been able to improve their health (at least as measured by infant mortality and life expectancy) while actually reducing their per capita energy consumption.

Energy provides a benefit for Ontarians, including a health benefit. We must, however, identify the adverse health effects to various generating options to determine whether adverse health effects outweigh health benefits.

1.3 Public Health: Principles and Practice

Public health practice is based on an awareness of the scientific evidence of disease causation, as well as effective health protection, health promotion and disease prevention measures. As an applied science, it must also be sensitive to social and political realities. The distinguished Canadian public health leader, Professor John Last, has written:

> Prevailing social values determine the perception of health problems and community responses to them, so that to some extent public health is a political activity. The history of public health provides many examples of heated debate in a political arena that arose from opposition to beneficial proposals (see T.Hancock paper on "The Public Health Approach").

Public health reflects conflicting values, in particular the conflict between mercantile interests and public health officials. Keeping all people, both rich and poor, in good health was not only humane and sensible since contagion could strike both, but also cost-effective. For example, in 1873 in Munich, Max von Pettenkofer argued successfully that the installation of sewers would save more money than they would cost, due to the reduction in illness and the better health and productivity of the labour force.

By its nature and history, public health tends to the protection of the group more than the individual. While clinical medicine deals with the straightforward care and treatment of individual patients (the success of which is usually apparent), public health deals with the state of health of populations where the criteria for success are more complex, require extended periods of time to become evident, are less apparent and depend on the cultural, social and economic characteristics of the target group.

The ethical underpinnings for public health lie in the philosophy of utilitarianism by which "the central place of the greatest happiness for the greatest number ... determines the aims of the law as well as the responsibilities of the state and the legislature ... The state maintains security, supplies means, and last but not least, promotes equality. Next to fighting poverty, the promotion of public health is the important feature." (Kerkhoff, 1987. In T.Hancock: 'The Public Health Approach')

Society balances the benefits derived from individual rights and freedoms with those arising from attention to collective interests in a variety of areas including the general health and wellbeing of the population. Thus, legislation exists to regulate and limit individual behaviour in such areas as trade and commerce, occupational health and safety and environmental protection. Two major industries, the food and pharmaceutical, are subject to specific public health legislation that regulates the quality and purity of their products.

The individual's right to privacy is limited by public health imperatives that require a physician to report certain diseases and patient information when society's health is placed at risk. These limits have been extended in recent years to include seat belt, crash helmet, and anti-smoking legislation to name but a few initiatives. These and other initiatives such as water chlorination and fluoridation illustrate the value our society places in balancing individual and collective rights and responsibilities to promote and protect public health.

Adherence to the values embodied in public health leads the PHC to define the following principles:

1. Health is a positive state of wellbeing, not just the absence of disease and disability. Health is determined by a wide array of social, environmental, cultural, economic and behavioral factors - an holistic model of health.

2. Public health is concerned with preventing disease, disability and premature death and promoting health and well-being: prevention is better than cure.

3. Public health is concerned with the health of populations, as well as that of individuals: the greatest health for the greatest number.

4. Public health is a collective, publicly funded and controlled societal undertaking.

5. Public health actions are addressed to the agent, the host and the environment, preferably simultaneously, using a variety of social, environmental, educational and service delivery strategies.

6. Broad social and environmental measures are generally more effective than specific individual interventions.

7. For the good of the public's health, collective rights may supersede individual rights.

8. Decisions should be made on the basis of the best scientific knowledge currently available.

9. When evidence exists to suggest that the public's health may be placed at risk, it is better to err on the side of safety in making decisions. In the face of uncertainty, take the action which best protects the public's health. This is the policy of "prudent avoidance".

10. To be effectively implemented, public health policies must be socially and politically acceptable.

11. Where the social and political climate is not favourable to public health, public health practitioners should seek to change it through education and advocacy.

1.4 Energy Planning within A Bioecology Framework

Hydro's planning takes place within a technological and scientific framework, which views human society and the economy as essentially independent of and dominant over the bio-physical world. Human activity is considered to be constrained only by technological bottlenecks and institutional inefficiency; there are no fundamental limits on economic growth. From this perspective, Hydro can and does interpret its mandate as satisfying the demand for whatever energy level seems necessary to fuel the growth and development of the Ontario economy.

In contrast, human bioecology sees the human enterprise as a wholly dependent and integral component of the ecosphere. This means that human activity is ultimately constrained by rates of biophysical productivity and the absolute need to maintain the integrity of the life support functions of the ecosphere. No foreseeable technological advance or institutional streamlining can significantly affect this reality. Mounting evidence suggests that the consumption of essential ecological goods and services already exceeds sustainable levels of production, and that humanity may have already come up against unprecedented thermodynamic limits to growth. As defined by the Brundtland Commission (see PHC study by R.Labonté on "Public Health Policy and Decision-Making"), sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs.

The ecological bottom line for sustainability is that humankind must learn to live on the "interest" generated by remaining stocks of biophysical resources (natural capital). Accordingly, the emerging hybrid discipline of ecological economics has advanced a "constant capital stock" criterion as a necessary condition for sustainable development. Each generation should inherit an adequate stock of natural capital assets no less than the stock of such assets inherited by the previous generation. Further reductions of natural capital may impose significant risks on society, even in resource-rich countries. At the least, Gross

Domestic Product [GDP] growth based on natural capital depletion eventually becomes uneconomic growth that impoverishes. From the global perspective, because of the unique essential services provided by ecological capital, conserving what there is may be essential for survival.

Natural capital can be usefully related to the concept of "carrying capacity". For human beings, carrying capacity can be interpreted as the maximum rate of resource consumption and waste discharge that can be sustained indefinitely without progressively impairing the functional integrity and productivity of essential ecosystems. The corresponding human population is a function of sustainable production divided by per capita demand.

The inverse of carrying capacity provides an estimate of the natural capital requirements of a given population. Instead of asking what population a particular region can support, the question becomes: How much land in various categories is required to support the region's population? Preliminary data show that, depending on material living standards, average per capita consumption continuously co-opts up to several hectares of productive ecosystem. This per capita index can then be used to estimate the total land area required to support any defined population. Analysis shows that the actual "ecological footprint" of urban regions is typically one to two orders of magnitude greater than the land contained within the associated built-up area. Urban industrial areas necessarily appropriate the carrying capacity of large unseen "hinterlands" through trade and the free unmonitored flow of ecological goods and services. (See the PHC study by R.Rees on "Carrying capacity perspectives on energy, health, and the ecosphere - assessing Ontario Hydro's 25 year plan".)

The PHC has noted above that there is more to health than life expectancy and infant mortality; and there is more to energy policy than the simple provision of energy. In the view of Hooker et al., "energy policy is a fundamental social policy ... The proper aim of energy policy should be the long term enhancement of the quality of life in a society" (see T.Hancock: Energy and Health). The social implications of energy policy extend beyond mere settlement patterns to include fundamental questions about the shape of society. As Hooker et al. state: "The long term public interest calls for a sustainable resource base utilized as far as possible in the pursuit of social equality, diversity and freedom of choice; social institutions that nurture responsible political participation and as much local autonomy as possible; and a flourishing, self-reliant economic life."

This sort of energy future, variously called the sustainable or conserver society, is one that, in our view, is better for human health and well being, particularly in the long term.

1.5 Healthy Public Policy and Energy Policy

Healthy public policy is a recent description of the emerging policy practice of public health. In contrast to traditional public health policy, which is concerned with health services and protection, healthy public policy is strategic and long-term, and is concerned with all public sector decision-making that may affect the health of the public.
Based upon public health and bio-ecology principles, seven specific energy policy and healthy public policy principles relevant to Hydro's Demand/Supply Plan are as follows:

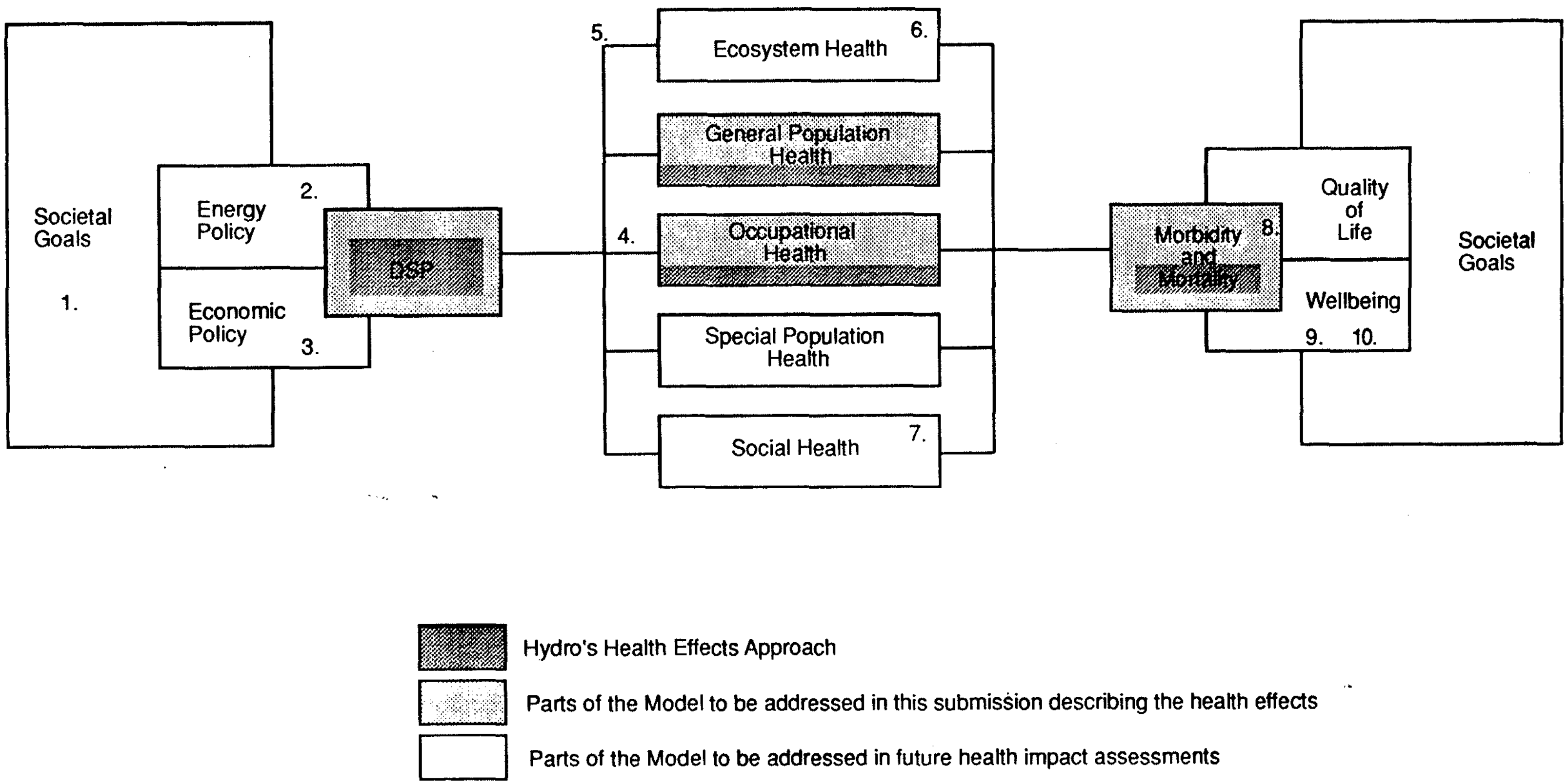
1. Energy use should benefit human health;
2. Energy use should be indefinitely environmentally sustainable;

3. Energy use should not foreclose the health opportunities of future generations;
4. Energy use should ensure an equal opportunity for all to be healthy;
5. Energy use should enhance social, economic and political equity, intranationally and internationally;
6. Energy use should be adequate to meet human needs;
7. Energy use should enhance the ability of individuals to participate fully in community life and to increase control over their lives and over decisions which affect their health.

1.6 Example of Health Impact Assessment Model

The emerging policy practice of public health includes the development of various health impact assessment models. The PHC submits Figure 1 as an illustration of the range of matters which should be taken into account in determining health impacts. The shaded portions of the figure show both the parts addressed by Hydro, the parts addressed by the PHC, and the parts which should be addressed in future health impact assessments. While Hydro has generally focused on its own costs when assessing impacts, the PHC submits that costs should include not only the cost to Hydro, but the total cost to the province. The model shows areas which require further study and analysis.

Figure 1: Health Impact Assessment Model



Notes to the Figure

1. Societal goals refer to the value bases in which public and private policy decision-making occurs. As already stated, these policy values should generally address the kind of society we want, and specifically have quality of life, wellbeing, empowerment, collaboration and other measures of human development as outcomes.
2. Energy policy refers to decisions about the overall level of energy use, and the mix of energy supplies. The Board should recommend that the Government of Ontario develop an overall energy policy for the province and that this energy policy should define the appropriate role of electricity in the overall energy supply.
3. Economic policy refers to decisions based upon criteria for environmentally and socially sustainable economic development.
4. This is the pathway of direct effects of the DSP on three categories of population health: the general public, workers and special populations (i.e. those living near generating facilities or transmission lines, sensitive populations such as the very young or very old, or persons in their reproductive years).
5. These are pathways of indirect health effects of the DSP, one through impacts on the physical environment (ecosystem health) and another through impacts on the social environment (social health).
6. Ecosystem health refers to major bioecological impacts such as those on climate change, food chain / ecotoxicity, biodiversity/resource depletion, all of which are indicators of ecosystem carrying capacity.
7. Social health refers to major impacts on equity (improvements in socioeconomic inequalities/ status between groups), citizen participation (empowerment) and employment.
8. In addition to routinely collected or coded morbidity and mortality data, the PHC is particularly concerned with impacts that are subtle, long-term and intergenerational.
9. Wellbeing and quality of life refer to subjective evaluations of health. In addition, quality of life also refers to development of appropriate social (human development) indicators that reflect societal goals and policy values.
10. Our assessment of the health costs of the DSP is based on data pertaining to morbidity, mortality and wellbeing.

1.7 Proposed Agency

There are many uncertainties in the assessment of the health effects of Hydro's DSP which will become more apparent in the course of this report. An ongoing review of emissions and adverse health effects is required since better assessments can be made as the database increases.

For this reason, the PHC asks that the Board consider recommending to the Ontario government the creation of an agency composed of members of the public, scientists, and representatives of key stakeholders including Hydro, government, and regulatory agencies. The PHC will make detailed recommendations respecting a proposed mandate for this agency throughout this report.

Chapter 2
Methodology

2.1 PHC's Analytical Framework

To evaluate the alternative DSP for electricity, the PHC believes that its analytical framework must identify the community whose health is affected by the plan. Certainly, direct health care expenditures associated with illness and disease attributable to electricity generation are borne mainly by the Ontario Ministry of Health for Ontario residents. Neighbouring jurisdictions may also bear direct health costs for hazardous discharges resulting from Hydro generating options. Ultimately, the constituency whose health is at risk encompasses all human society at the local, provincial, national and international levels.

This description of society is incomplete, as it is confined to one moment in time. Where hazardous exposures lead to delayed effects (as in carcinogenesis) or to intergenerational effects (based on the notion of genetic and teratogenic health effects), the health of all future members of society must also be considered.

The PHC's analytical framework must include the health of all present and future members of society who are or may be at risk from the decision to undertake any Hydro demand/supply option. This definition includes the full range of health effects for both workers and the general public - accidents, injuries, disablements, diseases, deaths and psychosocial factors - across present and future society.

In Chapter 3, the PHC raises the practical issue of limiting consideration of the future health consequences of current Hydro programs to a workable time frame of one thousand years. This is a contentious issue in the nuclear context, and bears significant implications for the commitment of Hydro resources as to warrant separate consideration by the monitoring agency proposed by the PHC.

2.2 The Assessment of Adverse Health Effects

The material in this section has been drawn in large part from PHC expert reports on risk assessment (Bertell; May 26, 1992; GlobalTox; June 29, 1992).

The determination of risk to the health of human populations from hazardous exposures draws upon the collective knowledge of different branches of science (such as industrial and environmental hygiene, health physics, toxicology and epidemiology) and of medicine.

Epidemiology is concerned with the distribution and determinants of disease in human populations. The first evidence of adverse health effects from some previously unrecognized hazardous exposure often appears in the form of epidemiologic reports in the scientific literature. In many instances, these reports follow a common format. They document a series or cluster of cases exhibiting the following characteristics: at least one putative etiologic agent or hazardous exposure for all reported cases; a pathway linking the exposure(s) to the cases; a constellation of symptoms and/or diseases among the cases; and a hypothesis (or hypotheses) associating the agent(s) with the cases.

Although human experimentation in our society except under the most rigid and ethically approved of circumstances is abhorred, it is not well enough recognized that occupational exposures to workers from a host of unknown agents whose toxicological properties in many instances remain unknown (despite their use in the workplace) constitute the world's only ongoing natural human experiment. As a consequence, first reports of new potential hazards usually spring from worker studies.

Following these reports, epidemiologists are often commissioned to conduct confirmatory observational studies which take the form either of cohort studies (involving longitudinal and usually retrospective follow-up of exposed and non-exposed workers to determine the relative frequency of adverse health effects in each group) or of case/control studies (which examine the exposure histories of diseased cases and matched controls to determine the likelihood that the exposure in question is causally related to the adverse health effect). Usually more than one confirmatory study in different settings is necessary to provide convincing evidence of a causal association, and to estimate the relationship between level of exposure and severity of adverse health effect. Animal studies are conducted to provide additional supporting evidence of the plausibility of the putative causal association.

The issue of determining causal association in a regulatory environment is enormously complex; varied means have been established in Europe and North America to structure such determinations.

The following criteria for scientifically confirming a causal association were first identified and refined by Sir Bradford Hill in 1965:

1. Strength of association. The rate of disease in the exposed group must be higher, in a statistically significant sense, than in a control group matched for age, sex, calendar period, etc. The level of significance is usually set at 5% although this is mere convention. A 5% level means that the observed difference in rates would occur 5 times out of 100 (or less) by chance alone if there were no difference between the rates. The level of significance measures the so-called Type I error, or the likelihood of accepting an observed difference as real when it is in fact due to chance alone. A complementary concept, developed since the time of Hill, referred to as the power of a statistical test, is the Type II error which measures the likelihood of rejecting an observed difference as unreal when it is in fact real. When the level of significance used to test an observed difference is made more stringent, the power of the test to detect a real difference is decreased.
2. Consistency of association. The same exposure/disease association is found in studies of other populations separated by geography, time and circumstances. In other words, the observed association is reproducible.

3. Specificity of association. The uniqueness of the disease strengthens one's confidence in causality. For example, Minimata's disease occurs specifically following mercury poisoning. However, with environmental and other ubiquitous agents, specificity is often difficult or impossible to prove.
4. Temporal association. Exposure to the hazard must precede the disease. However, latency periods for carcinogenesis (e.g. from smoking) may extend over decades.
5. Dose-response relationship. Exposure increases should lead to increases in disease incidence. This criterion can be modified in certain circumstances by competing causes of death, all-or-nothing biological responses which cannot be repeated, and resonance related phenomena such as electromagnetic radiation in which the dose-response relationship oscillates depending upon frequency and field strength.
6. Biological plausibility of association. The disease mechanism must be observable in animal models using the methods of different disciplines (e.g. pathology, microbiology, etc.).
7. Coherence of relationship. There are similar studies confirming the relationship as well as studies in other branches of science and bioscience which support the relationship, such as studies of animals in the wild.
8. Experimental confirmation. Laboratory studies on animals are used to test the causal relationships between hazards and disease. This requires that appropriate animal models be available to test the relationships.

Animal studies are conveniently employed to identify hazardous agents, and to determine an identified hazard's dose-response relationship. There are at least two difficulties encountered in extrapolating findings from such studies to issues of human health risk: the extent to which the animal species serves as an accurate model of the human physiological system in question (e.g. the respiratory system); and the errors resulting from projecting high dose effects in animals to low dose effects in humans. Nevertheless, such studies are routinely used to determine acute toxicity dose levels as well as the short and long term effects (involving lifetime and multi-generational studies) of sub-acute exposures.

Additional scientific evidence on disease causation is also derived from "in vitro" studies which examine cell behaviour outside of the organism, and from extrapolations of the known properties of toxic substances with similar molecular chemistry.

To facilitate making comparative statements, the PHC's submission will use the scientific literature on adverse health effects associated with the various components of Hydro's proposals to systematically identify and quantify, where possible, risk (defined in the next section) to human health from each demand/supply option as a function of units of annual electrical energy production (or displacement), population at risk, and other relevant considerations.

The PHC recognizes that much of the evidence it presents relies upon quantitative (epidemiological, toxicological) data. As noted earlier, the PHC is also concerned with quality of life and wellbeing, in which the experience of disease (measured through quantitative studies) is only one factor. Qualitative research in areas pertaining to the quality of life and wellbeing, and the development of appropriate indicators is also required.

2.3 Terminology for Assessing Health Effects

The following terminology will be used in discussions of human health risk from hazardous exposures:

- Hazard refers to a substance whose physical, chemical or biochemical properties may under certain conditions be detrimental to health (e.g. radioactive, carcinogenic, flammable, corrosive, etc.);
- Risk is a measure of the likelihood or probability that a hazardous substance will produce an adverse health effect. The projected number of such health effects is expressed either as cases per thousand or cases per million. The term "risk coefficient" is often used to indicate the risk per unit dose received of the hazard. Where dose/risk relationships are not linear or proportional, it becomes necessary to specify the dose range for which the coefficient is valid;
- Source of exposure (e.g. smoke stack, effluent pipe, landfill, etc.);
- Pathway of exposure (which links the source of exposure with the exposed individual, whether by air, water or food); it may also be expressed as a presence in an electromagnetic field, for example, in the presence of a high tension wire or gamma radiation source;
- Route of entry (i.e. ingestion, inhalation or absorption);
- Dose is the total amount of the exposure agent or hazardous material either entering an individual, sometimes expressed per unit of body weight (e.g. 10 mg/kg of body weight) or received by tissue (e.g. 4 rem whole body dose);
- Dose rate is a measure of the time rate of exposure to the agent (e.g. dose per kilogram of body weight per day; or dose per person per day);
- Collective dose is a measure of exposure to a whole population of, for example, workers; and is calculated by multiplying average dose per person by the number of exposed persons.
- Threshold of effect refers to a level of exposure to a hazard below which no risk is imparted. For genotoxic carcinogens, there is no threshold and, therefore, health risk follows any such exposures.
- Attributable Proportion is the proportion of cases, cancers, birth defects or other measurable detriment attributable to exposure to a risk factor. It depends on the case incidence rate in the unexposed population, the relative risk associated with exposure and the proportion of the population in the exposed group. The Attributable Proportion places a limit on effective public health intervention. For example, if 10% of lung cancers are attributable to smoking then a campaign to reduce smoking can at best reduce lung cancer incidence rate by 10%. Calculations of Attributable Proportion are now possible for sex and age specific groups, and for competing variables such as smoking and radon gas, each associated with lung cancer. There have been significant developments in this area of biometry during the 1980s and its use in environmental health assessment is strongly recommended.

2.4 Identifying all the Costs of Adverse Health Effects

The PHC touched upon the direct health costs borne by society and associated with the health effects attributable to decisions to deploy alternative demand/supply electricity options. Additional societal costs are incurred in these decisions and include the loss in economic output resulting from either lower on-the-job productivity or through absenteeism (due to ill health) borne by employers and various social insurance programs. The lower quality of life attributable to illness, disease and psychosocial factors limits social activity and is borne both by the afflicted individuals and by their families and friends.

A comprehensive framework for analyzing the total health economic costs associated with alternative demand/supply options requires the measurement and valuation of the impact of adverse health effects on the stream of consumption and investment benefits of human health capital. These health economic concepts are defined below (and in a PHC commissioned report by P.Coyte; November 15, 1992). The PHC submission takes the view that human health is a durable asset which may be adversely affected by elevated rates of morbidity and mortality, or indeed by any erosions to the quality of human life.

The investment effects resulting from a depreciation of human health capital may be summarized as:

1. The direct costs of all health effects attributable to alternative demand/supply options on health care and other direct expenditures. Direct costs refer to those payments and/or expenditures that are actually incurred because of the adverse health outcome. They include health care expenditures associated with the prevention, diagnosis, and treatment of adverse health effects, which are incurred by the public health care system (e.g. the Ontario Ministry of Health) and financed out of general revenues. They also include other direct costs such as out-of-pocket expenses associated with obtaining health care services (e.g. fees paid, transportation costs incurred, etc.) and costs of household modifications, etc.;
2. The indirect costs of all health effects on economic output. These losses in output occur through mortality (i.e. premature death) and morbidity (i.e. illness induced limitations on market and non-market activities) of affected individuals which result in lost time from work or household activities, or in the reduced productivity of such time. Indirect costs are measured in terms of the present value of lost earnings and the associated imputed value of lost household work. Additional indirect costs result from reduced work productivity, the time spent in obtaining health care services and the time spent by informal care givers to the affected individual; and
3. Other costs borne elsewhere in the general economy as a result of adverse health effects such as societal costs resulting from the support of offspring with genetically induced problems (such as the costs of special education for children born with learning defects).

While it may seem that the breakdown of direct, indirect and other costs account for all incurred costs, these costs do not account for the erosion of individual wellbeing attributable to an adverse health effect. This health effect appears on the PHC's quality of life dimension of health, and is a psychosocial cost distinct from the aforementioned economic costs. It is not quantified as a financial loss in this submission, although it could be argued that psychosocial "costs" may sometimes include financial costs.

The distinction between economic and psychosocial costs is crucial to an understanding of the PHC's proposed framework for health costs. Adverse health effects lead to additional health care expenditures, which require reallocation of scarce societal resources towards the health care sector and away from other economic sectors. This reallocation results in foregone alternatives, which we have noted to be the direct cost of such health effects. Further, lower productivity leads to the availability of fewer goods and services for consumption, which yields our measure of indirect costs. Societal resources are further reallocated where generational health effects necessitate specialised goods and services to support the afflicted offspring.

Finally, the erosion of wellbeing is a cost borne by both individuals afflicted with illnesses as well as their family and friends. While these costs are just as important as the other costs, this loss in wellbeing does not directly alter the allocation of resources in society. Thus, economic costs result in a reallocation of societal resources whereas psychosocial costs leave societal resources unchanged. Nevertheless, cost estimates which ignore these quality of life effects will underestimate the "full" health costs.

One reason that individuals invest in health capital is to derive consumption benefits. Good health is valued in itself. As such, it enhances wellbeing and therefore, yields a psychic return over and above the return from either lower health expenditures or greater economic output. Coyte's study notes that the method used to measure consumption benefits is based on a willingness-to-pay for a change that will reduce the probability of an adverse health effect. In practice, attempts to adopt this method lead to difficulties in the determination of the valuation based on income distribution (with the rich able and willing to pay more than the poor for a reduction in adverse risk), and on individuals' inability to value small reductions in the probability of death.

The PHC has identified three effects on consumption benefits resulting from any depreciation of human health capital:

1. The direct effects of increased pain, discomfort and suffering caused by adverse health effects attributable to alternative demand/supply undertakings on individual quality of life;
2. The direct effects of adverse health effects on social interactions and leisure; and
3. The indirect effects to the quality of life of the afflicted individual's family and friends.

In the PHC's analytical framework, consumption and investment benefits are combined to form extended cost-of-illness estimates of the potential adverse health effects of alternative demand/supply options. The rationale for combining these estimates is based on the proposition that willingness-to-pay studies may consistently underestimate both the direct health care expenditures and the indirect loss in economic output due to adverse health since these costs are not generally borne by those afflicted with ill health.

As noted in Coyte's report, there are two reasons why these costs are not generally borne by Canadians afflicted with ill health. First, financial barriers to the use of all necessary health care services are prohibited by the Canada Health Act. Second, since Canadians have access to an elaborate network of universal social insurance programs, providing protection against the loss in earnings following an adverse health outcome, their exposure to financial risk is limited. Nevertheless, the PHC maintains that the full range of these health costs should be included in public policy planning.

2.5 The Development of Cost Estimates Associated with Adverse Health Effects

This submission illustrates the appropriate framework for identifying and evaluating the consequences to public health from the deployment of various proposed options in Hydro's demand/supply plans. In the previous section, four main components of cost from adverse health effects were identified based on the extended cost-of-illness approach: medical and other direct costs; indirect costs resulting from losses in economic output; quality of life losses; and other costs borne elsewhere in the general economy.

It is well beyond the PHC's current resources to fully develop all the health costs associated with all the adverse health effects of each such option. Nevertheless, the PHC will have accomplished one of its principal objectives in these hearings if it can define an appropriate framework for costing the health consequences of alternative demand/supply options; and pursue the requisite calculations as far as its resources permit. The PHC notes that this objective was diligently pursued in the Ontario context in 1980 by the Porter Royal Commission on Electric Planning (in Volume 6 of the Commission's final report entitled "Environmental and Health Implications of Electric Energy in Ontario"). The current effort may be viewed in part as an update to the Porter Commission's findings.

The PHC has provided preliminary estimates for the first three of the above four components of total health costs. To simplify the estimation procedure, the analysis focuses on major ICD-9 (for International Classification of Diseases, 9th revision) disease groupings for the more commonly recognized adverse health effects, namely respiratory diseases, neoplasms and injuries and poisoning. In the absence of locally available health economic studies, the PHC used available Ontario, Canadian and American data to derive per capita estimates in 1990 Canadian dollars of: lifetime direct health care expenditures; per capita single episode direct costs for hospitalization; indirect costs of foregone earnings due to premature death; and quality of life loss (as measured at age 35 by the value of a 'statistical life' or the present value of the foregone consumption benefits for a person with a remaining life expectancy of 40 years). See Table 2.1.

Table 2.1
Range of Estimates of Health Costs From Adverse Health Effects
(in thousands of 1990 $ Canadian on a per patient basis)

HEALTH COST/DISEASE GROUP	LOW ESTIMATE	HIGH ESTIMATE
1. LIFETIME DIRECT COSTS:		
Respiratory disease	$206.6	$268.4
Neoplastic disease	$51.1	$766.3
Injuries and poisonings	$140.4	$332.9
2. DIRECT COSTS OF A SINGLE EPISODE OF HOSPITALIZATION:		
Respiratory disease	$2.6	$4.2
Neoplastic disease	$4.1	$6.6
Injuries and poisonings	$6.8	$11.1
3. INDIRECT COST OF FOREGONE EARNINGS:		
All disease groups	$310.7	$746.5
4. QUALITY OF LIFE LOSSES:		
All disease groups	$2,800.0	$4,400.0
TOTAL ESTIMATED HEALTH COSTS:[a]		
Respiratory disease	**$3,317.3**	**$5,414.9**
Neoplastic disease	**$3.161.8**	**$5,912.8**
Injuries and poisonings	**$3,251.1**	**$5,479.4**

Notes: a. Total estimated health costs equal the sum of items 1, 3 and 4 above, and omit other costs borne elsewhere in the economy.

Additional information on health costs which will be used in this submission is shown below. Table 2.2 provides data on the present value of foregone consumption benefits only from various categories of lifetime disabling injuries. Table 2.3 (based on a lost investment stream) shows the cost per person-day lost from work, by age group and gender, for workers and the general public.

Table 2.2
Health Costs Associated with Lifetime Disabling Injuries[a]

CATEGORY	MEAN	RANGE
Moderate	$46,000	± 22-23% of mean
Serious	$185,000	± 22-23% of mean
Severe	$480,000	± 22-23% of mean
Critical	$2.26M	± 22-23% of mean
Death	$3.6M	± 22-23% of mean

Notes: a. Adapted from: Rice, D.P., MacKenzie, E.J. and Associates (1989). All figures are in Canadian $1990.

Table 2.3
Cost per Person Day Lost for Workers and General Public by Age and Gender[a]

CATEGORY	MEN	WOMEN
Workers:		
Age: 35-44	$169.08	$113.77
45-54	$178.53	$110.42
55+	$152.13	$97.83
Public:		
Age: 35-44	$112.30	$47.60
45-54	$120.78	$46.24
55+	$100.83	$41.36

Notes: a. Based on Canadian full time salaries (in 1990 dollars) as reported by Statistics Canada by age and gender (and assuming 48 weeks/year and 5 days/week), unemployment rates, participation rates and full time to part time employment ratios in Ontario.

In the following chapters, the PHC will examine each major Hydro demand/supply option and will identify the adverse health effects associated with each option. Where appropriate, estimates of the level and range of health effects per GWa of electrical energy production (or displacement) will be developed. Lastly, the per capita cost figures shown above will be applied against these health effects to provide the Board with preliminary estimates of the overall health costs of each proposed demand/supply option.

These calculations will necessarily be incomplete because of the paucity of available information. However, the PHC affirms that the analytical framework for these determinations is sound; that the ranges of estimates for health effects and health costs reasonably reflect the scientific and health economics literatures; and lastly, that application of this methodology yields correct estimates, at least to an order of magnitude, of the health consequences of each proposed Hydro demand/supply option.

Chapter 3
Health Effects from the Nuclear Generating Option

Although the nuclear option originally proposed by Hydro in its 1989 DSP as part of its then undertaking has now been withdrawn by the Corporation, the information in this chapter should be employed in the consideration of alternatives to the current undertaking which rely heavily on the nuclear option.

The issue of hydrogen sulphide emissions from the Bruce Nuclear Power Development [BNPD] will be addressed by another Intervenor before the Board, Mr. Eugene Bourgeois.

Contributors to this chapter were: R. Bertell, H. Boermans, M. Goldberg, J. Heller, K. McNeill, C. Rousseaux, H. Sharma and A. Stewart. Reviewers were: R. Bertell, K. McNeill, K. Z. Morgan, and A. Stewart.

3.1 Uncertainty and the Nuclear Option

Any serious effort to determine risk to human health from the nuclear (or any other) generating option must contend with the issue of uncertainty. Sources of uncertainty arise in the quantification of dose and health effect and can be categorized as follows:

1. Hazardous emissions (their types; the quantities of each type released; and the rates of release);
2. Human exposure (the level and rate of exposure to humans and to the ecosystem as a whole); and
3. Human health effect(s) from exposure to given dose levels and rates.

In theory, if it were possible to measure exactly the amount of hazardous material emitted to the environment by a nuclear facility (whether a mine, mill, processing plant, nuclear station or waste disposal site), it should be possible to capture that material and prevent its dispersion. That this is patently not the case means that emission estimates must be based on sample measurements provided by monitoring equipment and the relationships between these surrogate measures and the actual levels and rates of hazardous emissions. This is true for "routine" emissions, but is complicated further when accidental emissions occur (e.g. the heat exchanger leaks at Pickering NGS in August 1992 which led to a significant discharge of coolant and tritium into Lake Ontario). In those instances, even greater reliance is placed on engineering calculations, devices and surrogate measures to derive reasonably accurate emission figures. The PHC maintains that measured values of emissions have significant associated uncertainties.

The next section of this chapter explores the uncertainties surrounding the question of what happens to these emissions once they leave the facility. It is extraordinarily complicated to trace the migration of radionuclides through the environment in order to determine human exposure levels and rates. Beyond the typical environmental monitoring programs (to measure atmospheric, aquatic, biotic and related dosages), nuclear operators and their regulators must rely on extensive dispersion modeling studies by their own scientists and official international organizations, from which inferences are drawn concerning resulting exposures to individuals as well as to eco-habitats. These inferences are then used to establish emission limits for the associated nuclear facilities.

Abundant evidence suggests that significant uncertainties surround all inferences drawn from these methodologies. An example of this is found in a documented statement by the late A. Dory (the former Manager of the AECB's Uranium Mining Division) concerning the accuracy of historical radiation level measurements in Ontario uranium mines (Industrial Disease Standards Panel, 1989). Mine exposure records are based solely on area monitoring and not on individual exposure records; periodic reporting to the AECB of these area readings for each miner only became a regulatory requirement in 1968. Dory made the following assertions concerning estimates of individual miner's exposure to radon gas and its products in Ontario uranium mining:

- Prior to 1960, the uncertainty in exposure estimates was up to 1 order of magnitude (i.e. from 0.1 to 10 times the recorded values);
- From 1960 to 1970, the uncertainty was of the order of plus or minus 200%;
- From 1970 on, the uncertainty was of the order of plus or minus 100%;
- From about 1978 onwards, the uncertainty was within plus or minus 50%.

This example provides one record of local evidence addressing the difficulties in even approximately measuring human exposure levels to hazardous radiation emissions.

Measurement of dose to the public is also fraught with difficulty. For example, the acidity of soil can affect both the transport of radionuclides and their uptake by plants and animals, and human intake depends on life style and eating habits which vary significantly between infants and adults. Averaging these variables or using a "standard man" approach is likely to introduce considerable uncertainty in individual dose estimates.

Converting dose into a human health response requires choosing a biological endpoint (and ignoring other outcomes) and a reliable representative database from which a dose response can be calculated. Until recently, the Atomic Bomb database (USA) and the Ankylosing Spondylitis radiation therapy cases (UK) have dominated the regulatory schema. Both of these databases dealt with high doses of radiation delivered in a short period of time. Hence, extrapolating the findings to low doses spread over a number of years has generated considerable controversy and competing models since 1970. The PHC predicts that this database will soon be replaced by data on nuclear workers. Certainly, direct dose-response data at low doses and slow rates is to be preferred once it is available.

In this chapter, the PHC will examine various sources of uncertainty as it develops estimates of health effects from Hydro sourced radionuclide emissions. The PHC will use Hydro's profile of existing nuclear generation potential as of 1993 (Table 3.1) to systematically derive ranges of estimates for the expected level of adverse health effects to society over Hydro's planning horizon [1989-2014] resulting from radionuclide emissions to the environment over the entire cycle for uranium fuel used to operate these nuclear reactors. Because the subject of radiation related health effects covers a host of injuries, diseases and disablements extending across generations, the PHC has been forced to concentrate on specific and recognized conditions (i.e. neoplastic fatalities and non-fatalities and intergenerational effects) to illustrate its framework methodology for deriving health costs associated with the nuclear option. Health effects to Hydro workers and the general public will be addressed within this methodology. The derived results in this chapter should not be seen as definitive or exhaustive, but rather as illustrative both of the methods and uncertainties which will need to be considered in obtaining complete estimates of health costs associated with the nuclear option.

Table 3.1[a]
Nuclear Generation in Ontario: 1993 to 2014

NUCLEAR STATIONS	NOS.OF UNITS	IN SERVICE DATES	PEAK CAPACITY (MW)[b]	AVG.CAP. FACTOR (%)	TYPICAL ENERGY OUTPUT (GWh/yr)[c]	(GWa)[d]
Pickering A	4	1971-1973	2,060	86	15,257	1.74
Bruce A	4	1976-1978	3,076	58	15,435	1.76
Pickering B	4	1983-1985	2,064	85	15,103	1.72
Bruce B	4	1984-1987	3,440	83	24,711	2.82
Darlington	4	1991-1993	3,524	85	25,885	2.95
TOTAL	20		14,164	78	96,391	11.00

Notes:
a. Source: Fig.4-20, Existing System Generation. In 'Providing the Balance of Power': Hydro Demand/Supply Report.
b. Megawatts of electrical energy.
c. Gigawatt hours of electrical production per year.
d. Gigawatt years of electrical energy production per year.

Assuming that the above nuclear stations will continue to operate at the shown levels of electrical energy output between 1993 and 2014, the expected yearly environmental impacts can be calculated using a variety of sources of information, including Hydro data (Porter Commission's Vol. 6: Hausmann, 1980; AECB, 1990; UNSCEAR, 1988; Hydro, Exhibits 4 and 507). The methodology for the detailed calculations is provided in reports by PHC experts (Bertell, July 27, 1992; Sharma, October 23, 1992).

The total electrical power capacity in Ontario in 1993 is expected to be 32.8 GW, of which 14.2 GW (or 43.3%) is nuclear, which will carry most of the base load. Annual peak demand is at about 24.0 GW indicating a reserve capacity of some 36% in Ontario. Assuming an average capacity factor of 78%, the current nuclear capacity in Ontario will provide an estimated 11 GWa of electrical energy annually during the time period 1993 to 2014.

3.2 Migration of Radionuclides through the Environment

a. Overview

The material for this section is drawn from the PHC report by H.Boermans on 'Migration of Radionuclides Through the Environment' (September 23, 1992).

Radioactive contamination of the environment results in human exposure to radioactivity. Humans have long depended for safety from the effects of potentially toxic substances on the large scale dilution and natural breakdown of substances released into the atmospheric, terrestrial, or aquatic environments. However, the introduction of long-lived radionuclides into the environment increases the pool of environmental radionuclides above the general background level. Different chemical forms of these radionuclides can imply differences in bioavailability and biochemical interaction with the human body. In addition to the actual intake of radioactive material, humans can be exposed to gamma rays (similar to x-rays) from isotopes such as cesium-137 or iodine-131, which can irradiate from a distance. Unlike chemical contaminants, radionuclides do not need to contact or be incorporated into living material in order to affect it.

Humans can be exposed to intake of environmental radioactivity in a number of ways. If water is contaminated, human exposure can occur directly through drinking. If the contaminant is initially airborne, the radioactivity particles may be inhaled or may be deposited on the skin. Tritium, for example, is absorbed as readily through skin as it is through inhalation. Particles deposited on surfaces are seldom absorbed through intact skin or leaf surfaces, but can be resuspended by wind action or human activity and then inhaled.

The most complex mechanisms, however, are those that involve ecological pathways and contamination of food chains. The importance of ecological pathways is becoming appreciated as we learn more about the movement of long-lived radionuclides in the environment. For example, the long-lived radionuclide zinc was shown to appear as a radioactive contaminant concentrated in living plants from the soil or marine organisms taken from the sea. Hazard to humans from airborne radioactive iodine was shown not due entirely to inhalation of the dust or vapour but rather involved a pathway of deposition on leafy surfaces such as forage or grass, followed by grazing of dairy cows and goats and secretion of radionuclides in milk. Because a dairy animal grazes a large surface area, it absorbs more radioactive iodine by ingestion than inhalation. Since the radionuclide is secreted in milk, it can in this way be passed to humans in a concentrated form. Thus biomagnification of radionuclides in the environment and through the human food chain increases the potential of human exposure and exemplifies the need to understand more fully the factors controlling the movement of radionuclides in our environment.

There are differences and similarities between radioactive and chemical contaminants. For example, the aromatic hydrocarbon benzene (C_6H_6) is highly toxic to bone marrow. If benzene is oxidized in the environment or in the body, its toxicity disappears and new innocuous compounds are formed (CO_2 and H_2O), both of which are essential to living organisms. However, if the original benzene was formed from the radioactive isotopes ^{14}C and ^{3}H, both the CO_2 and H_2O would continue to be radioactive. Thus, changes in the chemical compounds in which radionuclides are incorporated cannot alter their basic radiotoxic properties, except as the particular compounds have different ecological or metabolic properties. Incorporation of radionuclides forming differing compounds with differing ecological or metabolic properties may in fact increase the potential of toxicity from the radionuclide involved. Organically bound forms of radionuclides such as zinc, occurring after plant uptake or food animal ingestion, have increased absorption when present in human diets. Furthermore, organic forms of radionuclides will have far greater movement in both the environment and human body since organic forms are capable of reaching organs not accessible to inorganics.

A quantitative understanding of the interrelated pathways by which the radionuclides are eventually ingested or inhaled by humans is required to assess the risk to humans from an existing or contemplated source of radioactive emissions to the environment. The reliability of the estimated quantitative models is of obvious importance to both the regulator and the regulated to determine performance of emission controls, to ensure compliance, and to avoid unnecessary expenditures due to overly large safety factors. Atmospheric diffusion models which have been developed over many years may now be used reliably in many instances to estimate radionuclide concentrations downwind from a point source emission. Unfortunately, few other environmental transport models have been validated in the field or evaluated through statistical studies. Although atmospheric diffusion is a relatively predictable process, transport through geological media, or convection, diffusion, and sorption processes encountered in the aquatic and terrestrial environments have proven to be more complicated with poorly predictable factors. For example, Table 3.2 gives a list of some of the factors that influence the radiation dose to humans as a result of contamination of a pasture by a radionuclide in rain.

Table 3.2
Partial List of Factors that Influence Dose to Humans From Deposition of a Radionuclide by Rainout over a Pasture[a]

1.	Rate of rainfall
2.	Size of raindrops
3.	Particle size distribution of radionuclide
4.	Percent of ground area covered by forage
5.	Percent of rainout retained initially by forage
6.	Rate of removal of fallout from forage by effects of weathering
7.	Soil-to-plant uptake factors via root absorption
8.	Quantity of radionuclide ingested by cow
9.	Fraction of each of the radionuclides that passes from the gut to blood (for cows and humans)
10.	Fraction of the radionuclide in blood that transfers to each organ (for cow and humans)
11.	Rates of metabolic elimination from each organ
12.	Concentration of the radionuclide in meat or milk
13.	Quantity of milk and meat consumed by humans
14.	Dose rate conversion factors following intake in humans

a. See PHC study by H.Boermans: Migration of Radionuclides through the Environment for reference to M.Eisenbud, 1987.

The values of some of these parameters cannot be specified within an order of magnitude (Kocher, 1983). Since the ultimate effect of many of these parameters on the dose assessment will be multiplicative, the uncertainties in the dose estimates may cover several orders of magnitude. Thus caution is necessary in regard to mathematical models in their present state of development. The type of radiation (x-ray, gamma, beta or alpha), its disintegration energy, biochemical properties and half-life also influence dose to humans.

b. Atmospheric Transport of Radionuclides

Most man-made atmospheric contaminants are injected into the "friction layer" which extends to about 1 km above ground level and which has properties somewhat different from the rest of the atmosphere because of influences of surface features on atmospheric flow. Nuclear energy, in particular the testing of nuclear weapons and potential nuclear explosions, extend the problem of forecasting the fate of atmospheric contaminants above the friction layer to altitudes of 30 km and the spread of radionuclides throughout the atmosphere on a global scale. Some of the known factors determining transport of radioactive contamination in the atmospheric environment are described below.

The lower region of the atmosphere (up to 11 km), the troposphere, is a comparatively unstable turbulent region containing about 75% of the atmospheric mass, and almost all the moisture and dust. Radionuclides are therefore well-mixed, diluted and interactive with components in this region. Above the troposphere is the stratosphere which has relatively smooth quiet air motions. Beginning at about 30 km is the mesosphere, characterized by an increasing temperature gradient, and an extremely thin atmosphere. Radionuclides that reach the stratosphere through stratospheric-tropospheric exchange or from a nuclear explosion are not subject to precipitation and unpredictable weather patterns. Contaminants entering the stratosphere in the tropical regions are heated, rise to altitudes of about 30 km and begin to move toward the poles (UNSCEAR, 1982). Since the top of the troposphere is lower in the polar areas, contaminants may enter and leave this region more easily. Discontinuities in the troposphere in the temperate areas cause vigourous vertical mixing which facilitates the transfer of radionuclides. Thus, the mean residence time of a stratospheric radionuclide depends on the altitude at which it is introduced, the time of year, and the latitude.

Radionuclides introduced into the atmosphere in the form of a gas vapour or aerosol are diluted by molecular and turbulent diffusion. The total range of values of the diffusivity coefficients controlling rates of dilution is enormous, from 0.2 cm^2/sec for molecular diffusion to 10^{11} cm^2/sec for the mixing due to large-scale storms (Gifford, 1968). The motions of turbulent diffusion are so complicated that exact mathematical theories are not available to describe the behaviour of radionuclides. However, statistical methods have made it possible to predict the diffusion of contaminants in the atmosphere under a *given* set of meterological conditions.

Vertical temperature gradients strongly influence the mixing characteristics of radionuclides in the atmosphere. In the troposphere the temperature normally decreases with height. This temperature gradient referred to as "adiabatic" is normally about 6.5°C/km. The stratosphere is isothermal (constant temperature) which is partially responsible for the smooth air motions in this region. During normal daytime conditions, the earth's surface absorbs solar radiation and becomes warmer than the overlying atmosphere. At night, the surface of the earth begins to cool more rapidly than its overlying atmosphere. During these diurnal temperature changes, the temperature of the overlying atmosphere increases or decreases respectively at a rate exceeding that which would occur if the air were permitted to expand adiabatically. Under these superadiabatic conditions, all vertical motions of air tend to be accelerated, and the atmosphere is unstable. Should cloud cover limit solar heating, the inversion may persist throughout the day. Changes in temperature greatly affect the characteristics of contaminants released to the atmosphere.

Radionuclides may be emitted to the atmosphere at an elevated temperature and with considerable velocity. The problem of combining the various meterological parameters together with the effluent temperature and velocity is a complicated one because of the way in which the various parameters interact. For example, while a temperature inversion suppresses vertical height, it reduces turbulence to such an extent that a more persistent temperature difference results in a slow rising of the plume and ultimately causes the maximum concentrations to reach many km from the source. Conversely, during unstable conditions with greatly enhanced vertical motion, plume "looping" may occur with maximum concentrations being very close to the source contaminating areas normally receiving low levels of radionuclides.

The uncertainties of the models used to predict downwind concentration from a continuous point source vary with the type of terrain, period of time over which observations are made and distance from the source, making it difficult to monitor and predict exposure. Three distinct zones exist around structures downwind of a contaminant release:

1. The displacement zone is the area where the contaminated air is deflected around the structure;
2. The cavity zone is the area immediately downwind of the structure in which high concentrations of radionuclides may be found; and
3. The wake is a turbulent zone beyond the cavity where mixing occurs.

Air movement in the vicinity of structures such as buildings may be so complex as to require wind tunnel tests to determine contaminant movements. Terrain features such as mountains and valleys may result in isolated areas of high or low concentration of contaminants especially if combined with an inversion. Variation in concentration of the contaminant due to buildings or terrain alter basic assumptions and greatly complicate the prediction of contamination. Site-specific diffusion coefficients must be determined if any degree of accuracy in predicting radionuclide contamination is required.

Atmospheric radionuclides eventually deposit on terrestrial, aquatic or human surfaces. Deposition may occur dry, due to impact or gravitational settling, or due to precipitation. Suspended radionuclides will fall at a rate determined by gravitational force and shape (irregular shapes fall at a slightly slower velocity). In the absence of a theoretical basis for estimating the deposition velocity many investigators provide measurements for a variety of surfaces (Sehmel, 1984). Unfortunately, reported deposition values are extremely variable due to different ground covers and leaf size, which makes their use questionable. When radionuclides are deposited due to falling rain it is termed "washout". At high altitudes dust particles may serve as a nucleus for condensation and form a raindrop, known as a "rainout". Although concentration of the contaminant is reduced downwind during the precipitation of radionuclides, the local affected area is exposed to far greater levels than expected. No useful guidelines to predict deposition as a function of the type and rate of rainfall are yet available (Slinn, 1984).

c. Terrestrial Transport of Radionuclides

Radionuclides contaminate soil, plants and animals in the terrestrial environment. The contamination reaches the human food chain through many complex mechanisms. Natural and artificial (man-made) radionuclides in soil are metabolically incorporated into plants. Environmental contamination results in root uptake and deposition on foliar surfaces. Consequently, humans ingest radionuclides directly, through consumption of contaminated foliage or indirectly, through products from animals that consume contaminated foliage. Some of the known factors determining pathways of radioactive contamination in the terrestrial environment are described below.

Radioactive substances contaminate plants by direct foliar deposition from the atmosphere or from trace substances present in soil by the mechanism of rain splash (Dreicer, 1984). Particles less than 100 µm can be deposited on plant surfaces to a height of 40 cm by impacting rain. The significance of surface contamination varies with the growing season and plant type. Danger from direct contamination of crops is greatest just before or during harvest, or when animals are actively grazing. Danger is lowest in winter months with no standing crops, although permanent pastures may be affected. Mechanical harvesting has been shown to be the major cause of contamination of soybeans and wheat grown in soils contaminated with plutonium (Adriano, 1982). Foliar contamination also depends on the structure of the plant and the use of plant parts relative to human and animal diets. Wheat was a major source of ^{90}Sr due to fallout capture by wheat heads. Surface foliar contamination can be removed by radioactive decay, volatilisation, leaching by rain, other weathering effects, loss of plants or washing prior to consumption. Although ^{90}Sr was found to have a half-life due to field loss of 14 days, this half-life was influenced by differences in physical and chemical properties of the different plants and radionuclides involved (Miller and Hoffman, 1982). The prediction of foliar contamination is a multifactorial problem requiring site-specific biological, physical and meterological knowledge.

Soils consist of minerals and organic matter, water, and air arranged in a complicated physiochemical system that provides support and nutrition for plants. The vertical profile through soils reveals horizontal layers which differ in their physical characteristics and which determine the movement of contaminants and the kind of vegetation the soil will support. The inorganic portion of soil consists of textural classes: sand (60 µm - 2mm), silt (2-60 µm) and clay (less than 2 μm). The abundance of negative surface charges present on small clay particles results in clay's ability to attract nutrients and radionuclides. Sandy soils tend to have low exchange capacity while silt stands at an intermediate level. Therefore the fraction of ions adsorbed by soil is usually inversely proportional to particle size. Organic matter can increase the binding capacity of sandy soils. The effect of this ion exchange capacity is that nutrients in soil-water are adsorbed on the surface of particles which prevents them from being leached and thus makes them available for plant nutrition.

Radionuclides coming in contact with soil behave similarly to nutrients since they adsorb to soil particles, complex with organic compounds or remain as an ion in solution. When contaminated water moves through geological media, sorption of radionuclides occurs at different rates. A distribution coefficient, K_d, has been determined for various radionuclides by the rates of sorption and desorption on the soil (NCRPM, 1984). This constant indicates the retention or rate of retardation of the radionuclide in specific soil types. Uptake of radionuclides by plants depends on their remaining within the root zone and on chemical availability for transport to root endings. Some radionuclides, similar to many elements, are bound so tightly to soil particles that they are not leached or are not available for plant uptake. Cations are more strongly absorbed than anions and the smaller multivalent ions usually exhibit larger K_d values meaning that they are more strongly adsorbed. The effects of these factors are shown in the following examples. ^{90}Sr and ^{137}Cs fallout from nuclear weapons testing is held tightly in the upper 10 cm of soil (Alexander et. al. 1960; Alexander, 1967). ^{129}I was estimated to reside in the top 30 cm and is less tightly bound and more readily available for plant uptake than ^{90}Sr and ^{137}Cs.

Radionuclides, like any other ion present in the soil, will probably be present in plants grown on that soil. Although many elements are required for normal plant metabolism, some such as iodine, cobalt, uranium, and radium are known to be present in plants, yet serve no metabolic function. The extent to which plants absorb radionuclides from soil depends on the following: i) form of the radionuclide; ii) distribution coefficient K_d; iii) metabolic requirements of the plant; and iv) physicochemical properties of the soil. Radioisotope elements, such as ^{45}Ca, required by plants become part of the soil pool and are absorbed in a manner similar to stable isotopes of calcium, independent of radioactive properties. Plants are unable to distinguish between chemical congeners and thus do not discriminate: calcium and strontium are absorbed similarly. Hansen (1964) found that ^{131}I and ^{90}Sr content of milk from cattle on well fertilized fields was 50% lower than from cattle on badly fertilized fields. By increasing the non-radioactive pool of nutrients and causing dilution by rapid plant growth, these workers were able to decrease foliar contamination. Although NCRP (1984) has published tables of recommended "default values" that can be used in dose assessment where no field studies are available, there are many complications. The recommended values also have huge ranges for some elements and field tests in the area of concern are suggested to more closely approximate uptake.

Plant type effects the uptake of radionuclides from soil. Elements pass to the root tips with the soil water, in which dissolved elements are in equilibrium with the adsorbed phase on soil particles. Roots of plants are located at soil depths characteristic of the plant species.

For example, spinach root is less than 30 cm in contrast to alfalfa and asparagus roots which penetrate to 3 m or more. Therefore, radionuclides adsorbed close to the surface (ie ^{90}Sr and ^{137}Cs) would be more readily absorbed by spinach than deep rooted crops such as asparagus or alfalfa. Root structure is also a factor in absorptive capacity. Large absorbing surfaces as illustrated by winter rye, where a single plant may have a surface root area of 638 m^2, will greatly facilitate radionuclide absorption (Wadleigh, 1957). Much remains to be learned about the mechanisms by which individual radionuclides pass from soil to the root and from the root to the edible portion of the plant. It is sometimes possible to predict the behaviour of a radioelement from knowledge of its chemical congener since, as noted earlier, plants do not discriminate. The mechanisms by which radionuclides pass from plants and soil through the body of animals and into the milk, meat and eggs of livestock is discussed elsewhere.

It should be noted that prediction of congener behaviour in animals is not always identical. For example, cattle are able to discriminate metabolically to some extent between Ca and its congener ^{90}Sr in the production of milk. The extent to which discrimination takes place has been determined experimentally using a predictor for the concentration of milk ^{90}Sr if herbage ^{90}Sr and Ca levels are known (Comar et al, 1956). Unfortunately, the predictor is not known for all radionuclides in all milk-producing species, including humans.

Other factors mobilizing long-lived radionuclides in the terrestrial environment include erosion processes in large watersheds. This mechanism for transport of radionuclides incorporated into soil requires extensive knowledge of soil erosion. In addition, erosion by wind action causes radionuclides that have settled on the surface to be resuspended and increases the likelihood of inhalation exposure. The importance of soil ingestion by grazing animals has been discussed elsewhere. However, for certain radionuclides with high K_d and poor plant uptake (Pu, Th, Am), soil ingestion may be the predominant route of intake (Zach and Mayoh, 1984). Research has shown that although generalizations concerning the relative degree of fixation of many radionuclides in soil are possible, the behaviour of the radionuclide is dependent on site-specific factors such as rainfall, drainage, and tillage.

d. Aquatic Transport of Radionuclides

Radionuclides enter the aquatic system through a number of routes. Discharge by condenser cooling systems of power stations adds radioactive contamination directly into water. Atmospheric radionuclides eventually deposit on soil or bodies of water. The main mechanism for removal of contaminants from soil involves transport by surface runoff or leaching into soil water that eventually seeps into streams. Surface waters are connected to subsurface aquifers, soil, and the atmosphere, so that radionuclides may enter deep ground aquifers and in time reach surface waters and eventually reach the atmosphere.

In oceans, mixing of radionuclides is rapid near the surface water to a depth of 200 m due to wind action and currents controlled by wind patterns carrying contaminated materials. The vertical gradients of temperature, salinity, and density are also near uniform in this area. Deep water is characterized by decreasing temperatures and increasing salinity and density. The intermediate zone lighter water where density changes are greatest restrict exchange between surface and deep waters. For example, fission products entering water in the Marshall islands moved 225 km in 40 days and to a depth of 30-60 m (Folsom and Vine, 1957). Vertical velocity in the Pacific and Atlantic oceans has been estimated to be 0.5 to 6 m/year at depths between 750 and 1,750 m which would results in radioactive solutions not reaching the surface in at least 1000 years (Pritchard, et al, 1971).

Mixing of radionuclides in estuaries, rivers and costal waters is of great importance since these waters serve as spawning grounds for many fish and a source of many other human foods. A general approach to the dispersion of radionuclides introduced into these bodies of water is not currently possible. The rate of mixing is dependent on the depth of water, type of bottom, shoreline configuration, tidal factors, wind, temperature, and the depth at which the pollutant is introduced. Each body of water has its own mixing characteristic. Useful dispersion equations are site-specific requiring site parameters and are at best extensive studies including scale models. Fresh water lakes require independent studies.

Over time, mixing of radionuclides is affected by the physical characteristics and biological processes of the aquatic environment. Radiocontaminants in solution can sorb on suspended organic and inorganic solids or be assimilated by plants and animals. The tendency of sediments to remove pollutants depends on both their capacity to sorb ions and the salinity of overlying water. Soil types in the aquatic environment control sorptive capacity in a similar manner described above for terrestrial soils. It is more difficult to predict dispersion of radionuclides with a large distribution coefficients, K_d, (favour sorption to a particulate phase) is more difficult than for those that remain in solution. Elements which are easily adsorbed on sediment are Cs, Mn, Fe Co, and the actinides, while elements that easily remain in solution are Sr, Cr, and Sb (Hair, 1974).

Radionuclides in suspended solids can settle to the bottom, be filtered by organisms, or attach to plant surfaces. Dissolved contaminants can be used as nutrients by all biota, especially phytoplankton, or can be lost due to volatility and decay. A portion of all radionuclides, however, reach the sediment through particle sedimentation or later in biota remains. Sediments often act as a "sink" for radionuclides as for many contaminants in our environment. Suspended solids, and dead biota settle to the bottom to become part of an organic-rich substrate that supports a community of living organisms. Microorganisms present in the sediment are capable of converting radionuclides into organically bound elements capable of biomagnification. Alternatively, this sink of pollutants may be temporary and act as a secondary source of radionuclides after being resuspended during turbulence and dredging.

Nutrients in water are absorbed and metabolized using solar energy by two aquatic food producing organisms: i) Rooted and large floating plants, and ii) minute floating plants called phytoplankton. Since higher plant forms live only in relatively shallow water and make up a small portion of total plant mass, the phytoplankton is responsible for converting the majority of aquatic nutrients into food for higher living organisms. Aquatic organisms sequester radionuclides to varying degrees depending on concentration of the contaminant, species of aquatic organism, type of element, availability of other nutrients particularly congeners, and chemical/physical characteristics of the water.

The ratio of the concentration of a radionuclide in an organism to the concentration in the water is known as the concentration factor (CF). Regulatory agencies have published and recommended CFs for many of the elements, although the justification for their use is debatable. CFs are affected by all the parameters described above resulting in a wide range of reported CFs for each radionuclide (Blaylock, 1982). For example, the high concentration of potassium in salt water results in the CF for ^{137}Cs in fresh water to be many orders of magnitude higher. The significance of the CF is also partly dependent on the part of the marine organism in which the radionuclide accumulates. Clams, oysters, crabs, and scallops store ^{90}Sr in their shells which are not consumed by many higher organisms including humans. In contrast, ^{65}Zn and ^{60}Co are concentrated in the muscle or edible portion of marine biota, and thus the CFs based on whole body analysis underestimate the danger of consumption.

The biotic cycle of radionuclides in water begins with phytoplankton intake of dissolved radiocontaminants. Intake may be passive or active; as previously described, congeners may be taken in place of the true nutrient element. Phytoplankton serves as food for zooplankton, filter-feeding fish and bottom-dwelling animals which in turn serve as nourishment for several higher trophic levels. Biomagnification may occur at all stages as one moves up the aquatic food chain, sometimes ending with human intake. The cycle is completed by decomposition of dead plants and animals and the excrement of aquatic animals which releases the radionuclide and makes it available again for phytoplankton and other biota.

3.3 Concepts, Quantities and Units in Radiation Risk Assessments

This section was prepared by J. Heller and K. McNeill and reviewed by R. Bertell.

When energy travels through space, it is referred to as radiation. This radiated energy may be absorbed as it passes through matter. References to ionizing radiation imply that the absorbed energy will result in the removal of electrons from the atoms of the absorbing medium, producing ions. Ionizing radiation is produced naturally from the disintegration of radioactive nuclides found in the earth's crust. It is also produced in devices such as nuclear reactors. Material capable of spontaneous disintegration releasing ionizing rays or particles is said to be radioactive.

The phenomenon of radioactivity is measured in terms of its activity and radiation dose. The activity of a radioactive material is the number of nuclear disintegrations per unit time. One disintegration per second is termed a *becquerel*. An older unit is the *curie*, which is 37 billion (3.7×10^{10}) disintegrations per second, and was coined originally in reference to the approximate activity of 1 gram of radium-226. A nuclear disintegration can release gamma rays (e.g. cesium 137 or iodine 131), alpha particles (e.g. plutonium or uranium) or beta particles (e.g. tritium or strontium 90).

Radiation dose can refer to absorbed dose, dose equivalent, effective dose equivalent, committed dose, or collective dose, all of which are defined as follows. The *absorbed dose* of radiation is the energy imparted per unit mass of the irradiated material. The older unit of absorbed dose, the *rad*, equals 0.01 joules/kg. The present unit is the *Gray* (Gy) and 1 Gy = 1 joule/kg = 100 rad.

Since different types of radiation have different Relative Biological Effectiveness (RBE) or potential for causing radiation damage, the term RBE has been developed to convert a level of absorbed dose from a given type of radiation into the equivalent dose from a reference type of radiation (usually x or gamma radiation) necessary to cause the same effect. The older unit of 'weighted' absorbed dose, or *dose equivalent*, is the *rem* and is the quantity resulting from multiplying a quality factor (or Q) by the absorbed dose in rads. Q refers to the capacity of each type of radiation to produce ionization in matter (as expressed by the linear energy transfer or LET which is the amount of deposited energy per length of the radiation track in material). The suggested values for Q are: for x rays, gamma and beta radiation, Q = 1; for fast neutrons, alpha and heavy particles, Q = 20. Since 1982, the new unit for dose equivalent has been the *Sievert* (Sv) which equals 100 rem.

Early in its work (1962), the UNSCEAR Committee ('United Nations Scientific Committee on the Effects of Atomic Radiation') introduced the concept of *committed dose* to measure the contamination from long-lived radionuclides to individuals and populations resulting from one year of practice (the Committee's term for the fallout from the continuing nuclear test explosions of that era). Later on, the definition of committed dose was extended to cover the sum of all doses delivered to the world populations over all future time from a specified practice. By 1977, the UNSCEAR Committee had introduced another concept, the *collective dose*, to refer to the product of the number of exposed persons and their average radiation dose. The value of the notion of collective dose depended on the assumption of proportionality (or linearity) between dose increments and resulting increments in the risk of harm. The collective dose commitment would therefore be the total collective dose expected from a given practice over all future time.

In 1977, the International Commission for Radiological Protection (ICRP) recommended the use of a weighted sum of radiation dose equivalents, called the *effective dose equivalent*, as the basis for radiation protection assessments for exposures of different organs and tissues. The unit of measurement was to be the same as for the dose equivalent, i.e. the sievert, and was to be determined by the addition of dose equivalents to exposed organs using organ weighting factors recommended by ICRP; these factors were based on risk assessments of fatal cancers.

The question of dose assessments is complicated further. We quote from the 1988 UNSCEAR report:

> The effective dose equivalent was originally intended to reflect the relative organ risks for an average member of a working population. It gave the same weight to a severe hereditary defect in the exposed individual's first two generations of offspring as to the occurrence of a lethal cancer in that individual. It gave zero weight to curable

> cancer. The concept was appropriate considering the intended use of the quantity. The same quantity has since found widespread use in the asssessment of collective doses to members of the public. Here, where its failure to account for the difference between the age distribution of workers and that of the public at large and its non-inclusion of curable cancer and hereditary harm in generations beyond the second are known deficiencies, the use of the effective dose equivalent may be questionable. Various corrections to compensate for these limitations have been suggested, but for the purposes of radiation protection, and considering all other uncertainties, the extensions of the use of the effective dose equivalent have mostly been accepted.
>
> In looking for ways of presenting radiation doses from various sources and practices, UNSCEAR ... has not been able to find an alternative way of expressing radiation exposures by a single number.
>
> In the definition of the effective dose equivalent there is an addition of cancer risk and risk of hereditary harm. The risk coefficients for cancer and hereditary harm, as applied to the effective dose equivalent, are clearly identifiable only if all organs receive one and the same dose. In cases where they do not, the effective dose equivalent gives a basis for estimating the total risk but gives no indication of the relative proportions of the cancer risk and the genetic risk. ... To simplify the presentation of doses and dose comparisons, [UNSCEAR] has had to resort to more and more complicated terms, and there is, unfortunately, no easy way out of this dilemma. (Excerpted from paragraphs 38-41 (p.10) UNSCEAR, 1988.)

In this submission, the PHC will follow reporting practices employed by the BEIR (Biological Effects of Ionizing Radiation), ICRP and UNSCEAR international bodies (UNSCEAR, 1988; NAS-NRC/BEIR V, 1990; ICRP, 1991) when referring to individual radiation dose from the nuclear fuel cycle resulting from the operation of Ontario nuclear generating stations.

The 1988 UNSCEAR report notes that natural radiation is by far the largest contributor to the collective dose received by the world population. Natural sources can be classified into: (a) external sources of cosmic radiation and of terrestrial radiation (present in the earth's crust, in building materials and air); and (b) internal sources from naturally occurring radionuclides inhaled or ingested by the human body. Table 3.3 shows the relative contributions of annual effective radiation dose equivalent from all natural sources. Note in particular that doses from the indoor inhalation of radon and thoron decay products are estimated to account for almost 50% of the mean annual effective dose equivalent of 2.4 mSv which is received by the adult part of the population. If uranium, one natural source, is mined, then it and its decay products radon become more bioavailable. In Table 3.3 therefore, one should note that the doses shown from the U and Th series refer to the materials in their undisturbed (unmined) state. It also must be appreciated that these figures are rough averages of widely varying values. For instance, the UNSCEAR 1988 report (Table 4, p.97) shows ranges of typically 5 times to more than one order of magnitude differences in different parts of any one country with respect to terrestrial radiation sources. Radon decay products, giving internal dose, show even larger local variation. Note that radon exposure can be reduced by proper ventilation.

Table 3.3
UNSCEAR Committee's Estimates of Annual Effective Dose Equivalent from Natural Sources[a]

SOURCE OF IRRADIATION	ANNUAL EFFECTIVE DOSE EQUIVALENT (mSv)		
	EXTERNAL	INTERNAL	TOTAL
Cosmic rays			
Directly ionizing component	0.30	-	0.30
Neutron component	0.055	-	0.055
Cosmogenic radionuclides	-	0.015	0.015
Primordial radionuclides:			
Potassium-40	0.15	0.18	0.33
Rubidium-87	-	0.006	0.006
Uranium-238 series			1.34
Uranium-238 to uranium-234		0.005	
Thorium-230		0.007	
Radium-226	0.10	0.007	
Radon-222 to polonium-214		1.10	
Lead-210 to polonium-210		0.12	
Thorium-232 series:			0.34
Thorium-232		0.003	
Radium-228 to radium-224	0.16	0.013	
Radon-220 to thallium-208		0.16	
TOTAL	0.80	1.60	2.4

Note: a. UNSCEAR, 1988; Table 4, p.24.

The assessment of exposure from the nuclear fuel cycle requires consideration of the contributions from each of the following steps: mining of uranium ores; milling and processing of uranium ores; fabrication of fuel elements; production of energy in the reactors; transportation of nuclear materials between fuel cycle installations; and the disposal of radioactive wastes during and after reactor decommissioning. At each step in this cycle, some radioactive discharges to the environment take place. Most of these releases will be of local and regional concern, because the radionuclides have short half-lives and are limited in their environmental mobility. However, some nuclides, because of their long half-lives or rapid transfer through the environment, may contribute to the irradiation of people on a global scale.

The UNSCEAR Committee identifies four populations at risk from radionuclide emissions: workers in nuclear installations; populations living within 100 km of a plant (called local); populations living within a few thousand kilometres (called regional); and the world population. The UNSCEAR Committee does not consider it practicable to monitor radionuclide uptake in the public, and instead recommends monitoring the migration of radionuclides through the environment through the monitoring of foodstuffs and water as well as from experimental and modelling studies.

3.4 Estimates of Radionuclide Emissions, Effluents and Waste from the Nuclear Fuel Cycle in Ontario

Radioactive waste, resulting from the operation of nuclear reactors, is classified by quantity related to each unit of electrical energy production; and by the concentration of the various radioisotopes present in the waste materials. Thus, waste is classified as low-level [LLW], intermediate-level [ILW] or high-level waste [HLW].

For the 1993 nuclear generation profile shown in Table 3.1, the PHC has employed Hydro data to derive annual resource requirements, (i.e. uranium fuel, nuclear reactor water coolant and mining water), shown in Table 3.4; and the consequent emissions, effluent and waste production, shown in Table 3.5. Note that omissions in Hydro's DSP of atmospheric and aquatic effluent figures do not permit a straightforward completion of these tables. In subsequent sections, the PHC will use this data to develop radionuclide emission estimates for various steps in the uranium fuel cycle.

Table 3.4
Ontario Hydro Nuclear Generation Resource Requirements

1. **Uranium Fuel** per year [TWh x 19 = Mg]:

Pickering A	290 Mg (or tonnes)
Bruce A	293 Mg
Pickering B	287 Mg
Bruce B	470 Mg
Darlington	492 Mg
	1,832 Mg (or tonnes)

2. **Cooling Water** per year [TWh x $1.8x10^8$= m^3]:

Pickering A	$27.5x10^8$ m3
Bruce A	$27.8x10^8$ m3
Pickering B	$27.2x10^8$ m3
Bruce B	$44.5x10^8$ m3
Darlington	$46.6x10^8$ m3
	$173.6x10^8$ m3 or $4.75x10^{10}$ litres/day

3. **Mining Water** per year [TWh x 2779.5 = m^3]:

Pickering A	4.24×10^4 m^3
Bruce A	4.29×10^4 m^3
Pickering B	4.20×10^4 m^3
Bruce B	6.87×10^4 m^3
Darlington	7.19×10^4 m^3
	26.79×10^4 m^3 or $73.3x10^4$ litres/day

4. **Mining Land Use**[a]

[[TWh x 6.81 (mine area)] + [TWh x 1.197 (tailings)] = Hectares (Ha)]:

Pickering A	122 Ha
Bruce A	123 Ha
Pickering B	121 Ha
Bruce B	198 Ha
Darlington	207 Ha
	771 Ha

a. PHC experts R. Bertell and K. McNeill questioned the correctness of the Hydro formula for mining land use.

5. **Generation Related Land Use** - Hydro assumes that any new site requires 1000 ha land area. (Hydro Demand Supply Environmental Analysis, p.A1)

Table 3.5
Ontario Hydro Nuclear Emissions, Effluents and Wastes

1. **Atmospheric Emissions of Radionuclides**:

Not quantified by Hydro

2. **Aquatic Thermal Discharge** per year
[TWh x 2.12 x 3600] Terajoules (Tj):

Pickering A	1.16×10^5 Tj
Bruce A	1.18×10^5 Tj
Pickering B	1.15×10^5 Tj
Bruce B	1.89×10^5 Tj
Darlington	1.98×10^5 Tj
	7.36×10^5 Tj

3. **Aquatic Dicscharge of Radionuclides**:

Not quantified by Hydro

4. **Uranium Mining Effluence** per year [TWhx 2779.5 = Mg]:

Pickering A	4.24×10^4 Mg
Bruce A	4.29×10^4 Mg
Pickering B	4.20×10^4 Mg
Bruce B	6.87×10^4 Mg
Darlington	7.19×10^4 Mg
	26.79×10^4 Mg

5. **Used Nuclear Fuel Waste** per year [TWh x 19 = Mg]:

Pickering A	290 Mg
Bruce A	293 Mg
Pickering B	287 Mg
Bruce B	470 Mg
Darlington	492 Mg
	1,832 Mg (or tonnes)

6. **Low Level Radioactive Waste** per year [TWh x 7.6 = Mg]:

Pickering A	116 Mg
Bruce A	117 Mg
Pickering B	115 Mg
Bruce B	188 Mg
Darlington	197 Mg
	733 Mg (or tonnes)

7. **Uranium Mine Tailings' Waste** per year [TWh x11,970 = Mg]:

Pickering A	1.83×10^5 Mg
Bruce A	1.85×10^5 Mg
Pickering B	1.81×10^5 Mg
Bruce B	2.96×10^5 Mg
Darlington	3.10×10^5 Mg
	11.55×10^5 Mg (or tonnes)

Reporting radioactive waste by weight gives no information about the level of risk and persistence of the hazard. A more appropriate way to assess hazard to human health from radioactive waste would be to base it on the number of Becquerels (disintegration per second) for each of the specific radioactive isotopes found in the waste.

The PHC used the UNSCEAR Committee's assembled data during the six year period 1980-1985 on radioactive emissions from various nuclear installations around the world which employ technologies similar to those in use by Hydro and its provider companies to estimate radiation related health effects in this chapter.

Table 3.6 displays a range of estimates for various radionuclide emissions (normalized to refer to GWa of nuclear generated electricity) resulting from different steps in the entire uranium fuel cycle. The table provides ranges of normalized emission estimates for all portions of the cycle up to and including the operation of Hydro nuclear stations, but omits consideration of emissions from transport and storage of spent fuels, waste management, the decommissioning of stations and incidents or accidents with abnormal releases.

The PHC expert paper by R. Bertell (July 1992) analyzes the reactor emissions for each of the five Ontario sites. There are considerable variations in radionuclide emissions. For example, between 1979 and 1988, Bruce A reactors emitted an average of 1,237 TBq/GWa tritium to air while, in the same time period, Pickering A emitted an average of 374 TBq/GWa. Generally speaking, Bruce A reactors have the poorest emission record. Pickering A reactors also appear more polluting than some of the more recent reactors. The Hydro estimates of health effects were based on Darlington-type reactors, not the currently operating Ontario models.

A further unknown area is the quantity of tritium emissions which will result from the full scale operation of Darlington's Tritium Removal Facility [TRF]. Currently, the PHC is led to understand that the TRF is accepting only limited quantities of used heavy water from Pickering NGSs, none from the Bruce NGPD (and Darlington NGS is not yet operating at full capacity). PHC estimates used in Table 3.6 are based on an Atomic Energy Control Board report of radioactive releases from Canadian NGSs in 1990 [AECB INFO-0210(E)Rev-3]. That AECB report also provides DEL [Derived Emission Limit] standards for both tritium oxide (210,000 TBq) and tritium gas (140,000,000 TBq) emissions for the TRF facility. Hydro strives to maintain a standard of performance for its emissions at or below 1% of the DELs for each fission product at each nuclear station.

Note that these DELs were based on pre-1990 ICRP maximum permissible dose levels. Table 3.6 combines Hydro reported emissions' data along with information appearing in the 1988 UNSCEAR report which was sent to that Committee by the AECB (see table footnotes). UNSCEAR upper and lower bounds on specific emissions are drawn directly from its report. For nuclear station operations, UNSCEAR bounds are based on averages normalized to $(GWa)^{-1}$ (for CANDU heavy water reactors [HWRs] located in Canada and Argentina) $\pm$ one standard deviation. PHC ranges are then based on the lowest and highest values appearing in the Hydro and UNSCEAR information. For emissions from mining, milling and fuel fabrication processes, UNSCEAR estimates were adopted. In all cases, data was normalized using Hydro data and assumptions for annual ore requirements (from Tables 3.4 and 3.5) and GWa of nuclear powered electrical energy (from Table 3.1).

Table 3.6
Estimated Radionuclide Emissions over the Uranium Fuel Cycle
From 1 GWa of Hydro Nuclear Power Production

STEPS IN THE NUCLEAR FUEL CYCLE	REPORTED RADIONUCLIDE EMISSIONS (PER GWa)			
	UNITS	Hydro[a]	UNSCEAR[b]	PUBL.HLTH.COAL'N.[c]
URANIUM MINING AND MILLING:				
Radium effluent	GBq	-	0.1-1.0	0.1-1.0
Airborne radon (from mines)	TBq	-	1.4-3.0	1.4-3.0
Mine and mill tailings	TBq	-	0.06-2.4	0.06-2.4
Uranium-238	GBq	-	0.2-1.0	0.2-1.0
Thorium-230	GBq	-	0.05-0.5	0.05-0.5
Radium-226	GBq	-	0.05-0.5	0.05-0.5
Lead-210	GBq	-	0.05-0.5	0.05-0.5
Radon-222 from mills	TBq	-	0.12-0.8	0.12-0.8
FUEL FABRICATION:				
Uranium to water	GBq	-	1.1	1.1
Uranium to air	GBq	-	0.002	0.002
REACTOR EMISSIONS TO WATER:				
Tritium	TBq	477	222-358	222-477
Gross beta	GBq	9.1	17-34	9.1-34
REACTOR EMISSIONS TO AIR:				
Tritium	TBq	278	480-860	278-860
Noble gas	TBq	191	164-260	164-260
Iodine-131	GBq	0.052	0.15-0.31	0.05-0.31
Particulates	GBq	0.122	0.024-0.056	0.024-0.122
Carbon-14	TBq	11.0-19.4[d]	2-9	2.0-19.4
TRITIUM REMOVAL FACILITY [TRF]:				
Tritium oxide	TBq	20.5	-	20.5
Elemental tritium	TBq	530	-	530
SPENT FUEL ELEMENTS DISPOSAL AND SAFE STORAGE/DECOMMISSIONING OF PLANTS/ETC.: These aspects of the fuel cycle are not considered in these calculations.				

Notes: a. Ontario Hydro emission data are derived from its Annual Summary and Assessment of Environmental Radiological Data for 1991 (Report No.HSD-HP-92-9), Tables 2A and 2B, p.4-5. For all reported emission categories excepting tritium oxide, emissions for BNPD and Pickering are normalized using 1991 energy production levels to the level of 1 GWa. Carbon-14 emissions to air from reactor operations are not routinely reported by Hydro; and the data shown are drawn from the Hydro Social Cost Studies report of October, 1989 (Table 2.4-1) and normalized to a denominator of GWa. Neither tritium gas nor oxide effluent levels are shown separately for the TRF facility at the Darlington site in Hydro's annual emissions' report. Furthermore, current emission levels do not serve as useful guides for estimating future emission levels. At some point in the future, the TRF will be reducing used heavy water from all Hydro NGSs. For these reasons, the PHC has chosen to use estimates based on a 1990 report for TRF emissions [AECB: "Radioactive Release Data from Canadian Nuclear Generating Stations 1972-1988"; January, 1990; INFO-0210 (E) Rev.3] and showing 226 TBq of tritium oxide and 5830 TBq of elemental tritium. These represent less than 0.1% and 0.01% of the respective DELs. Elemental tritium gas is expected to drift to the upper atmosphere where it is relatively stable chemically. It is not expected to pose a local public health problem. However, because it has a 12 year half-life it may eventually interact chemically in the upper atmosphere adding to the globally available tritium oxide derivatives. The 1990 estimates were then normalized (by dividing by the annual nuclear electricity production level of 11 GWa).

b. All data are drawn from UNSCEAR, 1988 report (Annex B). Since UNSCEAR reported Canadian data for the period 1980-1985, figures were normalized to $(GWa)^{-1}$ where necessary by assuming electricity production levels for Bruce A and Pickering A NGSs during this time. The following UNSCEAR Annex B material was used: Radium mine and mill effluent (Para.30, p.140); Radon gas from Elliot Lake mines (Table 4, p.164; and assuming that 10% of production goes to Hydro); Mine and mill exhalations from tailings (assuming 200 kilotonnes of ore per GWa; 5 gm/cc of ore density; leading to 1 ha of tailings with a depth of 4 m.; and at 0.2-7.6 Bq m^{-2} s^{-1} from Para.27, p.139, for Elliot Lake exhalations, this yields 0.06-2.4 TBq); Airborne emissions from mill processing (Para.24 and 25, p.139; and Table 5 figures, p.164, halved to 0.1% Elliot Lake ore grade); Liquid and atmospheric discharges from Port Hope, Toronto and Peterborough fuel fabrication plants (Table 12, p.168). The UNSCEAR report also provides additional information on radiation emissions from CANDU heavy water reactors [HWRs] located in Canada and Argentina. This data is dominated by Canadian information (except for Carbon-14) which accounts for over 90% of the HWR nuclear capacity for these two countries. The reactor effluent data ranges are based on UNSCEAR averages $\pm$ one standard deviation:

1. For tritium discharged in airborne effluents from HWRs, the average normalized activity for the period 1980-84 was 670$\pm$190 TBq/GWa.
2. For tritium discharged in liquid effluents from HWRs, the average normalized activity for the period 1980-1984 was 290$\pm$68 TBq/GWa.
3. For liquid releases excluding tritium from HWRs, the average normalized activity for the period 1980-1984 was 25.7$\pm$8.7 GBq/GWa.
4. For particulates discharged in airborne effluents from HWRs, the average normalized activity for the period 1980-1984 was 0.040$\pm$0.016 GBq/GWa.
5. For iodine-131 discharged in airborne effluents from HWRs, the average normalized activity for the period 1980-1984 was 0.23$\pm$0.08 GBq/GWa.
6. For noble gases discharged in airborne effluents from HWRs, the average normalized activity for the period 1980-1984 was 212$\pm$48 TBq/GWa.
7. For carbon-14 discharged from HWRs, the average normalized activity for the period 1980-1984 was 6,336$\pm$3,333 GBq/GWa.

c. PHC estimates are based on the lowest and highest values from the previous Hydro and UNSCEAR columnar data.

d. Carbon-14 emissions are projected from Pickering A data for 1985-88, the only reported data (Hydro Social Cost Studies; October, 1989; Table 2.4-1). Emissions are presumed to have been released from all reactors.

Because of the previously mentioned omissions from Table 3.6, health effects' estimates derived from these data should underestimate the overall health risks over the nuclear fuel cycle resulting from normal operation of Hydro nuclear reactors during the planning horizon 1993-2014.

There are important differences between Hydro Exhibit #507, submitted to the Board, and UNSCEAR Committee data in the recorded emissions of iodine-131 (usually an unmeasured amount of iodine-129 with a half life of 1.6×10^7 years is also released) and in the omission of carbon-14 (with a half life of 5,700 years). There is also concern over the longer lived radioactive iodine isotopes and those noble gases with energy in the keV range (e.g. krypton-85) which are the main sources of radiation exposure for the general public. These have not been routinely measured in reactor effluence by Hydro. (See paper by K.Z. Morgan.)

To summarize PHC concerns about long-lived radionuclides, there are problems concerning the lack of reporting of carbon-14 and iodine-129 emissions from reactors, as well as radon emanations from mining and mine tailings (thorium-230, with a half life of 8×10^4 years, is the effective parent) and long-lived actinides leaking from high-level waste repositories. The PHC believes that the omission of these radionuclides will tend to bias downwards health effect estimates and will contribute to underestimates of associated health costs.

3.5 Estimates of Radiation Induced Fatal Cancers

In order to predict the number of fatal cancers in a population one needs to know the average dose to the population and the number of people exposed. The product of these two numbers gives the collective dose, usually expressed as Person Sieverts (Person Sv). The problems connected with estimating average dose have been discussed earlier. Determining the size of the exposed population also poses problems since some radionuclides affect mainly the local area (strontium and cesium for example), some affect the Northern Hemisphere (radon gas) and some affect the global population (krypton 85 and carbon 14).

Once an estimate (or range of estimates) is obtained for Person Sievert dose to specific populations (such as nuclear workers or persons living in the vicinity of a uranium industry, nuclear generator or nuclear waste facility), one applies a risk estimate in terms of cancer deaths per 100 Person Sieverts to complete the determination of cancer fatalities. In summary:

(Person Sv Dose/100) x (Ca deaths per 100 Person-Sv Dose) = Ca deaths

The risk estimate expressing cancer deaths per 100 person Sieverts is derived from a major database where both exposure dose and cancer deaths are known as well as possible. Radiation protection standards are also based on such risk estimates and are designed to limit the overall risk of radiation exposure including the number of deaths.

The currently enforced maximum permissible radiation doses to the public in Canada are those recommended by the ICRP in 1957. They are now being made more stringent.

In April, 1986, the AECB sent consultive document C-83 entitled "Proposed General Amendments to the Atomic Energy Control Regulations," for public comment. This was the proposed Canadian implementation of ICRP 26 (1977) which included the ALARA principle (keeping radiation exposure as low as reasonably achievable), and the concepts of effective and aggregate dose. On July 15, 1991, prior to the completion of the above legislative process, referred to as General Amendments to the Atomic Control Regulations, the AECB issued Consultive Document C-122, "proposing new dose limits, to announce at the earliest stage its intent to revise further the AECB Regulations, to reflect the new risk estimates developed by the ICRP 60 (1990)." On page 3 of this document the AECB states the implications of this proposed regulation C-122:

> There are two main implications of this new limit. The first involves the need to revise the definition of an atomic radiation worker which has been dealt with in subsection 2.1.1. The second is for operating levels for emissions from nuclear facilities, which will have to be reassessed by licensees by applying the ALARA principle, using the detriment associated with the new risk factors. Operating levels should be determined on a case by case basis for each facility, and should be given in a quantitative form such as a release rate or external dose rate and not as a percentage of a limit derived from the dose limit. Section 2.2.1 C-122.

The Japanese atomic bomb data has been the database used in support of international and Canadian radiation protection standards. By 1965, an epidemiological cohort of the exposed Japanese population had been assembled (known as the T65DR dataset) with individual radiation doses. The atomic bomb life span study (LSS) sample consisted of 120,218 persons of whom 91,228 (75.9%) were exposed, another 26,517 (22.1%) were "not in the city" at the time of the explosion, and 2,383 (2.0%) for whom the T65DR could not be estimated. A new assignment of lower doses to LSS participants in 1986 (known as the DS86 data base) replaced the T65DR data. The atomic bomb survivors for whom DS86 doses are assigned are called the DS86 subcohort. That subcohort consists of: 75,991 survivors (100%) of whom 18,500 (24.3%) had directly computed doses and 57,491 (75.7%) had estimated doses based on the directly computed doses.

Atomic bomb analyses are now based on those DS86 cohort deaths which occurred between 1 October, 1950 and 31 December, 1985. The PHC notes that for leukemia, but probably not for the solid tumours, there is evidence of substantial excess mortality prior to 1950 (RERF TR 9-87). This means that leukemia risk coefficients are probably underestimates. Mortality from all causes in the DS86 subcohort (1950-1985) is 28,737 (37.8% of the population). Of these deaths the breakdown by cause was: 202 leukemias (0.7%); 5,734 cancers except leukemia (20.0%); 22,801 non-cancers (79.3%); totalling 28,737 deaths.

The change in dose assignment to the Atomic Bomb survivors prompted the 1990 ICRP change in risk estimates and recommended radiation protection standards.

The dispute over doses to the atomic bomb survivors is not yet over. In October, 1992, they were again challenged by Dr. Tore Straume at Lawrence Livermore National Laboratory because of the failure of the DS86 dose assessment to distinguish between "fast" and "slow" neutrons. If true, this would lower risk estimates again. PHC expert K.Z. Morgan has alerted the PHC that mistaken assumptions on humidity, i.e. that the Nevada desert was similar to Japan, will again bring about an increase in risk estimates. Water in air tends to absorb neutrons.

Dale L. Preston, director of atomic bomb research in Japan, together with Donald Pierce, published new cancer mortality risks in 1987. In his report, Preston notes possible non-linearity between dose and response both at the high doses (above 4 Gray) and low doses.

He states with respect to carcinogenic response to low LET irradiation at low doses: "Very little can be inferred from this data." Preston also mentions "the extent of systematic overestimation of doses in the higher range" and calls for a re-examination of this point. Preston states: "there are certainly quite substantial random errors in dose estimates, and the fact that an individual **survived** is important information to be combined with the conventional estimates, which take no account of this" (emphasis in the original, RERF TR9-87). This important point has been referred to frequently in the work of PHC expert Dr. Alice Stewart. Clearly, there are still serious uncertainties.

A smaller uncertainty is caused by not knowing what RBE (or Q) is used for the neutron component of the dose. Results based on Preston's report using a linear estimate of the dose-effect relationship are given in Table 3.8 as cancer deaths per 100 Person-Sv. This is equivalent in the linear picture to 10,000 persons, each receiving 10 mSv. There is, however, a widely held belief, based on the known non-linearity of dose-survival curves for cells, for instance, and on the known healing of damaged DNA, that in humans also the effect per dose will be less under the low dose, low dose rate situations met with in health physics practice than under the high dose, high dose rate situation given by bombs. A Dose, Dose Rate Effect Factor [DREF or DDREF] has therefore been introduced by ICRP and others. Table 3.7 provides both the "Linear Estimate" conclusions and the range suggested by the use of such factors.

Table 3.7
Cancer Deaths per 100 Person Sieverts Excluding Leukemia
Based on Japanese A-Bomb Survivor Data (DS86 Subcohort)

RELATIVE BIOLOGICAL EFFECTIVENESS[a]	LINEAR ESTIMATE[b]	RANGE SUGGESTED BY UNSCEAR FACTORS FOR LOW DOSE[c]
5	16.7	5.6-11.1
10	16.2	5.4-10.8
20	15.2	5.1-10.1

Notes:
a. Relative Biological Effectiveness used for neutrons (see Sect.3.3).
b. Linear Dose Response for atomic bomb data.
c. Dose Response Effectiveness Factor [DREF] between 1.5 and 3.

Table 3.7 suggests that direct linear extrapolation of dose response from atomic bomb data (age and sex averaged) produces an estimate of approximately 16 cancer deaths per 100 Person-Sv excluding leukaemias.

There are different fatal cancer risk estimates for possible use in radiation risk assessment. The PHC has organized these into three tables:

- Table 3.8 sets out risk estimates given by national and international regulatory or recommending bodies;
- Table 3.9 sets out risk estimates given by the atomic bomb researchers and by independent analyses of atomic bomb published data;

- Table 3.10 sets out risk estimates given by researchers directly analyzing large databases of nuclear workers.

The PHC notes a narrowing of the differences between risk estimates based on atomic bomb survivors and those based on nuclear workers. Hydro uses fatal cancer risk estimates of 4 per 100 Person-Sv for the public based on ICRP 1990 (Hydro Exhibit 507). These estimates reflect low dose and slow dose rate reduction factors (DREF and DDREF) applied to atomic bomb risk estimates by recommending bodies on theoretical grounds.

Table 3.8
Excess Lifetime Mortality from all Cancers, Attributable to 1 Gy Acute Uniform Whole-body Low-let Irradiation of the General Pop'n.[a]

SOURCE OF ESTIMATE[b]	PROBABILITY OF DEATH (%)	
	ADDITIVE RISK MODEL	MULTIPLICATIVE RISK MODEL
BEIR I, 1972	1.2	6.2
UNSCEAR, 1977	2.5	-
BEIR III, 1980	0.8-2.5	2.3-5.0
NUREG, 1985[c]	2.9	5.2
UNSCEAR, 1988	4.0-5.0	7.0-11.0
BEIR V, 1990	-	8.85
ONTARIO HYDRO, 1992[d]	4.0 for workers 5.0 for public	

Notes: a. Taken from Table B-10, Annex B of the 1990 Recommendations of the International Commission on Radiological Protection. The referent population is that of Japan.

b. The first four estimates are based on unrevised dosimetry for Japanese A-bomb survivors; the next two (UNSCEAR, 1988; and BEIR V, 1990) are based on the revised dosimetry.

c. NUREG, 1985 refers to a major risk evaluation sponsored by the Nuclear Regulatory Commission in 1985.

d. Hydro risk coefficients are based on ICRP, 1991 recommendations.

The additive risk model, sometimes called the absolute risk model, assumes that a unit dose of ionizing radiation will be associated with a fixed number of fatal cancers regardless of the population and its historical cancer rates. The multiplicative model, sometimes called the relative risk model, assumes that ionizing radiation exposure will increase fatal cancer rate by a multiplier of the current fatal cancer rate in the population. The multiplier is called the relative risk. For example, if a population has a lifetime expected fatal cancer rate of 20 per

100 and then experiences an increase in rate to 25 per 100 after exposure to some carcinogen, we can interpret the increase in two ways:
1. The carcinogen at this level of exposure induces or adds five extra fatal cancers regardless of current fatal cancer rate in the population (additive model); or
2. The carcinogen at this level of exposure increased the fatal cancer rate by 25% (the multiplicative model).

The distinction is important when applying the findings from one population (Japanese) to another (Canadian). BEIR V (1989) and ICRP (1991) recommend use of the multiplicative model. (See BEIR V: "the Committee believes that the constant absolute or additive risk model is no longer tenable" (p.5).)

Two estimates of fatal cancer risk have been provided by Dr. Preston and his colleagues who undertook the reanalysis of the atomic bomb data with the DS86 doses at the Hiroshima Radiation Effects Research Foundation. Dr. J. Gofman and Dr. R. Nussbaum provide independent analyses of a-bomb data. PHC expert A. Stewart has also included in her testimony a critique of atomic bomb data and an analysis of its compatibility or incompatibility with other major peer reviewed/published risk studies.

Table 3.9
Excess Lifetime Mortality from all Cancers Attributable to 100 Person-Sv Exposure to Whole Body Irradiation of the General Pop'n.

SOURCE	CA DEATHS PER 100 PERSON SIEVERT
John Gofman[a]	26
R. Nussbaum[b]	24 [10 to 38]
Preston, D.L.[c]	17
Preston, D.L.[d]	11

Notes: a. J. Gofman, "Radiation Induced Cancer from Low-dose Exposure: An independent Analysis", Committee for Nuclear Responsibility 1990. Dr. Gofman is a Medical Doctor and Ph.D. nuclear physicist who formerly directed Health Studies at the U.S. Lawrence Livermore Laboratory. See also "Warning from A-Bomb study about low and slow radiation exposures," J. Gofman, Health Physics 56: 117-118, 1989.

b. R. Nussbaum is a Ph.D. nuclear physicist, Professor of Physics at the Portland State Un. in Oregon. His complete reanalysis of Atomic Bomb data is peer reviewed and published in German, but a brief version was also contained in Correspondance, Health Physics Journal Vol. 56, No.6, pp 961-962, 1989. Prof. Nussbaum looked at cancer fatality risks in atomic bomb survivors with less than 200 mSv total dose.

c. Preston D.L. and D.A. Pierce. RERF Technical report TR9-87, Hiroshima 1987 (p.35) This is an age averaged linear extrapolation with neutron RBE of 1 (central estimate).

d. Preston D.L. and D.A. Pierce. "The Effects of Changes in dosimetry on cancer mortality risk estimates in atomic bomb survivors" Radiation Research 114: 437-466, 1988. Preston and Pierce changed the linear extrapolation without explanation although they mention UNSCEAR 1977 and 1986 "risk reduction factors." This estimate was apparently again reduced by ICRP to 5 cancer death to accommodate "slow dose rate."

The PHC is aware of the necessarily long time between radiation exposure and the publication of complete data (about 80 years or so to the death of all members of the cohort), and requests the consideration of different possibilities.

The scientific dispute over extrapolating the atomic bomb findings from high dose and fast dose rate conditions in a traumatized population to low dose and slow dose rate normal situations which characterize exposures from routine uranium and nuclear industries may soon be by-passed by using direct data on workers. These estimates would need to be extrapolated to children and the elderly, and also to some disabled persons normally excluded from the workforce. However it may be less formidable to add a protection factor to worker estimates when considering more fragile sectors of the population, than to overcome all of the difficulties associated with extrapolating from the atomic bomb database to everyday dose rates.

The nuclear worker deaths now form a very large database. A subset of this database includes: Hanford workers (1,732); Oak Ridge workers (1,524); British nuclear workers (6,660); AECL (Canada) (229); totalling 10,145 deaths. Again, there are still many more workers in these cohorts still alive.

Some new estimates based on nuclear workers are given below. Only the highest worker estimates are given so as to determine the range of disagreement over risk estimates. What seems clear is that these newly published worker studies do not justify the DREF or DDREF assumptions which have been applied to the atomic bomb data.

Table 3.10
Excess Lifetime Mortality from all Cancers Attributable to 100 Person-Sv to Nuclear Workers (Male, 20 to 64 Years Old)

SOURCE	CA DEATHS PER 100 Person-Sv
Kendall[a]	10 [0-26]
Wing[b]	27
Stewart[c]	19 [8-31]

Notes: a. Kendall, G.M. et al. "Mortality and occupational exposure to irradiation: First analysis of the National Registry for Radiation Workers." British Medical Journal 304: 220-225 (1992)

b. Wing, S. et al. "Mortality Among Workers at Oak Ridge National Laboratory," Journal Am. Medical Assoc. 265:11, 1397-1402 (1991). Wing and Assoc. used a log per cent methodology and calculated a 4.94% increase per 10 mSv. The risk in the table was calculated as follows:

100 Person Sv. = 10^5 Person mSv
$(1.0494)^5 = 1.27$

Therefore an excess risk of 27 per 100 Person Sv. collective dose is predicted. Wing, in a personal communication, considers his estimate 10 times higher than atomic bomb based estimates given by E. Gilbert, Ref.3 and 4 in his paper.

c. Kneale, G.W. and A. Stewart "Reanalysis of Hanford Data: 1944-1986 Deaths Am. Journal of Industrial Medicine 1992 (Accepted for publication). This data base now includes 7343 deaths with an average total exposure of 22.3 mSv, therefore 163.7 Person Sieverts exposure. Depending on the analysis model one can obtain significant excess cancers as: 12.5 to 50.9. This yields a range of 7.6 to 31.1 fatal cancers per 100 Person Sv. Dr. Stewart cautions that this applies only to a population of the same age structure as the Hanford workers. The estimate 19 is a simple average of the two significant extremes.

Given the independent analysis of the atomic bomb data and recent estimates of nuclear worker risk, the PHC will provide several scenarios, one of which is based on the same risk estimates used by Hydro in Exhibit 507 (labelled 'median') and additionally:

1. a 'low' estimate of half the median cancer deaths per 100 Person Sv;
2. a 'high' estimate predicting twice the median cancer deaths per 100 Person Sv. exposure; and
3. a 'higher' estimate predicting four times the median cancer deaths per 100 Person Sv. exposure.

The collective effective dose equivalent (CEDE) for workers is measured by personal dosimeters, film badges and area monitors. It is less difficult to estimate than the dose to the public.

As was noted in the early part of this chapter, the dose of ionizing radiation received by the public depends not only on emissions but on meteorological and watershed data, plant and animal uptake, food habits, population density, etc. Little site-specific data for Ontario is available, hence the PHC was forced to rely on generic estimates made by UNSCEAR and Hydro data on emissions. The PHC notes in particular the unique location of Hydro nuclear reactors on the Great Lakes. The UNSCEAR 1988 estimates of water distribution assume either a "model river" or "coastal waters," (Tables 38 and 39, for example). The Great Lakes have a slow water turnover rate and the Lake Ontario current moves in a counter clockwise direction (as seen from above) putting the densely populated Metro Toronto area at risk from liquid discharges from Pickering and Darlington. The Hydro methodology used a cut-off for estimating the affected dose and population size: namely, drinking water intake pipe within 25 km of the plant, eliminating a main Metro Toronto water intake (at the foot of John Street). Hydro used the population within 30 km of the plant for dose estimates of airborne effluence. These cut offs may not be realistic but it is beyond the mandate of the PHC to propose new ones.

UNSCEAR 1988 defines a local population as being within about 100 km; a regional population within about 1000 km; and the remainder as world population (Paragraph 7, page 137). That report also provides a cautionary note: "The results do not apply to any one reactor or any one location, and the collective dose commitments should not be applied to a given reactor with known discharge data to obtain estimates of health detriment." (Paragraph 87, page 147).

Lacking Ontario specific data, the PHC used UNSCEAR 1988. The PHC alerts the Board to the urgent need of site-specific evaluations of the uranium and nuclear emissions in Ontario and of independent and reliable Person Sievert collective dose estimates.

As noted above, to determine health risk from the nuclear generating option, the PHC will employ several risk estimates for excess cancer fatalities associated with a collective dose of 100 Person Sieverts, which enable the development of a broad range of scenarios:

Table 3.11
Alternative PHC Estimates of Risk of Excess Cancer Mortality

ALTERNATIVE SCENARIO	WORKER EXCESS CANCER RISK (deaths/100 Person-Sv)	PUBLIC EXCESS CANCER RISK (deaths/100 Person-Sv)
Low	2	2.5
Median	4	5
High	8	10
Higher	16	20

Note that the numbers of expected cancer deaths will be the product of these risk estimates and the associated CEDE values for workers and the general public. For workers, the CEDE is based on individual film badge readings or plant/mine area monitoring. The CEDE for the general public is based on each radionuclide emitted from nuclear facilities at every step in the uranium fuel cycle. These expected numbers derived by the PHC will be larger with larger risk values than those of Hydro because of the inclusion of sources of emissions not considered or incompletely considered by Hydro in its own planning. These include:

1. Tritium releases from Hydro's TRF and other sources;
2. Radon gas emissions from uranium tailings related to Hydro's fuel requirements.
3. Carbon-14 emissions to air from Hydro reactors; and
4. Uranium mining and milling emissions based on the use of data for underground mining at Elliott Lake (from UNSCEAR, 1988) in preference to uranium mining data from Saskatchewan.

The translation of emissions into collective effective dose equivalent commitments [CEDECs] is largely based on site-specific dispersion modeling studies corroborated, to the extent possible, by actual measurements of radionuclide levels at selected locations around nuclear facilities (such as boundary sites, residential areas, drinking water inlets, etc.). Tritium dose estimates do not take into account the probable organically bound tritium [OBT] component.

Tritium, in the form of tritiated water, has a short residence time in the human body. Like carbon-14, tritium can also be incorporated into protein and DNA in the cell's nucleus (OBT) meaning longer residence time there and potentially more biological damage per disintegration.

PHC expert K. McNeill has commented on the implications of OBT once newly emitted tritium has reached an equilibrium in the environment:

> With a person in equilibrium, the longer or shorter half-life does not alter the mass of material, or of T, merely the time to get to or from equilibrium; and the percentage tritiation of the material is given solely by the percent tritiation of the diet. A long half-life does not mean a correspondingly higher dose rate.

McNeill has drawn the PHC's attention as well to published reports of concentrations of tritium in precipitation and estimated equilibrium body burden [NCRP Report, Vol.94, 1987; Appendix B, Table B.6, p.161]. In 1952, the natural level of tritium in precipitation was 0.6 Bq/l (also quoted as 600 Bq/m^3, or 16 pCi/l; and for which the equilibrium body burden was 26 Bq). With the fallout from nuclear weapons testing, these levels peaked in 1963-64 at several hundred times the natural level, or at about 360 Bq/l (and 15,000 Bq of body burden). The 1987 NCRP report notes that these concentrations have decreased since 1968 with a half-life of about three years, but had not as of 1987 returned to natural levels. This would imply that higher than natural background levels of tritium are to be expected everywhere, including the vicinity of nuclear facilities. Without properly controlled studies, it would be difficult to attribute the presence of tritium in organic materials around nuclear facilities to those facilities.

The conclusions of Myers and Johnson (1991) on the metabolism of OBTs is instructive as well:

> There are large variations in the rate of turnover of OBT from one tissue to another and from one tissue constituent to another in the body. However, tritium levels in OBT approach similar levels in most tissues after prolonged chronic exposure to HTO. The specific activity of OBT is considerably smaller than that of body water under these conditions, because much of the bound hydrogen in organic constituents of the tissues is derived from bound hydrogen in organic constituents of the diet and not from body water. Animal experiments indicate that OBT contributes about 6% to total radiation dose to the cell after exposure to HTO. The data are in reasonable agreement with the correction factor for OBT recommended for routine bioassay programs for occupational HTO exposures in Canada.
>
> Special considerations are required for calculations of radiation doses from tritiated foodstuffs. Radiation doses would probably be underestimated by about 2-fold in cases where the only source of tritium was dried tritiated produce and presumed radiation doses were calculated from tritium levels in urine or body water. This underestimation would probably be reduced to about 35% if the sole source of tritium from the environment were fresh produce containing 30% organic material and 70% water with tritium levels in equilibrium. Some uncertainties associated with these numbers have been noted in this review.
>
> If all of the produce and all fluids consumed contained tritium at equilibrium in the environment, radiation doses to soft tissues should be essentially identical to radiation doses to body water.

> The contribution of tissue OBT to total radiation dose accumulated over two or more decades in offspring of mothers exposed to HTO during pregnancy and lactation also requires special consideration. Data available at the present time suggest that this is probably not a major problem for purposes of radiation protection, but the available data are insufficient to estimate accurately the cumulative radiation doses to cell nuclei.
>
> [Myers, D.K. and Johnson, J.R.: Toxicity and Dosimetry of Tritium: A Review; AECB INFO-0377(E); January, 1991]

Since it takes decades to reach tritium equilibrium, the implications of the non-equilibrium situation need to be further explored.

The PHC wishes to emphasize that it should not be too quickly assumed that nuclear facility operators (such as Hydro and its suppliers) or their regulator (the AECB) are performing complete, exhaustive and repeatedly verifiable studies of appropriate CEDECs based, for example, on the mapping of dispersed emissions from each facility by radionuclide and as a function of local, regional and global atmospheric, aquatic and terrestrial conditions to human exposure levels. Undoubtedly, such studies as do exist incorporate a variety of simplifying assumptions such as uniformity of radionuclide distribution. These modeling assumptions result in the assumption of average doses for exposed populations. However, without the more exhaustive analyses, it is not possible to state that the DELs which form the basis of performance for nuclear facilities are reasonable and appropriate. As already noted, the currently used DELs require modification to new ICRP recommendations to limit maximum permissible doses to workers to 20 mSv/year and to the public to 1 mSv/year (ICRP, 1990).

In the development of CEDEC estimates, a ground for policy debate and resolution naturally arises in considering doses to future society from the longer lived radionuclides mentioned above (such as carbon-14 with a half life of 5,730 years; or iodine-129 at 1.6 x 10^7 years). What value does society place in considering dose commitments beyond some reasonable period of time, say 1,000 years? Should planning be based, therefore, on time frames of one millennium? In the case of carbon-14, this would have the effect of reducing the estimated CEDEC for this radionuclide to about 19% of the value derived from integrating dose commitments over all time. (See UNSCEAR 1988, p.161. paragraph 187.)

For purposes of stimulating debate on this issue (and others), the PHC has used in its planning methodology CEDEC values based on the approximate truncation of dose commitments at one thousand years. This is not unlike the time span used in the traditional teachings of our aboriginal communities when considering the ramifications of their decisions upon future generations of their people (some traditions consider effects up to seven generations).

Based upon these considerations, the PHC has developed its own CEDEC estimates which it will employ to develop projected cancer fatalities from nuclear generation of electricity (Table 3.12). For comparison purposes, Table 3.13 depicts the UNSCEAR Committee's estimates of the CEDE (normalized to GWa of annual electrical energy production and averaged over all types of reactors) for worker populations as well as local, regional and global populations.

Table 3.12
Estimated Collective Effective Dose Equivalent Commitments From 1 GWa of Electricity from Hydro Nuclear Generating Stations: 1993-2014

STEPS IN THE NUCLEAR FUEL CYCLE	P.H.C. ESTIMATES OF RADIONUCLIDE EMISSIONS(per GWa)	COLL. EFFECTIVE DOSE EQUIVALENT (person-Sv/TBq)[a]	COLL. EFFECTIVE DOSE EQUIVALENT (person-Sv/GWa)
URANIUM MINING AND MILLING:			
Radium effluent	0.1-1.0 GBq	0-0.6	(0.0-0.6)E-3[b]
Radon gas (to air)	1.4-3.0 TBq	0.015	0.021-0.045
Mine tailings	0.06-2.4 TBq	0.015	0.0009-0.036
Uranium-238	0.2-1.0 GBq	7	(1.4-7.0)E-3
Thorium-230	0.05-0.5 GBq	30	(0.15-1.5)E-3
Radium-226	0.05-0.5 GBq	0.6	(0.03-0.3)E-3
Lead-210	0.05-0.5 GBq	1	(0.5-5.0)E-4
Radon-222	0.12-0.8 TBq	0.015	(0.18-1.2)E-2
FUEL FABRICATION:			
Uranium to water	1.1 GBq	-	Total of
Uranium to air	0.002 GBq	-	0.0028E-3
REACTOR EMISSIONS TO WATER:			
Tritium	222-477 TBq	0.0008	0.18-0.38
Gross beta	9.1-34 GBq	-	0.001
REACTOR EMISSIONS TO AIR:			
Tritium	278-860 TBq	0.011	3.1-9.5
Noble gas	164-260 TBq	0.00012	0.02-0.03
Iodine-131	0.05-0.31 GBq	0.387	(1.9-12.0)E-5
Particulates	0.024-0.122 GBq	5.4	(1.3-6.6)E-4
Carbon-14	2.0-19.4 TBq	-	100[c]
TRITIUM REMOVAL FACILITY [TRF]:			
Tritium oxide	20 TBq	0.00081	0.016
Elemental tritium	530 TBq	0.011	5.8
TOTAL CEDEC (person-Sv GWa^{-1})			about 100

Notes: a. CEDE values are derived from UNSCEAR, 1988 report, Annex B: Uranium mining and milling emissions (Table 8, p.166); Fuel fabrication (the normalized CEDEC is taken from Para.46, p.142); Tritium in liquid effluents (Para.98, p.148 suggests that a CEDEC of 8.1E-4 person-Sv TBq^{-1} be assumed based on a river model as a source of drinking water); Gross beta in liquid effluents (Para.110, p.150, suggests a collective dose of 1.1E-3 person-Sv GWa^{-1} for PWR releases of significant radionuclides into drinking water from a river model); tritium to air (Para.96, p.149, suggests a CEDEC to local and regional populations from inhalation and ingestion of 0.011 person-Sv TBq^{-1}); noble gases (Table 32, p.208, and Para.88, p.148, suggest a CEDEC of 0.026 person-Sv GWa^{-1} for Pressurized Water Reactors [PWRs] which are considered similar enough in design to HWRs); Iodine-131 (taken from Table 36, p.209, for HWRs and dividing CEDEC value of 0.089E-3 person-Sv GWa^{-1} by normalized I-131 activity of 0.23 GBq GWa^{-1}); Particulates (Table 37, p.209, for collective dose per unit activity of 5.4 person-Sv TBq^{-1}); Carbon-14 (Para. 100, p.149, suggests 11 person-Sv GWa^{-1} for local and regional collective doses and Para. 187, p.161, gives 490 person-Sv GWa^{-1} for global doses totalling 500 person-Sv GWa^{-1} which is multiplied by 0.19 to reflect truncation to 1,000 years); TRF tritium oxide (based on tritium in liquid effluents); and TRF elemental tritium (using tritium to air CEDE value).

b. Scientific notation is used. Thus, for example, 1.8E-5 = 0.000018.

c. For consistency, all CEDEC values in this table should be truncated to 1,000 years. However, the truncation only for Carbon-14 reflects the dominance of this emission to the data in this table. For costing purposes the local/regional CEDE for carbon-14, namely 11 Person Sv per Gwa, may be used rather than the 1000 year projection.

Table 3.13
UNSCEAR Committee's Estimates of Collective Dose per Unit Practive of Nuclear Power Generation[a]
(person-Sv per GWa)

AT RISK POPULATION	OVER NEXT 100 YEARS	OVER ALL TIME
Mill tailings (radon), long term	1.5	150
Globally dispersed nuclides and waste	6.0	60
Local and regional exposures	4.0	4
Occupational exposures	12.0	12
TOTAL	24.0	230

Note: [a] From UNSCEAR, 1988; Table 6, p.27.

Table 3.12 allows the PHC to derive an overall CEDEC value (admittedly underestimated) of about 100 person-Sv for each GWa of nuclear electricity. Exposures from TRF tritium and reactor tritium and carbon-14 emissions dominate this CEDEC estimate. These isotopes are particularly strongly emitted from HWRs (see UNSCEAR, 1988; Para. 68, p.145; and Table 25, pp.184-5). For costing purposes, the PHC recommends the use of 20 Person Sv per GWa reflecting about 50% contribution of carbon-14 and its local/regional 10 year committed dose.

It is now possible to estimate the number of excess cancer fatalities to the general or global public over the next one thousand years as a result of emissions from the entire uranium fuel cycle as a result of the production of one GWa of nuclear electricity. Table 3.14 shows the number of cancer fatalities to the general public from Hydro radiological exposures and conventional accident fatalities using PHC assumptions and Hydro projections.

Table 3.14
Estimates of Cancer and Accident Fatalities to the Public per Gwa of Nuclear Electricity Based Upon PHC Scenarios and Hydro Projections

TYPE OF FATALITY	ONTARIO HYDRO[a]	ALTERNATIVE PHC SCENARIOS			
		LOW	MEDIAN	HIGH	HIGHER
Radiological	0.040	2.5	5	10	20
Conventional Accident	0.013	0.013	0.013	0.013	0.013
TOTALS	0.053	2.513	5.013	10.013	20.013

Note: a. From Ontario Hydro Exhibit 507, Table 5-1, p.5-28.

More than 80% of each PHC scenario's estimate of public cancer fatalities is attributable to received doses from carbon-14, an issue not currently addressed in Hydro documents of environmental health effects and annual summaries of radiological emissions. Most of the remaining fatality estimates can be attributed to tritium releases from Hydro reactors and its TRF facility. The 10-year local/regional projection for costing purposes would be 0.5 to 4 fatal cancers per GWa.

For estimates of worker fatalities, the PHC has consulted the UNSCEAR, 1988 report on occupational exposures from nuclear power production (Annex B). For radiation exposure to underground uranium miners during the early 1980s, UNSCEAR estimates average annual effective dose equivalents of about 10-12 mSv (and about 5 mSv for surface miners). When normalized, the CEDE is about 0.7 person-Sv GWa^{-1} (Para.36, p.141). For uranium fuel fabrication workers, occupational exposures average 0.2 person-Sv GWa^{-1} during the years 1980-84 (Para.49, p.142; and Table 15, p.169). For reactor operations, UNSCEAR estimates of occupational exposures include internal doses from exposure to tritium and average about 4 person-Sv GWa^{-1} (Para.118, pp.151-2; and Table 42, p.214).

In total, therefore, and only counting exposures from underground mining, fuel fabrication and reactor operations, the PHC estimates Canadian radiation worker exposures to be about 5 person-Sv GWa^{-1}.

Following the procedure for estimating public cancer fatalities, Table 3.15 shows the number of worker cancer fatalities from radiological exposures and conventional accident fatalities using PHC assumptions and Hydro projections.

Table 3.15
Estimates of Cancer and Accident Fatalities to Workers per Gwa of Nuclear Electricity Based Upon PHC Scenarios and Hydro Projections

TYPE OF FATALITY	ONTARIO HYDRO[a]	ALTERNATIVE PHC SCENARIOS			
		LOW	MEDIAN	HIGH	HIGHER
Radiological	0.12	0.1	0.2	0.4	0.8
Conventional Accident	0.045	0.045	0.045	0.045	0.045
TOTALS	0.17	0.15	0.25	0.45	0.85

Note: a. From Ontario Hydro Exhibit 507, Table 5-1, p.5-28.

The PHC is now in a position to estimate the total public and worker cancer fatalities associated with the Hydro's nuclear option.

Table 3.16
Estimates of Total Cancer and Accident Fatalities to Workers and the General Public per Gwa of Nuclear Electricity Based Upon PHC Scenarios and Hydro Projections

TYPE OF FATALITY	ONTARIO HYDRO	ALTERNATIVE PHC SCENARIOS			
		LOW	MEDIAN	HIGH	HIGHER
General Public	0.053	2.5	5.0	10.0	20.0
Workers	0.17	0.15	0.25	0.45	0.85
TOTALS	0.22	2.6	5.2	10.4	20.8

The 10-year local/regional projection for workers and the general public would predict 0.6 to 5.0 fatal cancers per GWa in Ontario or its environs.

3.6 The Issue of Reconciling Estimates of Low Dose, Low Dose Rate Exposures to Ionizing Radiation

The PHC has commissioned a paper on this subject from Dr. Alice Stewart (1992) of the University of Birmingham, which paper was reviewed in turn by Dr. Elizabeth Cardis of the International Agency for Research on Cancer (October 19, 1992). Lastly, Dr. Stewart responded to the Cardis review (November 4, 1992).

This subject is complex and contentious, and has formed a large part of the deliberations of the most recent BEIR V Committee's work.

Stewart's 1992 PHC paper continues her exploration of the A-bomb thesis that "both a tissue destructive effect of the radiation (i.e. marrow damage, whose only distinctive effect is aplastic anemia) and an effect of the early deaths (i.e. selection in favour of infection resistant persons) are still influencing the life expectancy and causes of death of A-bomb victims" (Stewart, 1992, p.3).

In view of the contentious nature of this subject, the PHC asked for comments on Dr. Stewart's 1992 material from Dr. E. Cardis. Dr. Cardis commented, in part, as follows;

> At present, there is little evidence that the current radiation risk estimates derived by BEIR V and used by ICRP in its new recommendations are far wrong. The data on which these are based have obvious limitations, and attempts have been made to account for them. Until the results of careful and large enough studies of populations receiving long-term low dose rate exposures, in which precise estimates of individual dose over time are available, are published, the current risk estimates, taken with their associated uncertainties, must still be considered the best basis for radiological protection. I find Dr. Stewart's conclusion overly pessimistic although I share her concern - and that of BEIR V and ICRP 60 - that no amount of radiation can be considered harmless. [Cardis; October 19, 1992]

Since the preparation of her 1992 PHC paper, Stewart has completed the extension of the low dose Hanford worker studies to the year 1986. The results of her studies have since been accepted for publication and will be available in March 1993. Stewart's findings will also be included in an update to the PHC's evidence.

3.7 Estimates of Radiation Induced Non-Fatal Cancers

This section was prepared by R. Bertell and reviewed by K. McNeill.

The probability of a cancer being fatal depends on various factors: age and sex of the patient; his/her general health history; stage of the disease when diagnosis and treatment occur; level of available medical care, etc. Many people would include factors such as positive outlook on life, good interpersonal relations and life satisfaction. Survival following a diagnosis of cancer can be defined as being alive as little as 5 or as long as 20 years after diagnosis. Mortality rates can be affected by: competing causes of death especially among the elderly; socio-economic status; infectious disease epidemics and catastrophic accidents (which would mask underlying conditions); etc.

The ICRP's 1990 report references U.S. Dept. of Health and Human Services Data for 1989 to derive site-specific cancer lethality estimates for use in radiation risk assessments. Table 3.17 below compares U.S. estimates of 5 year mortality rates with 1991 Ontario data to show their similarity.

Table 3.17
Five Year Mortality Rates for Selected Cancers: U.S.A. and Ontario

SITE	% FATAL	
	U.S.A.[a]	ONTARIO[b]
Bladder	22	23
Brain	75	70
Breast	24	27
Cervix	33	30
Colon	45	48
Kidney	48	44
Leukaemia (acute)	98	-
Leukaemia	-	61
Liver	95	-
Lung and Bronchus	87	84
Oesophagus	92	-
Ovary	62	59
Pancreas	97	92
Prostate	26	30
Melanoma skin	-	83
Stomach	85	78
Thyroid	6	-
Uterus	17	14
All Cancers	-	48[c]

Notes: a. ICRP, 1991.
b. Ontario Cancer Treatment and Research Foundation estimates for 1991.
c. excluding non-melanoma skin.

The percent lethality for most cancers increases dramatically over a 20 year follow up period. The following lethality fractions have been recommended in Annex B of ICRP Publication 60 (ICRP, 1991).

Table 3.18
1990 ICRP Recommendations for Lethality Fractions

SITE	% LETHAL	% NOT LETHAL
Bladder	50	50
Bone	70	30
Brain	80	20
Breast	50	50
Cervix	45	55
Colon	55	45
Kidney	65	35
Leukaemia (acute)	99	1
Liver	95	5
Lung and Bronchus	95	5
Oesophagus	95	5
Ovary	70	30
Pancreas	99	1
Prostate	55	45
Skin	0.2	99.8
Stomach	90	10
Thyroid	10	90
Uterus	30	70

In Appendix 2 of Hydro's Exhibit 507 (p. AP 2-15), Table 2-2 shows "Age-Averaged Lifetime Excess Cancer Mortality After Exposure to Low Doses of Uniform Whole Body Radiation". This information will be used as the basis for the PHC's first estimate of non-lethal cancers attributable to radiation exposure of the general public.

The PHC notes Hydro's apparent preference for absolute risk models (in Table 2-2 of Hydro's Exhibit 507) which yield lower cancer fatality risk estimates than do relative risk models. Nevertheless, the latest BEIR Commission report [BEIR V] has noted, in its re-analysis of atomic bomb survivor data, that cancer deaths are roughly proportional to cancer incidence rates, pointing to the better fit of multiplicative type models. Table 3.19, from the 1991 ICRP report, highlights the differences in risk estimates which result from the choice of an additive versus a multiplicative model.

Table 3.19
1991 ICRP Projections of Lifetime Risk of Fatal Cancer for 10,000 Persons Exposed Rapidly to 1 Gy Whole-Body Low-Let Radiation[a]

	RISK PROJECTION MODEL	EXCESS FATAL CANCERS
Total population	Additive Multiplicative	400[b]-500[c] 700[c]-1,100[b]
Working population (aged 25-64 years)	Additive Multiplicative	400[c]-600[b] 700[b]-800[c]
Adult population (over 25 years)	Additive Multiplicative	500[c] 600[c]

Notes: a. Based on cancer mortality rates for the population of Japan.
b. Derived with age-specific risk coefficients.
c. Derived with constant (age-averaged) risk coefficient.

Table 3.20
Age-Averaged Lifetime Excess Cancer Fatalities and Non-fatalities After Exposure to Low Doses of Uniform Whole Body Radiation

	Excess Cancer Per 10^4 Person-Sv	
Organ or Tissue	Fatalities[a]	Non-Fatalities[b]
Bladder	30	30
Bone marrow	50	0.5
Bone surface	5	2
Breast	20	20
Colon	85	70
Liver	15	1
Lung	85	4
Oesophagus	30	2
Ovary	10	4
Skin	2	1000
Stomach	110	12
Thyroid	8	72
Other organs	50	50
TOTAL	500	267.5 without skin Ca 1,267.5 with skin Ca

Notes: a. Drawn from Table 2-2 in Hydro's Exhibit 507 (p. AP 2-15).
b. Calculated from Table 3.19 above.

Ontario Hydro uses the following age-averaged risks:

Total population 500 per 10^4 person-Gy (5 per 100 Person Gray)
Workers 400 per 10^4 person-Gy (4 per 100 Person Gray)

The preferred choice using age-specific risk coefficients with a multiplicative model yields:

Total population	1,100 per 10^4 person-Gy (11 per 100 Person Gray)
Workers	700 per 10^4 person-Gy (7 per 100 Person Gray)

Table 3.20 shows Hydro data for the expected number of cancer fatalities by site per 10^4 Person Sv of whole body, low dose radiation (apparently derived from the additive risk estimates in the 1991 ICRP report). Beside these figures, the PHC has used lethality fractions (from Table 3.19 above) to derive the expected non-fatal cancers corresponding to the same exposure. Proceeding in this way, the PHC calculates that the total number of expected cancers following whole body, low dose exposure to radiation could be obtained from the expected number of cancer fatalities by increasing that number by 267.5/500 or 53.5% (excluding skin cancers) or by 1,267.5/500 or 253.5% (with skin cancers).

From Table 3.16 which gave the PHC analysis of cancer fatalities per GWa, the PHC can now make an estimate of total cancers associated with each GWa electricity production:

- The 1000 year projection (workers and general public):

  2.6 to 21 fatal cancers
  1.4 to 11 non-fatal cancers (excluding skin)
  5.2 to 42 skin cancers
  9.2 to 74 cancers

- The 10 year local/regional projection (workers and general public):

  0.6 to 5 fatal cancers
  0.3 to 3 non-fatal cancers (excluding skin)
  1.2 to 10 skin cancers
  2.1 to 18 cancers

3.8 Epidemiological Studies of Hydro Nuclear Workers

The PHC has commissioned reviews by Dr. M.Goldberg of GlobalTox International. Consultants (dated 09/15/92) of epidemiological studies of Hydro nuclear workers by Anderson et al. (Interrogatory 9.22.32) and of AECL workers by Howe et al. (AECL-9442; 1987).

The Anderson study reviews the mortality experience from 1970-1988 of virtually all actively working (and "pensionable" or "beyond their probationary period") Hydro male employees or previous such employees living on Hydro pensions during this time period. The author notes that occupational studies are not "clean", since workers may be allocated to a particular job by educational level, preference, lifestyle, etc. (App.5, pp.35-36). These factors may introduce non-occupational differences between exposed and unexposed groups. The author uses this explanation to suggest that Standard Mortality Ratios [SMRs] of less than 200, which would indicate two times more mortality in exposed compared to non-exposed groups, may be "false alarms" or false positives and may not indicate a true difference.

However, Goldberg notes that the same logic could be employed to conclude that SMRs of just less than 100, as are seen in this study, may represent false negatives; since the same non-occupational factors can work to confound results in the non-exposed as well as in the exposed group.

Anderson (App.5, p.37) suggests that a dose-response gradient would be seen if occupational exposure were linked to cancer induction, such that the workers with the highest exposure over the longest duration would have a higher cancer mortality. Goldberg notes that, in theory, this is generally true for most toxicants. However, there is very little reliable data on the carcinogenicity of low doses of ionizing radiation. There may not be a straight line extrapolation from data obtained with higher doses. Rather, sensitive individuals may be more at risk than others, creating a "healthy worker" effect.

Anderson (App.5, p.37) identifies the problems associated with using only currently active or pensioned workers. A case is made for the inclusion of only these permanent workers in the database suggesting that this approach gives a "more accurate measure of true occupational hazards". Goldberg notes that it is much easier and cheaper to conduct this study by excluding workers who left Hydro, as it is difficult to locate their health records. These workers may have left after their initial exposure to ionizing radiation out of concern over potential adverse health outcomes. Goldberg notes that this approach introduces selection bias into the study by inflating the population at risk and the expected mortality (thus reducing the mortality risk estimate). The problem is even more pernicious than Anderson has noted. Counting such "leavers" mortality experience while they remain alive and healthy members of the active Hydro workforce both overestimates the expected risk in the denominator of risk estimates and potentially underestimates the observed mortality numerator of the same risk estimates since Anderson's methodology drops their further follow up (and possible death) once they leave the Hydro workforce.

The numbers of cancer deaths are small and thus, the author points out, "meaningful patterns are obviously not likely to be detectable, especially if the figures are further subdivided by dose category in order to see if there is any dose-response gradient" (Anderson; p.8). On the following page, the author states: "Overall, as a group, men on the dose register continue to show an elevated SMR for lung cancer... but the absence of a dose response gradient suggests that this is very unlikely to be due to occupational exposure to ionizing radiation".

The SMR for lung cancer is 122; Goldberg notes that this figure would likely be higher if the healthy worker effect [HWE] were taken into consideration. To properly take the HWE for lung cancer mortality into account, Anderson would have had to perform an analysis of a subcohort with at least 5 years of Hydro employment experience (see a report on this subject by the Industrial Disease Standards Panel; Government of Ontario; Rpt. No.3, July, 1988).

Anderson's table of lung cancers by radiation dose (p.9) shows a discrepancy in that the extended follow up (1972-88) should show the same or increased observed and expected numbers in each dose-specific cell as compared with the previous follow up (1972-86). However, the 50-99 mSv cell shows 2 observed cases in the shorter follow up period and 1 observed case in the longer period. This error biases downwards any estimate of a dose-response gradient in the extended follow up period. However, no analysis (with associated probability) of this gradient is provided to enable the reader to make an independent judgement.

With respect to the Howe study of AECL workers (which constituted the fourth part of a larger study of the health of AECL employees), Goldberg notes that a fire destroyed all primary dose records prior to February, 1956 including records containing 'the greatest exposure to radiation at Chalk River Nuclear Laboratories [CRNL] up to that time [which] occurred during the clean-up and reconstruction of the NRX reactor [after its accident] during the period 1952 December to 1954 February'. The authors used notifications of such exposure sent to branch offices to reconstruct doses for this period saying: "the assumptions involved in attributing dose in this way are considered to be valid".

Part III of the larger study, "Upgrading the database", suggests the method of reconstructing doses for the period surrounding the reactor accident cleanup was based mainly on retrieving data from branch office records for their employees who were notified when their exposure exceeded 300 mrems per week. Some notifications of 100 mrems per week were also reported to branch offices with unknown frequency. This would tend to underestimate dose in many cases. If exposure were less than 300 (or, in some cases) 100 mrems, it appears to have been omitted from the estimates. There is no estimate of the error involved in dose reconstruction.

Goldberg notes that mortality is less than expected for cancer and other causes of death suggesting the possible influence of a healthy worker effect (HWE). In a previously noted report on the HWE by the Industrial Disease Standards Panel of the Government of Ontario (1988), it was concluded that the HWE can result from 3 types of bias:

1. *Selection bias*-- one aspect of this bias is that less mortality is seen with prolonged followup. Put simply, over time there are fewer workers left in the study with associated risk factors, so the remaining workers show less severe occupational risk.

2. *Classification bias*-- is seen when different methods are used to establish data for worker and for reference populations.

3. *Confounding*-- using an inappropriate reference population.

The HWE can be corrected by incorporating a latency period equal to the posited time between the initiation of cellular changes leading to carcinogenesis and first diagnosis of the disease. When a latency period of 15 years is applied to the AECL worker data (Howe; Table 4), non-significant, elevated SMRs can be seen in 6 out of 11 cancer sites, including colon, rectum, pancreas, lung and trachea, prostate, and Non-Hodgkins lymphoma. Whether or not this adjustment provides evidence of a HWE in this population, Howe concludes that the findings of non-significant elevated risk are due to chance because of their inconsistency with previous such findings.

However, the PHC believes that further follow up of these workers is warranted because the current study lacks the power by itself to test the adequacy of current protection standards. Since this cohort of Canadian nuclear workers has been exposed to low dose, low dose rate radiation, the very conditions of public and worker radiation exposure, efforts should be made to ensure that its dataset can be standardized and pooled with other nuclear worker datasets to improve interpretation and the overall significance of findings.

3.9 Effects of Ionizing Radiation on Reproduction and Development

The material in this section was prepared for the PHC by C.Rousseaux and M.Goldberg (GlobalTox; Sept. 25, 1992) and reviewed by R. Bertell.

The health effects of ionizing radiation on reproduction and development have received considerable attention, particularly since the end of the second world war. Survivors of the Hiroshima and Nagasaki atomic bombing had a variety of ailments including failure of reproduction and increased structural deformities (such as head malformations) and functional anomalies (such as mental retardation) in the offspring. Ionizing radiation is a physical agent that causes somatic as well as germinal cell damage. In considering reproductive health effects, it is necessary to evaluate all involved individuals, namely the father, the mother and the developing child.

a. Paternal Effects

The testes are particularly sensitive to ionizing radiation because of their location, which provides very little shielding from external sources, and because the germinal cells are rapidly dividing. The seminiferous epithelium of the testis maintains a steady state of spermatogenesis throughout reproductive life, which involves the active proliferation and differentiation of spermatogonial stem cells. Radiation damage to the testis can impair fertility and fecundity. If the dose is high enough, varying degrees of lowered fertility and ultimately sterility ensue. The effect on spermatogenesis is dose dependent, with a threshold that varies amongst species and individuals of differing susceptibility. It appears as though repeated sublethal doses of radiation for spermatogonia are more damaging than a single high dose of ionizing radiation. The reason for this observation is that repeated insults destroy the recovering germ cell line resulting in eventual fatal damage to all germ cells. Ionizing radiation can produce both somatic and genetic changes in sperm. The somatic changes, such as abnormal sperm heads, duplicate tails, etc., can result in infertility; even though sperm numbers are normal, they are incapable of fertilizing an ovum. Genetic anomalies may cause infertility by introducing a lethal mutation into the fertilized egg, or by altering the chromosomes of the sperm. In summary, radiation can damage sperm in a number of ways. Therefore, men working in areas of moderate radiation emissions are at risk of reduced fertility, sterility and fetal abnormalities. Dose-related health effects from paternal radiation exposure are listed in Table 3.21 below.

Table 3.21
Paternal Effects of Ionizing Radiation

Organan and Species	Dose	Units	Effect	Reference
SOMATIC EFFECTS				
Testis Type A spermatogonia	0.15	Gy	X-radiation interrupts spermatozoa production as type A spermatogonia are killed. Infertility is temporary.	Fabrikant, 1972; Hall 1987.
Testis (human)	3-5	Gy	Dose received, either fractionated or total, results in permanent sterility.	UNSCEAR, 1982
Testis (dog)	1.2-1.7	mGy/day	No effect on sperm production.	Casarett and Eddy, 1968; Fedrov and Markelow, 1978;
Testis (mouse)	18	mGy/day	No effect on sperm production.	Fabrikant, 1972.
Testis (human)	0.15	Sv	Temporary sterility.	BEIR V, 1990.
Testis (human)	2.0	Sv/year	Permanent sterility when received for many years.	ICRP, 1990.
Testis (human)	0.4	Sv/year	Temporary sterility when received for many years.	ICRP, 1990.
Testis (human)	3.5	Sv	Permanent sterility when received as a single dose	BEIR V, 1990.
GENETIC EFFECTS				
Testis (human)	0.005	Sv^{-1}	The nominal hereditary effect coefficient for severe effects including multifactorial effects.	ICRP, 1991
Testis (primates with translocations)	<0.5	Gy	Several species showed definite translocations at doses of 0.5 Gy.	UNSCEAR, 1986.
Testis (humans with translocations)	<0.78	Gy	A NOAEL[a] was not determined in this case. The level given was the lowest level tested, hence NOAEL could be considerably less.	UNSCEAR, 1986.

Note: a. NOAEL = No Observed Adverse Effect Level

b. Maternal Effects

The radiosensitivity of the ovary is dependent on its degree of maturation and differentiation. The ovary is affected differently by radiation, as the number of oocytes in the ovary decreases throughout adult life through physiological attrition, and to a lesser extent, ovulation. Although less sensitive to radiation than the spermatic epithelium, a single dose of ionizing radiation large enough to kill an oocyte could result in sterility, as no new oocytes can be generated. Similar genetic damage to that described above can also occur in females. For dose-related health effects, see Table 3.22. The genetic effects of an average population exposure to ionizing radiation can be found in Table 3.24.

Table 3.22
Maternal Effects of Ionizing Radiation

Organ	Dose	Units	Effect	Reference
Ovary (human)	N/A	N/A	The threshold for permanent sterilization decreases with increasing age.	Upton, 1987.
Ovary (human)	0.65	Gy	Threshold for temporary sterility.	BEIR V, 1990.
Ovary (human)	2.5-6.0	Sv	Threshold for permanent sterility when received as a single dose.	BEIR V, 1990.
Ovary (human)	>0.2	Sv/year	Permanent sterility when received as highly fractionated for many years.	
Ovary (human)	6.0	Sv	Threshold for permanent sterility when received in highly fractionated or protracted exposures.	BEIR V, 1990.

c. Developmental Effects

c.1 Structural Deficits

Development of all mammalian species commences with the formation of a zygote, or fertilized egg. Following development through the morula, blastocyst, gastrula and embryo stages a fetus is formed. The fetal stage, which lasts for most of the pregnancy, has all basic tissue patterns in place, but is immature. The process of fetal growth is one of maturation, resulting in an individual who can survive without maternal life-support. Fetal development requires many intricate steps on the molecular, cellular and tissue level. For normal development to occur the well orchestrated sequence of events must occur in the correct time and place; failure to meet these time and space requirements causes abnormal development. Because there are so many steps in normal development, it is often difficult to attribute a specific type of abnormal development to a specific agent.

The outcome of developmental damage will depend to some extent on the stage of development. For this reason, damage by ionizing radiation in early development results in early embryonic death, a phenomenon difficult to detect as it occurs around the normal time for menses. Elevated levels of early embryonic death have been mistaken for infertility. It should be noted that early embryonic loss is a normal even to cull severely abnormal conceptuses. Approximately 30% of all conceptuses are lost in this manner.

Embryonic damage that does not cause genetic change usually results in perturbed physical development, which occurs when compensatory growth and other recovery mechanisms are overwhelmed, resulting in failure of tissues to reach a critical size at a critical time.

Fetal damage dose not usually produce physical abnormalities, as most tissue patterns have been determined at this time. As tissue specialization is occurring, damage to function usually occurs. In some organ systems, such as the nervous and immune systems, development continues after birth, and functional damage may not become apparent until after birth. For example, functional neurological deficits can be produced in children up to the age of 12, the time at which neural development is complete.

When considering the effects of ionizing radiation on the developing embryo it is necessary to consider the following:

1. Radiation dose. Generally the larger the dose the more likely a defect will occur.

2. *When* the dose is received is vitally important. An example of this is highlighted by the thalidomide tragedy. Only mothers who took the drug during the critical period for limb development had children with defective limbs. Embryonic development (the period of development before the fetus is formed) has periods of organ sensitivity, where a low dose of radiation can have dramatic effects. For example if a small dose of radiation is received during neural tube closure the effect may be fatal for the fetus at that time. Unfortunately, most severe defects occur before the woman knows she is pregnant (recognition of pregnancy is often made only when the fetal stage has been reached).

3. The *response* of a conceptus is individual. The response depends on the genes it inherited from its parents and the dose of radiation the conceptus, embryo or fetus received.

4. Abnormal development can, in most cases, be described by a dose-response curve. The greater the dose of radiation, the greater the probability of a defect.

5. Somatic defects are not passed on from generation to generation.

6. The range of defective development includes: death, malformation, deformation, intrauterine growth retardation and post natal functional disturbances.

The concept of the multifactorial threshold nature of anomalous development should also be noted. This concept states that every conceptus is given a set of "liabilities" for abnormal development which are additive and consist of genetic (inherited from the parents) and environmental (drugs, chemicals and physical) agents. Once a threshold of liabilities has been reached, abnormal development ensues. For this reason a conceptus with few liabilities could receive a larger dose of ionizing radiation than another conceptus with many liabilities, before abnormal development occurred. In other words, not all individuals will show defective development given the dose of radiation at the same stage of development. For dose-related health effects see Table 3.23.

Table 3.23
Human Epidemiology Studies on Somatic Damage Caused by Ionizing Radiation (Tissue Damage Causing Birth Defects) Exposure in Utero

Dose	Units	Effects	Reference
0.56-1.39	Gy	Leukemia within 15 years of life	Bithell and Stiller, 1988; Monson and MacMahon, 1984; Harvey et al., 1985; Stewart, 1987; Clarke et al., 1991[a]
0.5	Gy	Severe mental retardation	BEIR V[b]
0.1-0.2	Gy	Impaired school performance	Schull et al., 1988.
180-735	Gy	Abortion and polyploidy	Alberman et al., 1972.
N/A	N/A	Microcephaly	Plumber, 1962
0.6 -1.5	Gy	Cataract development	Merriam et al., 1972.

Notes: a. An excess of childhood leukaemia cases was found by Clarke et al. (1991) as determined by the mortality ratio by residence at birth for areas near two Ontario nuclear facilities including Pickering NGS. The authors suggest that the findings may be due to chance alone. However, further epidemiological studies of the issue have been launched.

b. Fetuses exposed to the atomic blasts in the second world war at 5-15 weeks of gestation were more severely affected than fetuses further along in gestation (Otake et al. 1987).

c.2 Functional Deficits

Anomalous functional development may occur as a result of both somatic and genetic damage by radiation. Although somatic damage is more common, genetic defects (especially mutations) can have severe effects on functional performance. For example, in some species a defect in development of the cerebellum (the part of the brain responsible for coordination) affects the individual's motor skills. This defect can be passed on from generation to generation. The more common effect of ionizing radiation is on somatic cells: damage can severely impair cellular and tissue function. In the case of brain development, radiation kills developing nerve cells resulting in severe mental retardation.

Table 3.24
Functional Deficits in Children Following In Utero Exposure to Ionizing Radiation

Dose	Units	Effect	Reference
0.1-0.5	Gy	Ranging from minor school performance deficits to severe mental retardation	BEIR V, 1990; Schull et al., 1988.

c.3 Genetic Damage to Individuals and the Gene Pool

Genetic damage affects reproduction via causing infertility and abnormal development. The types of genetic damage that occur include: chromosomal anomalies, (aneuploidy, balanced and unbalanced translocations, deletions and additions) and mutations (point and frame-shift). Infertility can occur because of failure in the maternal or paternal development (e.g., Turner's syndrome XO individuals look like females but are infertile), or because of severe non-viable defects in the conceptus such as Down's syndrome which can be induced by radiation (Boue et al., 1975). In addition, certain mutations can lead to infertility (e.g., dominant lethal mutations). More important to the species than infertility is a non-lethal, persistent mutation which becomes imbedded in the gene pool, thus becoming disseminated among all future offspring. The defective gene will still be spread, even though the mutation may be inherited in a recessive manner. BEIR V has summarized the persistence of genetic disease in the gene pool which can be attributed to either parent receiving a rem of ionizing radiation. The predominant effect is an excess of mutations leading to autosomal dominantly inherited or X-chromosome linked diseases. For dose-related health effects see Table 3.25.

Table 3.25
Estimated Genetic Effects of 1 rem per Generation[a]

Type of Disorder	Current Incidence per Million Liveborn Offspring	Additional Cases/10^6 Liveborn Offspring/rem/Generation	
		First Generation	Equilibrium
Autosomal dominant[b]			
Clinically severe	2,500	5-20	25
Clinically mild	7,500	1-15	75
X-linked[c]	400	< 1	< 5
Recessive[d]	2,500	< 1	Very slow increase
Chromosomal[e]			
Unbalanced translocations	600	< 5	Very little increase
Trisomies	3,800	< 1	< 1
Congenital abnormalities[f]	20,000-30,000	10	10-100
Other disorders of complex etiology[g]			
Heart disease	600,000		
Cancer	300,000	Not estimated	Not estimated
Selected others	300,000		
Total	37,300-47,300	24-53	115-205

Notes:
a. BEIR V Report, Table 2-1 (pp.70-71). Risks pertain to average population exposure of 1 rem per generation to a population with the spontaneous genetic burden of humans and a doubling dose for chronic exposure of 100 rem (1 Sv).
b. The expression of a mutation arising on the dominant allele of a gene on the autosomal chromosomes (chromosomes 1-22). This conditions is inherited in a Mendelian fashion.
c. A dominant pattern of inheritance in males due to a mutation at a recessive allele on the X-chromosome. (Males have only one copy of the X chromosome.)
d. A Mendelian pattern of inheritance seen when both alleles of a gene are mutated (e.g. cystic fibrosis or Tay-Sachs disease).
e. Disorders or diseases associated with structural or numerical changes in chromosomes. Structural changes may be unbalanced, usually resulting in early death. Numerical changes are called aneuploids (e.g. Down syndrome, characterized by trisomy-21- three instead of two copies of chromosome 21).
f. Malformations due to complex interactions of hereditary and environmental factors. These may be present at birth and not detected until later in life. The genetic component does not appear to follow a Mendelian pattern of inheritance.
g. These tend to be multifactorial diseases. The genetic component may provide a predisposition to the effects of environmental and other factors.

c.4 Carcinogenesis

Ionizing radiation-induced carcinogenesis is not limited to post-natal exposure. The same principles of radiation-induced carcinogenesis hold true for the developing child. Development of cancer during life can, in some cases be traced back to *in utero* exposure, even though the tumour was not evident at birth. Dose-related health effects for leukaemia are presented in Table 3.23.

d. Conclusion

Ionizing radiation poses a short term and long term hazard to human reproduction and fetal development. At low doses, infertility may result from fatal somatic and genetic changes to sperm or ova, or severe damage to an early conceptus. Low doses may also cause infertility through the production of abnormal sperm and ovum and the production of a conceptus with a lethal mutation. Low doses may produce abnormal development through damaging developing tissue so that time and space requirements are not met. Finally, subtle functional changes (such as mental retardation of varying degrees) may occur at very low doses. Long-term effects of ionizing radiation are harder to evaluate, but include: cancer, decreased life expectancy and chronic diseases. Immunosuppression (a radiation-type immunodeficiency) quite probably occurs, but retrospectively is often difficult to establish causality.

In summary, radiation causes both tissue and genetic damage. Both types of damage can result in infertility, fetal death, intrauterine growth retardation, functional deficits, structural abnormalities, cancer, long-term debilitation and genetic defects. The dose, type of radiation and period of development in which the radiation is received, are all important determinants of the effects of exposure to ionizing radiation.

The effects of ionizing radiation documented herein are not expressed in the irradiated individuals themselves but in their immediate offspring and in future generations. Under the hypothesized conditions of Table 3.25 (wherein one parent of 1,000,000 live offspring each had received 1 rem of radiation), an estimated range of 115-205 cases of genetically defective births would be permanently added to the genetic pool in each successive generation. Although the numbers are small in relation to the number of live births (some 0.01-0.02%) and to the number of currently estimated congenital defects (some 0.25-0.55%), any increase is cause for serious concern. To keep these estimates in perspective, the reader should bear in mind that, by the age of 30, the average person would have received a total of about 7 rem of radiation from natural sources (see Table 3.3). This issue is discussed further in the next section of this chapter.

3.10 A Discussion Surrounding the Uncertainty Underlying Estimates of the Genetic Effects of Ionizing Radiation

This section was prepared by R.Bertell and reviewed by M.Goldberg (GlobalTox International Consultants Inc.).

a. The Source of Uncertainty

A major difficulty in assessing genetic and teratogenic effects of radiation exposure and providing risk coefficients linking dose and response is the inability of the atomic bomb data to provide rough estimates (in contrast to the situation with respect to cancer induction). Even in the newest studies using the DS86 estimates, atomic bomb researchers caution against depending on this database for risk coefficients. There are several possible explanations: genetically impaired individuals in Hiroshima and Nagasaki were less likely to survive the early trauma, producing a healthy survivor effect; or a bias may have been introduced by the researchers matching of high and low-dose survivors by age and sex. Genetically significant doses were not calculated, and it is possible that medical examination of the offspring for congenital effects may have taken place too late to detect those severely damaged offspring who died before puberty.

More accurate databases for childhood cancer now exist. The largest and most consistent base is that developed in Britain by PHC expert A. Stewart. Her Oxford Study contains all childhood cancer deaths in the UK since 1950, with child controls matched for sex, date of birth and same interviewer (doctor or nurse). Consequently, it is among the best data available for childhood cancer.

A. Stewart was the first to show a statistically significant association between medical X-ray exposure *in utero*, at about 5 mSv, and childhood cancer. She also demonstrated a statistically significant association between background radiation exposure and childhood cancer. The X-ray association has been confirmed in other studies (see Table 3.25) and the risk coefficient was recognized by BEIR V as being consistent with atomic bomb data.

In 1957, WHO recognized the value of the Kerala, India, population living on thorium monazite sand as an appropriate population to use as a database for chronic low dose radiation exposure. With the exception of two studies on Down's Syndrome, this database was not fully exploited until 1988-89. The research on this database, which now consists of more than 92,000 births, has not yet been analyzed, although it should provide systematic dose estimates, background data on both parents and detailed medical investigations. In future assessments, it is hoped that realistic genetic and teratogenic data will be available from this database. The absence of risk coefficients cannot be equated with the absence of genetic and teratogenic effects.

There can be no doubt that ionizing radiation, even at low doses, can cause genetic damage. The International Atomic Energy Agency publication on Electricity and the Environment (IAEA-TECDOC-624 Background Papers for the Senior Expert Symposium, Helsinki, 13-17 May, 1991) notes the cellular damage due to radiation is as follows:

1. ***Loss of proliferative capability***. This type of damage becomes critical only when a high proportion of the stem cells of a functional unit is affected. This would include permanent sterility. The effect shows a steep dose/effect relationship with a threshold in the range of Sieverts.

2. ***Cell mutation***. This type of damage results in changes in the DNA of germ cells increasing the potential of genetically caused defects. There does not appear to be a threshold for cell mutation.

Genetic mutations are normally point mutations or deletions resulting in frameshift mutations (see Section 3.9 above for details). They require breaking the chemical bonds of the DNA, typically only 3 eV energy per bond. Ionization of an atom requires 10-15 eV. Radionuclides of the type released from a nuclear plant disintegrate with releasing energy in the range of 10,000 eV (10 keV) to 5,000,000 eV (5 MeV). For example, the noble gas Krypton 85, which is not monitored at nuclear facilities in Ontario, releases a maximum of 670 keV with each disintegration. Tritium energy release is 18.6 keV maximum energy and an average of about 5 keV with each emission of a beta particle, and can cause breaks in the weaker 3 eV chemical bonds of the DNA. The OBT can be incorporated into the cell itself and is cleared from the body more slowly than tritiated water. It is quite feasible that a single atom of Krypton 85 or of tritium could produce a mutation in human DNA.

A recent study commissioned by the AECB found significantly high levels of Down's Syndrome in Pickering and attempted to corrolate this with tritium releases. R. Bertell has prepared a critique of this study. The finding comes at a time when the presence of OBT in fruits, vegetables and foliage in the area also appears to be high according to Ministry of the Environment measurements and those commissioned by H. Sharma. As noted earlier, non-equilibrium OBT effects need to be examined. For discussion of tritium in equilibrium with the environment see Section 3.5.

Bertell notes another study undertaken in the vicinity of the CANDU reactor in Rajasthan, India, which has found significant untoward pregnancy outcomes and congenital anomalies. The study was carefully designed and involved medical examination of every suspected case in every household. There was a well matched control population surveyed in the same way as that of the village near the reactor. Many confounding variables were examined. The only one which may have biased the study away from finding anything abnormal near Rajasthan was the excess exposure to pesticides in the control village.

In summary, low dose ionizing radiation such as that released routinely from nuclear generation stations is capable of causing mutations in living cells. Acceptable dose-response quantification is not currently available from human data and most regulatory estimates rely heavily on animal (usually mouse) data.

b. Genetic Load

Bertell notes a publication by Herman Muller (1964), who received a Nobel Prize for his work on radiation and genetics in 1946, which identifies important principles:

1. While there are thousands of different kinds of mutations which produce their effects by the most diverse biochemical mechanisms, the overwhelming majority are harmful to the cell in one way or another.

2. When the mutant gene is received by an offspring from only one of its parents, as it usually is, with the other parent contributing a corresponding normal gene, resulting in what is called a heterozygote individual, the mutated gene does much less than twice the harm that it would do in an individual that had received it from both parents alike (homozygous), i.e. the mutated gene tends to be recessive and the normal gene dominant.

3. The dominance of the normal gene is seldom complete and the mutated gene may reduce the fitness of the heterozygous individual.

Muller uses as his example a gene which mutates, reducing fitness by 5%. Such an individual has a 1 in 20 chance of genetic death (failure of reproduction or inability of the offspring to survive to reproduce).

Muller is credited with elucidating the concept of genetic load, the accumulation of defective genes in a population. He has stated:

> if the load of mutations is increased in a non-specific way, as by an increase in the general frequency of mutations caused by radiation, the main influence exerted on the population is a decrease in fitness and vigour all along the line...an increase in frequency and intensity and a lowering of the age of onset of the kinds of infirmities that are common anyhow. [Muller, 1964; p.45]

Searle and Edwards (1985) have provided numerical risk estimates for recessive mutations. These harmful recessive mutations can arise at all loci coding for essential proteins (estimated to be at least 10,000). In contrast, mutations to dominant alleles appear to occur at relatively few loci. According to UNSCEAR (1986, page 100), those recessives known at present tend to have earlier and more severe effects than dominants. Induced recessive mutations can cause harm by:

1. partnership with another defective gene already in the population;
2. partnership with another recessive mutation induced at the same locus;
3. formation of homozygous decendents;
4. heterozygous deleterious effects.

Based on both human data and mouse experiments, Searle and Edwards (1985) concluded that a genetically significant dose of 0.01 Gy of X or gamma radiation received by each parent once in a stable population with a million live-born offspring would induce up to 1200 extra recessive mutations. Due to partnership there would be one extra case of a recessive disease; after the fourth generation homozygotes would arise; under certain circumstances ten extra cases of recessive disease would occur and 250 recessive alleles would be eliminated by "genetic death" by the tenth generation. These authors assumed a 2.5% reduction in heterozygote fitness.

It is clear that the ability of ionizing radiation to produce a lasting genetic load on future generations needs to be taken into consideration when regulating acceptable limits for routine emissions and in finding solutions to nuclear waste disposal and reactor decommissioning. The new laboratory tools and new epidemiological data, such as that from Kerala, India may help to clarify many disputed points in medical genetics.

c. Regulation of Genetic Load

Although geneticists such as Muller, Searle and Edward take heterozygotes seriously, regulatory bodies have tended to ignore them. The reason for this is the potential selective advantage of heterozygotes who carry mutations with a long history in the population. These are presumed to have had an original and probably local survival advantage. The example commonly used is the sickle cell anaemia gene, which is severely debilitating and can be lethal in the homozygous individual. In Africa, where it originated, heterozygotes had greater resistance to infection with malaria, which was a survival advantage. However, among the 7 to 13% of Black Americans heterozygous for sickle cell anaemia, researchers have noticed hypersensitivity to and increased risk from aromatic amino and nitro compounds, carbon monoxide and cyanide (Grandjean, 1991). It is now customary to call these heterozygotes persons with sickle cell trait. This issue of decreased fitness of heterozygotes is not dealt with in the estimates provided by BEIR V as shown in Table 3.25. Predicting the genetic load carried by heterozygotes and the effects of radiation exposure on this load has proven difficult. Some of these effects should show up in the last row of Table 3.25.

The last category of genetic disease in Table 3.25, disorders of complex etiology, covers a large number of illnesses known to "run in families": cancer, heart disease, diabetes mellitus, schizophrenia, etc. UNSCEAR (1977) estimated an incidence rate of 9% and predicted an increase in these types of diseases with radiation exposure based on prevalence data collected in British Columbia by Trimble and Doughty (1974). The B.C. study examined only those under 21 years of age.

The authors recommend the prudent measure of further investigation of Down's Syndrome in Pickering and Ajax using a case/control methodology. However, they note that "some statistically significant associations are a likely outcome when many statistical tests are done. Therefore, such a screening process must be viewed as a hypothesis-generating exercise and the potential for significant associations by chance alone should not be underestimated." [Johnson and Rouleau, 1991; p.iv]. A detailed review of the Johnson and Rouleau study is to be found in the Bertell paper (dated August 31, 1992).

In view of the importance of the findings of this PHC analysis, their implications and the contentious nature of the issue the PHC recommends:

RECOMMENDATION 3.1: The PHC recommends that an alternative based on the nuclear option should not be approved. There are unacceptable adverse health effects and associated health costs, including excess cancer deaths, non-fatal cancers, genetic and teratogenic effects arising from the nuclear option.

RECOMMENDATION 3.2: The PHC recommends, if an alternative based on the nuclear option is to be approved, that as a condition of approval Hydro be required to conduct research into sustainable life compatible alternative technologies, reduce radioactive emissions including tritium, carbon-14 and other radioactive emissions, and prepare a comprehensive and ongoing health impact assessment of nuclear power production.

RECOMMENDATION 3.3: The PHC recommends, if an alternative based on the nuclear option is to be approved, that as a condition of approval Hydro develop the following: a system to better monitor radionuclide emissions including the noble gases, correlated stack and ground monitoring systems for airborne radionuclide emissions from all Hydro facilities, and similar systems for waterborne radionuclides.

RECOMMENDATION 3.4: The PHC recommends, if an alternative based on the nuclear option is to be approved, that as a condition of approval Hydro be required to establish a comprehensive database consistent with the U.S. and U.K. databases for the follow-up of all Hydro workers employed for at least three years in jobs involving radiation exposure.

RECOMMENDATION 3.5: The PHC recommends that the proposed agency perform appropriate dispersion modeling studies for radionuclide emissions from all Hydro nuclear facilities. The studies should move toward site-specific dose reconstructions. The studies should enable the development of more accurate human radiation dose estimates, as well as the confirmation of or proposals to modify performance standards (i.e. DELs) for all such facilities.

RECOMMENDATION 3.6: The PHC recommends that the proposed agency recommend the time frame to be considered in determining radiation doses to future generations arising from current emissions of Hydro nuclear facilities. The agency should consider the time frame to be incorporated into its methodology for determining site-specific DELs.

RECOMMENDATION 3.7: The PHC recommends that the proposed agency discuss and research the issue of low dose, low dose rate effects of ionizing radiation and monitor the literature emerging in this area.

RECOMMENDATION 3.8: The PHC recommends that the proposed agency undertake a study of radionuclide dilution, persistence and elimination rates in fresh water lakes to determine an appropriate guideline for effluence releases into Ontario's lakes.

Chapter 4
Health Effects From the Fossil Fuel Generating Option

Although Hydro's 1989 Demand Supply Plan [DSP] considered the fossil fuel option, its 1992 Update chose to postpone a further examination of this option until later in the decade. The information in this chapter should be used to evaluate any alternatives to Hydro's current undertaking which rely significantly on fossil fuel.

4.1 Introduction

This chapter attempts to determine the health effects resulting from the use of fossil fuel generating options to produce electrical energy in Ontario. The material for the main topic of this chapter, the possible health effects from SO_2 (sulphate pollution) and Total Suspended Particulate [TSP] emissions from Hydro fossil fired generating stations, was derived from the PHC commissioned study by Prof. L.D. Pengelly, McMaster University, as well as from the ensuing dialogue between Prof. Pengelly and Dr. Robert Dales, University of Ottawa, and Dr. Ron Brecher of GlobalTox International Consultants Inc. (see: Pengelly, 07/01/92; Pengelly, 09/30/92; Dales, 09/08/92; and GlobalTox, 09/24/92).

Pengelly reviewed studies of the respiratory health effects of respirable particulates, aerosol sulphates and other "classical" pollutants (e.g. ozone, sulphur dioxide, total suspended particulate, oxides of nitrogen, carbon monoxide, etc.). His objective was to find studies quantifying the relationship between Hydro's fossil pollutants and health effects, to determine associated health costs.

This review strategy yielded substantive evidence for adverse health effects of pollutants emitted or produced as a result of fossil fuel combustion, at pollutant levels currently existing in Ontario. Various studies showed evidence linking non-accident mortality, respiratory mortality and cardiovascular mortality with levels of fossil combustion pollution. These discoveries justified the expansion of health concerns beyond respiratory-related health effects.

The Hydro study by Plagionnakos and Parker (Pengelly: Reference 41) demonstrates strong associations of health outcomes with sulphur dioxide, particulate and sulphate pollution in Ontario. The strongest associations of outcomes have been with non-cancer indicators of morbidity or mortality, probably because of the overwhelming effect of tobacco smoking on cancer in the population.

A modified approach to that previously adopted by Concord Scientific for Hydro (Pengelly: Reference 42), involving the use of "elasticities", described the dose-response relationship between pollution exposure and health outcome. By integrating the product of population and pollutant distributions around a source of pollution dispersion, it was possible to compute health outcomes associated with different emission scenarios.

The results of these calculations quantify the burden of mortality and morbidity associated with fossil-fuelled power generation in Ontario. For sulphate pollution, for example, the numbers may be as high as 52 respiratory deaths and 9,000 days spent in hospital per year (based on 1989 data). By employing proposed fossil fuel supply configurations as proposed by Hydro in its 1992 Update as well as assumptions concerning population growth and pollution abatement practice over the DSP planning horizon (1989-2014), it was possible to develop projected ranges for health effects from fossil fuel burning in Ontario to the year 2014.

4.2 Concepts and Terminology

In addition to carbon dioxide and water, combustion of fossil fuels produces a number of other products which are emitted into the air. Some of these substances have significant detrimental effects on the environment and on human health.

Hydro is one of the largest Ontario generators of sulphur dioxide (SO_2), second only to emissions associated with mining operations in the Sudbury area (see: GlobalTox, 09/24/92). Nitrogen oxides (NO_x), including nitrous oxide (N_2O), nitrogen dioxide (NO_2), nitric oxide (NO) and nitrate (NO_3^-) are also produced during combustion. Hydro is likely responsible for less than 25% of NO_x emissions affecting Ontario (see GlobalTox: 09/24/92). These substances are often collectively referred to as *acid gases*. They dissolve in water to yield acidic solutions, resulting in acid precipitation. These chemicals and their acidic aerosols are also associated with a variety of health effects. In particular, SO_4 may be up to 5 times as important as SO_2 as a determinant of adverse health outcomes.

A number of other substances are produced in smaller amounts. These include metals, organic compounds and carbon monoxide. Emitted metals, including lead and arsenic, represent a small fraction of Hydro's emissions. Furthermore, these substances come from other environmental sources which are likely to be more important than fossil fuel-fired power generating stations. The organic compounds emitted include hydrocarbons, the most significant of which are the polynuclear aromatic hydrocarbons, including benzo(a)pyrene. Other major sources of environmental benzo(a)pyrene and other hydrocarbons are tobacco smoke, incinerator, industrial and vehicle emissions. These organic compounds are present as components of particulate matter (particles of soot and smoke) and as gases. Metals and metal oxides may also be released as particulates.

Chemicals produced during the combustion of fossil fuels may react with other materials present in the air. In this way, NO_x can react with volatile organic materials in the atmosphere, under the influence of sunlight, to produce *photochemical smog*, a complex mixture of many organic and inorganic chemicals. NO_x emissions play an important role in the generation of ozone in the troposphere (the layer of atmosphere closest to the earth). However, most tropospheric ozone in Southern Ontario comes from emissions originating in the U.S. (see: GlobalTox, 09/24/92).

4.3 Background to Issue and Review of Scientific Literature

Fossil-fuelled thermal electric power generating stations [FFGS] emit a fairly well-defined group of pollutants into the atmosphere. The specific character and amount of these pollutants, as well as the variation in emission rates over time, depends on the nature of fuel burned, the power demand, and the nature and effectiveness of pollution abatement equipment and procedures.

The distribution of the emitted pollutants and the generation of secondary pollutants by atmospheric chemistry depends on the air pollution meteorology, which itself is a function of geography and climate. The outcome of this complex process determines the quality of the ambient air (the air available for breathing). Ambient air quality can be measured by networks of monitors, and described qualitatively and quantitatively in terms of the distribution in space and time of the concentrations of a variety of pollutants.

The health impact of the ambient air quality depends on the dose received by the population either to the original emitted pollutants themselves, or to secondary pollutants which arise from chemical reactions taking place in the atmosphere. In turn, the dose depends on the location and activity of the persons exposed (e.g. outdoors vs indoors; rest vs exercise) and the presence of other sources of the same pollutant species.

The expected health effects depend on host factors, such as individual susceptibility (e.g. youth, age, chronic lung disease), confounding factors (e.g. occupational exposure, tobacco smoking) and interactions between pollutants.

The health effects used to assess the health impacts of pollutants must conform to explicitly stated criteria. For example, sulphur oxides have a characteristically unpleasant smell which might be objectionable to citizens, leading to a sense of stress. On the other hand, there is evidence that high levels of SO_2 and TSP lead to an increase in the death rate in infants and the elderly. In between these effect types lie such measures as increased emergency visits or hospitalization for respiratory disease associated with air pollution, or acute small and reversible changes in pulmonary function in children associated with brief exposures to ozone. From the point of view of health economics, this submission will provide a framework for quantifying the dollar cost of premature death, or of increased rates of health services utilization. It is much less clear how effects such as the perception of odour, or brief and reversible changes in pulmonary function should be regarded in determining priorities of action in the field of public health.

In addition to carbon dioxide (CO_2) and water (H_2O), FFGS emit other oxides of carbon (CO), nitrogen (NO, N_2O, NO_2, referred to as a group as NO_x), sulphur (SO_2), and trace metals. Depending on the fuel, there may also be emission of organic compounds, especially under transient load conditions. Electrostatic precipitators reduce the emissions of particulate material to a small fraction of that generated by the combustion process. Nevertheless, those particles which escape the precipitators or filters are typically very small in size, and as a consequence can float easily into the lung, carrying with them other gas or liquid pollutants.

Many early studies of the health effects of SO_2 and/or suspended particles (sometimes referred to as "smoke") were initially carried out in locations where the level of these pollutants was very high by today's standards. The relatively unsophisticated design of these studies may have resulted in an underestimation of the effects of these "classical pollutants".

Relatively less work has been carried out to examine the population health effects of NO_x, but there is little evidence for direct effects of NO_x at the ambient levels at which it is found. On the other hand, the photochemical reaction involving NO_x and volatile organic compounds (VOCs) produces the oxidant ozone (O_3), which has well established health consequences, especially in combination with other pollutants.

Acid aerosols, formed as a consequence of the emission of acid gases (principally SO_2 and NO_X) and possibly fine metal oxide aerosol from FFGS, are also a serious concern. When this cloud of pollutant moves over distances (tens to thousands of kilometres) without being scavenged by precipitation in the atmosphere, chemical reactions take place that give rise to fine aerosols of acidic haze, of which the most toxic appear to be sulphuric acid mist (H_2SO_4). The production of the more toxic acid aerosols may be facilitated by O_3. Generally, the atmospheric conditions that favour the generation of ozone also favour the reactions that give rise to acid aerosols. Thus it appears that acid aerosols reach their highest concentration in Ontario in late spring and during the summer.

The connection of ozone with acid aerosols has not yet been fully established, but it gives new urgency for the concerns with respect to NO_x. The level of naturally occurring VOCs in Ontario is high (Management Plan for NO_x and VOCs [Canadian Council of Ministers of the Environment, 1991]). Reducing NO_x emissions is the most effective strategy to control ozone levels in Ontario.

A critical appraisal of health studies involving exposure to the following pollutants and/or their combinations was undertaken to assess the respiratory consequences of pollutants associated with Ontario FFGS: sulphur dioxide; suspended particles (including effects of size and composition); nitrogen dioxide and nitric oxide; acid aerosols (including sulphuric acid mist); ozone; trace metal and trace metal oxide aerosol; other gaseous pollutants (such as carbon monoxide); and toxic organics (dioxins, etc.).

In the contemplated modeling exercise, Pengelly considered it necessary to have more complete emission data (such as concentration of specific metal oxides and inorganic compounds in stack effluent), together with atmospheric chemistry, transport, distribution of ambient levels with respect to population distribution, and exposure estimation models to relate effects found in other studies of the Ontario situation.

Pengelly reviewed the epidemiological literature from 1979 onwards which examined the effect of air pollution on health, and which used regression techniques to model dose-response relationships. His report summarizes this review and shows the outcomes and pollutants, regression coefficients and elasticities for different outcome measures as a function of exposure to different pollutants.

The standard setting process for evaluating the cost of the health effects of fossil-fired electric power generation is summarized in the following quote from a review of air pollution epidemiology by Holland *et al.* which appears in the Pengelly report:

> At first glance, it appears perfectly logical to examine the decision process from the standpoint of weighing the risks of continuing or permitting the use of particular substances or processes against the benefits their use might confer on society. But such a simplistic if attractive approach suggests that the data for making such a decision are always available in adequate quality and quantity. This is clearly not the case. And there is also an inherent assumption that the benefits can be properly determined, and that these benefits will be regarded by all individuals in the same way as the regulator views them, from the standpoint of public good. Again, it would be naive to suppose that this were so. In the real world, standards must obviously be set to balance the level of health risk with economic and other considerations in a way that is socially, economically, and politically responsible.

4.4 Emissions from Hydro FFGS

a. Forecasted FFGS Capacity Needs

In the 1989 DSP, Hydro identified a need for 18.0 GW of new capacity which, in the proposed plan, was to be met by a mix of fossil (5.4 GW), nuclear (8.8 GW), Manitoba purchase (1.0 GW) and hydraulic (2.8 GW) components (Reference: 1992 Hydro Update, Fig.8). The 1989 plan also called for retirements of about 6.7 GW of fossil generation by 2014. The updated plan calls for 6 GW of new major supply with fossil generation retirements of about 2.4 GW (Hydro Update, Fig. 8). The need for approvals for this new supply has been deferred in Hydro's updated proposal.

Hydro makes no mention of the "Cases" it used in the original DSP in its Updated Plan. It is therefore more difficult to determine Hydro;s approach to meet the needs of power generation to 2014. In defining SO_2 emissions, for example (Update Fig. 9-4) only one profile of emissions is shown until 2010; beyond that date the profile changes depending on whether the "fossil" or "nuclear" option is chosen. This is a departure from the approach described in Figure 15-33 (DSP 1989), where many different profiles were shown, depending on the Case selected. In Section 6 of the Update, reference is made to "Appendix C", in which an "environmentally enhanced alternative" increased the level of emissions control from fossil stations. There is, however, no indication of the degree to which Hydro is committed to the environmentally "enhanced" option, although it is clear that this could lead to substantial reductions in SO_2 and NO_x emissions by the year 2000. However, if the "fossil option" is selected, even with the "enhanced" choice, by 2014 the emissions of both these species would have more than doubled from their levels in the year 2000. One useful working assumption might be that the "fossil option" is similar to "Case 26", applied to the "median load forecast" of the original DSP. This indicates that 33% of the load in 2014 (or approximately 10 GW) will be supplied by fossil fuel (DSP Plan Analysis Figure 6-10(c)). The maximum capacity of Hydro non-mothballed FFGS is 11.6 GW, and including mothballed sites is 13.2 GW. Thus

Hydro must be planning on operating all of its sites at a load level of 76% (10/13.2), or if only currently operating sites are considered, at 86% of capacity. In 1989, FFGS were operating at 37% of capacity.

b. Other NO_x Sources in the DSP

Hydro intends to reduce its new capacity requirements through demand management initiatives which include incentives for the customer to use less electricity (through the use of more efficient appliances, and fuel switching). Fuel switching involves Hydro incentives to switch from electricity to natural gas (Update, Section 3), typically in the area of residential and commercial space and water heating. Customers will be encouraged with financial incentives to replace electric heating systems with high-efficiency gas furnaces or boilers.

An estimate of the increases in NO_x emissions resulting from fuel switching can be made from data supplied by Hydro. The fundamental assumption is that gas will replace electricity in a significant fraction of circumstances. Data in Figure 3-1 (update) indicates that by 2014, 3.3 GW of electrical power will have been displaced by fuel switching, representing 3.3/31 or 11% of the total power requirement. Other assumptions are:

1. Thermal efficiency of FFGS is 40% (Exh. 465, Thermal Cost Update);
2. Thermal efficiency of heating is 90% (modern HE condensing gas furnace);
3. NO_x emissions of heating equal FFGS (likely an underestimate); and
4. 33% of power supplied for heating was generated by FFGS.

Thus, 3.3 GW of electric heating could be replaced by (3.3 x 0.4)/0.9 = 1.5 GW gas combustion. This represents an increase of 1.5/(.33x31) or 16% in FFG NO_x emissions.

Hydro appears to overlook the fact that an increased reliance on Non-Utility Generation [NUGs], of which Hydro estimates 74% will be natural gas fuelled (Figure 4-1, DSP Environmental Analysis [DSP EA]; Section 4, DSP Update), will lead to a major increase in NOx emissions. Hydro estimates that NUGs emissions "will be quite similar to larger conventional generating stations" (DSP EA, p 4-2) The proposal is for 4,200 MW of NUG power by 2014, implying a substantial increase in NO_x emissions. This increase can be estimated from the data for Fig 9-1 (Update) to be (0.74x24.4)/(27.9+26.6) or 33%.

By inclusion of the NO_x emissions from fuel switching and NUGs (Update, p. 25), the actual emissions can be estimated to be close to 50% greater by 2014 than Hydro has indicated, as a direct result of the actions built into the updated Plan. The increase in the number of high efficiency gas-fired home heating systems with exhaust close to ground level will increase the population's exposure to NO_x, especially during periods of stable boundary layer conditions in urban and suburban areas, such as in the October-November and February periods. Because the product of average exposure times number of persons exposed would be smaller, the public health problem would be smaller.

The environmental consequences of NO_x exposure from the short stacks of Combustion Turbine Units [CTUs] may be much greater than that from the Conventional Steam Cycle [CSC] generation which typically emits from tall stacks. Indeed, Hydro stated that NUGs tend to be "smaller, localized and more dispersed... across the province" which would point to a greater concern with respect to short-range effects of NO_x and perhaps ozone, than the long-range effects associated with NO_x emissions from tall stacks. The health effects of NO_x from these sources are thus likely to be greater than similar emissions from CSC sites.

c. Synthesis of Hydro FFGS Emissions Data

Hydro's DSP Update-1992 indicates that it is not currently requesting approval for major new fossil and nuclear supply because of "economic conditions, more demand management, additional economic non-utility generation, and the extension of fossil station lives. Most of the need for major supply now occurs later in the planning period. This is beyond the period for which Hydro is seeking approvals." Hydro clearly intends to use a growing fraction of its fossil capacity to generate electricity in the future, and for this reason all existing fossil sites, whether currently in operation or currently "mothballed" must be regarded as potential sources of future pollutant emissions and their concomitant problems. A reasonable estimate of Hydro's intentions by 2014 is that 33% of power generated will be from FFGS (Section 4.3.a. above) representing a substantial increase from the current level of 25% (DSP).

Estimates must be made of the pollution distributed by each major station and the population impacted by that pollution to determine the health impacts of FFGS. While various Hydro reports provide some of that information, there is no evidence that these reports have been validated or subjected to independent scrutiny. In order to carry this out, some basic information with respect to the FFGS locations needs to be summarized, as it does not appear together in a single document. Although pollution research relies on Hydro to provide generation and emissions data, there is some independent validation of these by way of ambient air pollution measurements made by the Ministry of the Environment.

On the basis of information provided by Hydro and Pengelly, FFGS-specific data on energy flux, fuel consumption, pollutant emission, combustion technology, fuel type, stack height, meteorological data, geographical location, etc., has been synthesized where available. This was done for the six active sites (i.e. Nanticoke, Lennox, Lakeview, Lambton, Thunder Bay [U2, U3] and Atikokan) as well as for the three "mothballed" sites (i.e. Hearn, Keith and Thunder Bay [U1]). Pengelly's report provides historical information on annual power generation and pollutant emissions for these sites for the years 1986-1990 inclusive. This data was used to develop health effects models.

4.5 Development of Health Effects Models for FFGS Emissions

In the early years of air pollution science and practice it was thought that "dilution is the solution to pollution". Storm and sanitary sewers, for example, were combined with the assumption that the drainage water would dilute the sewage and disperse it into the receiving waters, thus solving the urban sewage problem. This was an effective strategy only so long as the quantity of effluent released was smaller than the capacity of the receiving waters.

Similarly, early efforts to solve air pollution problems centred on the need to disperse smoke from combustion and industrial processes at some distance from the site of origin. Since air did not flow in contained channels like water, two new aspects of the problem had to be considered: the general wind direction, and the ability of the atmosphere to disperse the pollutants. If the wind could carry the pollutants away, they would be dispersed and diluted in the process, and the higher the smokestack from which they were released, the farther the "plume" would travel before some part of it touched the ground (at the so-called *point of impingement*). By the late 1950s there were engineering "dispersion models" which could be used to predict ground-level concentration, given meteorological characteristics of the atmosphere, stack height, and physical characteristics of the stack gas (viz. temperature, heat content, and exit velocity). These models generally predicted that, under most conditions, the higher the stack, the farther away the point of impingement, and the lower the concentration of the pollutant at that point.

The following assumptions were made to simplify early modeling exercises: the stack rose above a flat, featureless plain of infinite extent, with no complicating features such as water bodies or diurnal temperature changes; no chemical or physical reactions (such as droplet formation during condensation) took place in the plume; and the concentration distribution within the plume followed well-ordered mathematical distributions. These assumptions worked well so long as the amount of pollution and the number of sources were small.

By the end of the 1950s, it was clear that the dilution strategy was not proving effective, but the approach persisted through construction of higher stacks with added technologies (such as multiple orifices to keep exit velocities high). The culmination of this strategy in Ontario was the "Super Stack" in Sudbury, a structure over 330 meters high. Most of the Hydro FFGS stacks in Ontario are close to 200 meters in height (except for CTUs which have high exit gas temperatures and velocities, and thus shorter stacks).

Dispersion modeling has improved in sophistication in recent years with the advent of powerful and accessible computer facilities. Models have been validated through actual measurements of meteorology, emissions and levels of pollution ambient at various distances from the source. Agreement is often within an order of magnitude, and sometimes as close as a factor of 2. These models work best for pollutants which are relatively unreactive, such as carbon monoxide, since it assumes the unreacted dispersion of pollutants. Unfortunately, since there are many other CO sources close to ground level, it becomes difficult to apportion the contribution of the source being modelled.

For chemically reactive pollutants, such as SO_2 and NO, and physically and chemically reactive pollutants such as particles, classical modeling techniques have been much less successful. The whole science of atmospheric chemistry, particularly as it applies to air pollution, has recently received considerable attention. Models for tropospheric (near-ground) ozone or sulphates are currently being developed and many scientists in Ontario are recognized as world leaders in this work. It remains to be seen whether these models will prove to have predictive capability for health effects.

In Hydro's Social Cost Studies [SCS] report (Pengelly: Reference 42; Section 2.2.1), methods for determining pollutant concentrations in areas surrounding Hydro FFGS sites were referenced, and the areas of impact were defined. It was stated that, by using domains of 120 km x 120 km, "there would be no outcomes at the edges of the domains."

This statement was not supported by evidence. One can only assume that at this distance the levels of pollutant predicted by the proposed dispersion model were so low as to be negligible, or that the model gave unreliable results. Concentrations of reaction products of reactive pollutant species are likely unpredictable at this range, and as a result, the use of their precursors and resultant concentrations would be unknown. While the presence of pollutants directly or indirectly associated with FFGS beyond this range is highly likely, it is difficult to predict their concentration. It is more accurate to state that outcomes may be underestimated, as none beyond 60 km will be included.

For the purposes of Pengelly's modeling effort, the same domains were used (i.e. 120 km x 120 km), centred on each FFGS. Areas of impact for each FFGS site were allowed to overlap. This had important consequences for the Nanticoke/Lakeview domains, which overlap in a heavily populated region of the Niagara Peninsula.

Major fossil sites in bordering U.S. states, from which Hydro may occasionally import electricity, also impact southwestern Ontario and the Great Lakes basin. There are two important aspects of the site locations: (1) all 6 sites are oriented more or less along the same southwest to northeast line, with the largest sites at the westerly end, such that the prevailing west-southwest winds will superimpose the pollutant plumes as they travel eastward; and (2) the overlap of the Nanticoke and Lakeview domains is over the Brantford/ Hamilton/ St.Catherines conurbation.

Pengelly obtained 1986 Census population data from Statistics Canada, and systematically mapped the population around each FFGS onto a matrix of 24 x 24 (i.e. 5 x 5 km^2) cells in each of the 120 x 120 km^2 geographic impact zones (Pengelly's report contains the tabulated results for each FFGS).

Using available data, engineering assumptions, and a guide to the distribution of pollutants for each of Lambton, Nanticoke, and Lakeview FFGS found in Hydro's SCS report, Pengelly roughly estimated pollutant distributions. The distributions are roughly pyramidal in shape, with the orientation of the diagonal of the base of the pyramid in a north-south direction for Lambton and Lakeview, and in a northeast-southwest direction for Nanticoke. These observations led to the development of simple pyramidal models for pollutant distributions which are graphically illustrated by FFGS along with their associated data matrices (calculated for a unit maximum level) in Pengelly's report.

Pengelly employed the same principle used by Hydro to estimate yearly annual levels of pollutants. Since a "generic" pattern of distribution had been established which was linear, in principle the concentration of any non-reactive pollutant could be determined by multiplying the value predicted at any point of the model by the ratio of the emission rate of the new pollutant to be modelled over the emission rate for which the model was initially developed. In the case of the Hydro "generic" model for the annual mean at Lambton, the maximum concentration was predicted of 2.65 ug/m3 for an emission rate of 1 kg/s.

An emission rate of 1 kg/s corresponds to an annual rate of 31.56 kT/year. In 1989, the emission rate for SO_2 at Lambton was 89.2 kT/yr, which corresponds to 89.2/31.56 x 2.65 = 7.49 ug/m3 maximum annual concentration. This generic conversion was used to calculate maximum values for all sites, since the other physical characteristics of the sites were similar.

4.6 FFGS Health Effects Associated with Hydro DSP

In the studies reviewed by Pengelly to determine respiratory outcomes, the authors employed functional relationships in which population health effects were related to estimated dose based on ambient levels. In his report, those functions were used to predict future health effects where the dose itself had to be estimated on the basis of ambient levels modelled from predicted emissions, source factors, meteorology and atmospheric chemistry. This approach resulted in layers of uncertainty attributable only to the estimation of dose. A conservative estimate of this uncertainty would be at least an order of magnitude.

Nevertheless, Pengelly provides compelling responses to a reviewer's comments on issues of uncertainty in connection with ambient air pollution estimates and with the relationship between air pollution levels and health outcomes (Dales: 09/08/92; Pengelly: 09/30/92).

Pengelly shows a close correspondence of about 1.2% between Hydro's reported stack emissions data for Lakeview FFGS in 1989 and independent measurements by Ortech International in regards to stack emission measures. Further, he notes the correspondence between his simplified dispersion model (modified to reflect the effects of local wind direction) and the model used by Hydro to predict long-term concentrations (originally developed by the Ontario Ministry of the Environment [MOE]).

While the relationship between power generated and emissions could lead to errors of the order of $\pm$ 10%, there is much greater uncertainty about the amount of power required in a given year, and the extent to which pollution abatement technology will be implemented in the future. Pengelly assumes that abatement technology use by Hydro will remain at the 1989 level and that 33% of the load (or 10 GW) in 2014 will be supplied by fossil fuel. He also provides reasons to support his contention that estimates of ambient concentration (given any emission level) may be in error by as little as a factor of 2 or by less than a factor of 10. Support for a reduction of the upper bound of uncertainty is provided by the Ortech study of Lakeview emissions which showed that, when operating at close to full load, this FFGS was within 80% of the Regulation 308 "allowable concentration" at a point of impingement 4 km downwind on the basis of a short-term model (Pengelly: Reference 45). Had the model predicted a value 25% higher, Hydro would have exceeded this concentration limit and been obliged to take remedial action. He states: "It is clear that for economic reasons, neither MOE or Hydro could afford to work with a model with an error bound of an order of magnitude."

Dales noted the uncertainty in the relationship between air pollution and health outcome. Pengelly addresses Dales' point that his reliance on a log-log model (based on the Hydro study by Plagiannakos and Parker) represents 'the true biological response'. Both the Hydro study used by Pengelly and that cited by the reviewer used a regional approach. The Hydro study included many confounding variables such as age, education, availability of health care, smoking and alcohol consumption to account for these factors. The elasticity values for SO_2 related outcome variables used in the models for the PHC report were all at the low end of the range found in the Hydro study; while those selected for SO_4 were at the high end. Pengelly quotes a footnoted comment from that study: "the elasticity calculated by Plagiannakos and Parker for hospital admission rates for respiratory disease related to SO_4 is likely to be a low estimate. The use of this estimate will therefore be conservative or minimal."

As indicated above, Pengelly used a log-log model approach (Pengelly: References 42,44) to predict health outcomes. This approach makes use of "elasticities" or incremental outcome/pollutant concentration ratios and combines them with existing population and air quality information. The number of health outcomes associated with exposure to a given level of pollutant by a given group of people can be estimated using the elasticity for the required outcome, information with respect to the size of the population and the pollution exposure. Health outcomes of the current effects of Hydro FFGS were calculated based on 1989 emissions and ambient data. These are shown in Table 4.1 alongside results prepared by Concord Environmental (Pengelly: Reference 44) using a variant of the same methodology.

Table 4.1
1989 Health Outcomes Based on 1989 Pollution Emission Levels

Estimates Based on Pengelly Report					
	SO_2				TSP
FFGS	Resp. Hosp. Admissions[a]	Resp. Hosp. Days[b]	Respiratory Mortality[c]	Tot.Non-Acc't. Mortality[d]	Tot.Non-Acc't. Mortality[c]
Lambton	141	978	3	17	0.043
Nanticoke	363	3,246	23	92	0.221
Lakeview	600	4,814	26	124	0.300
3-Site TOTAL	1,104	9,037	51	233	1.000
Estimates Based on Hydro Concord Study					
For total system	247	1,802	8	-	-

Notes:
a. Annual respiratory hospital admissions (based on the International Classification of Disesaes, Revision 9, (ICD-9) numbers 460-519
b. Annual respiratory hospital days
c. Annual respiratory mortality
d. Annual total non-accident mortality

Hydro's 1992 Update provides the following clues concerning the future need for fossil fuels. The Update's Figure 9-1 (Energy by Type) and Figure 9-2 (Coal Energy Production) show approximate constant fossil sourced energy production (and related coal requirements) through the planning horizon until the year 2009 when possible expansion of fossil fuel generating capacity leads to an approximate doubling in FFGS by 2014. Since the three sites considered in Pengelly's health effects study were all operating at less than half their capacity in 1989, it is a reasonable assumption that these sites will be required to double their output by 2014. Unless Hydro commits itself to a major program of emission abatement (as indicated in the "Environmentally Enhanced" scenario), there will likely be a doubling of emissions from the 1989 level, with a consequent doubling of population dose. Since the equations used to determine the outcomes are linear, this implies a doubling of outcomes.

An assumed population growth of 1% per year over the 25 year planning horizon leads to an overall increase of 28% during the 1989-2014 planning horizon. The projected health outcomes should increase proportionately with this growth if the population distribution remains similar to its current pattern. However, current predictions assume an intensification of urbanization in southwestern Ontario with a consequent increase in adverse health effects. Rather than attempting to quantify this urban intensification, Pengelly simply applied the 28% population growth to yield a scaling factor of approximately 2.5 (2 x 1.28 = 2.56) for the 1989 level of outcomes to arrive at comparable values for 2014. The results of these calculations are shown in Table 4.2 alongside the Concord results for the same year.

Table 4.2
2014 Health Outcomes Based on 1989 Pollution Emission Levels

Estimates Based on Pengelly Report					
	SO_2				TSP
FFGS	Resp. Hosp. Admissions	Resp. Hosp. Days	Respiratory Mortality	Tot. Non-Acc't. Mortality	Tot. Non-Acc't. Mortality
3-Site TOTAL	2,760	22,593	128	583	2.5
Lennox	38	288	1	7	0
FFGS Total	2,798	22,881	129	590	2.5
Estimates Based on Hydro Concord Study					
For total system	1,057	7,813	38	-	-

Note that the Concord estimates assume a substantially increased level of pollution abatement as compared to 1989 levels and were generated using Hydro's DSP Plan Option 26 (all new fossil supply). A number of limitations to his study were identified by Pengelly and by one of his reviewers (GlobalTox: 09/24/92).

4.7 Sources of Uncertainty

Health effects may be underestimated by the exclusion of cancers associated with trace metal emissions of Hydro FFGS. The two Concord reports prepared for Hydro show less than 1 cancer outcome from trace metal emissions over the 25 year planning period. This estimate can be disregarded, as it is much smaller than the variability of other estimates of mortality.

Possible underestimation may arise from the restriction to outcomes in the geographic areas contiguous with the three FFGS sites: Lambton, Nanticoke and Lakeview. Both population and emission levels are small in the two Western sites (Atikokan and Thunder Bay), and the 1989 health outcomes predicted by Concord [respiratory health effects included 16 hospital days, 2 hospital admissions and 0.07 deaths] are within the variability of other estimations. Since these FFGS were operating at over 60% capacity in 1989, increased energy production is limited. The most easterly plant, Lennox, however, was operating at only 7.5% of capacity in

1989, and can be expected to increase its emissions at least tenfold by 2014. The corresponding Concord predictions for Lennox's respiratory health effects are 18 hospital days, 2.4 hospital admissions and 0.08 deaths. With a tenfold increase in the Lennox emissions, the overall contributions from this site to respiratory morbidity are significant. For this reason, the Lennox figures were added to Table 4.2.

Restricting the analysis to a 120 x 120 km^2 area containing each FFGS site excludes populations outside of these boundaries and underetimates the corresponding number of expected health outcomes.

The potential health impacts of some of the emitted chemicals, such as benzo(a)pyrene were not considered in his analysis. Their omission would tend to underestimate fossil fuel combustion related health outcomes, while at the same time raising the apparent background levels of these outcomes.

Pengelly's reliance in his analysis on average ambient emission levels is also a source of underestimation. Effects from chronic (long term) exposures to average levels may be qualitatively and quantitatively different than effects from brief excursions to higher levels. This may be particularly true for sensitive populations who may be less able to tolerate transient increases in pollution levels.

On the other hand, the following issues could lead to an overestimation in the number of health outcomes in his study. If Hydro actually deploys environmentally enhanced technologies when it burns fossil fuels in the future, then the predicted levels of health effects in Pengelly's study would overestimate the actual levels. Indeed, expenditures on such technologies could be seen as an investment in the reduction of predicted health detriments and their associated health costs.

For most, if not all, non-cancer health effects, it is widely believed that there is a threshold level below which effects are not detectable in *healthy* individuals. If this is so, the incremental effect of a change in Hydro emissions must be considered in the context of ambient levels due to non-Hydro emissions. The elasticity model used by Pengelly may be inappropriate for threshold effects, since there may be a range of concentrations (i.e. below the threshold) where the elasticity is zero. In other words, although it is relatively easy to estimate Hydro emissions, it is difficult to apportion outcomes among different sources, particularly for chemicals which, in the absence of other major sources, would be present at levels below detectable health effects. On the other hand, as the evidence for lead has shown, there will always be some sensitive individuals who will experience effects at any level.

Another source of overestimation is the fact that chemical exposures often occur at the same time, and their effects are not necessarily independent. Chemicals may interact with each other to either enhance or diminish health outcomes. For example, cigarette smoking may increase susceptibility to other air pollutants by damaging mechanisms and structures which hinder entry of chemicals and particulate into the lung. Recent declines in smoking levels may lead to reductions in related health outcomes directly or indirectly related to smoking. This improvement would also be enjoyed by "second hand" smokers (i.e. non-smokers who live or work in smoky environments). Pengelly notes that the elasticity estimates from the Plagiannakos and Parker study employed in his analysis included a smoking factor; the effect of this factor as source of overestimation is therefore likely to be small.

4.8 Additional FFGS Health and Safety Issues

a. Health Effect Estimates over the Coal Fuel Cycle

Cole's PHC report (September, 1992) provides data from the literature on the estimated deaths and injuries to workers and the general public from the extraction, transport and operation of coal fired electricity generating stations. Table 4.3 distils information from a number of studies in the United States, Norway and Sweden. Surface and underground coal mining lead to expected deaths from pneumoconiosis and accidents. The transport of coal is also responsible for a number of deaths and injuries to both the public and workers.

Table 4.3
Ranges of Estimated Deaths and Injuries over the Coal Fuel Cycle Based upon 1 GWa of Electricity Production[a]

HEALTH EFFECT	NOS. OF CASUALTIES
Coal Mining:	
Accidental deaths	0.44-2.84
Accidental injuries	32.8-1,385
Pneumoconiosis deaths	0-9.3
Pneumoconiosis cases	0.55-64
Coal transportation:	
Occupational deaths	0.073-5.0
Occupational injuries	0.44-315
Public deaths	0.4-2.5
Public injuries	1.56-28
Coal Station Operation:	
Accidental deaths	0.01-0.2
Accidental injuries	1.2-8.5

Notes: a. Cohen, A.V.; and Pritchard, D.K. (1980): Comparative risks of electricity production systems: a critical survey of the literature. London; Health and Safety Executive. Research Paper 11; Tables A1, A2, A3. Data are scaled up from a 1,000 MWe plant operating at 75% load.

b. Ontario Hydro FFGS Occupational Health and Safety Issues

Cole's report discusses Hydro's overview document on fossil fuelled generation (Ontario Hydro Jan 1992a) which summarizes a range of health concerns during the generation cycle. The Hydro document cites useful Canadian data (eg. Canadian coal mining fatality rates and coal power plant construction rates) and most impacts are normalized to the GWa denominator.

However, he points out that the document does not describe very well the range of worker health illnesses found in the literature on fossil generation or which come from Hydro's own work in occupational health and safety. This may be partly due to the lack of a comprehensive database for illness and disease morbidity comparable to that available with respect to injuries (response to Interrogatories 6.17.18, 6.17.15 and 11.17.12 #21A; and Sinclair, 1986). He describes several additional important impacts: noise induced hearing loss, asbestos related disease, respiratory disease due to fly or bottom ash exposure and cancer potentially related to multiple exposures.

As with hydraulic stations, extensive noise exposure assessment was carried out at five Hydro thermal generating stations in 1986-1987 (Behar 1990). Hundreds of staff were exposed to levels above 85dBA and even over 93dBA and recommendations were made for the implementation of engineering controls particularly at the Nanticoke station. Accepted noise induced hearing loss claims for the 1985-1990 period numbered 17 for health care and 4 for pensions (response to Interrogatory 6.17.18). Claims for design and construction staff working on renovations to thermal plants may add more claims to this reported total.

Asbestos was Hydro's leading cause of Ministry of Labour orders related to chemical substances designated for control under the Ontario Occupational Health and Safety Act, during the 1980s (Thomson, 1988). Six asbestos exposure related fatalities, cancer related save one, were accepted as related to Hydro exposures by January, 1990 (Hydro, 1990; HSD-91-19). These cases likely account for the majority of the eight allowed chest disease claims between 1985-1990 (response to Interrogatory 6.17.15). Five of the eight were in the Thermal Generation Division. This is consistent with the widespread use of asbestos in power stations in the past (Lerman, Finkelstein, Levo et al1990). Silica exposure was the second most common cause of orders, likely due to worker coal dust and fly ash exposure. Hydro hygiene staff carried out an extensive exposure assessment at five coal fired stations (Libich, 1982). According to Libich: 'Fourteen areas/jobs were identified which had mean dust concentrations over guidelines and a further thirteen areas/jobs had the 95% upper confidence limit of the mean over guidelines.' Reviews of the management and health effects of coal dust (Sinclair; 1986b) and fly ash (Sinclair; 1986a) followed. Both attempted to obtain illness data but none were available from Hydro and no claims had been recognized with the Workers' Compensation Board (WCB), perhaps because the most convincing evidence to date of chronic respiratory effects of fly ash exposure had not appeared (Schilling, Tams, Schilling, 1988). In 1989, follow up hygiene surveys showed continuing concern over exposures at Atikokan and Thunder Bay thermal generating stations and the potential need for formal arsenic and silica health surveillance programs (Ricci May, September & November 1989).

Interestingly, neither survey referred to earlier work by Hamilton and Wilson (1982) which showed a high standardized mortality ratio (SMR) for cancer of 119 (confidence intervals, CI, not provided) in contrast to an all causes SMR of 73 among thermal division employees over the 1970-1979 period. (Such a low mortality due to all causes among Hydro employees exhibits clearly the "healthy worker effect" whereby certain robust worker populations have a better health experience than the population as a whole which includes sick, disabled and poor people.) A similar though less marked increase for thermal generation employees has persisted into the 1980's (Anderson; 1991) but it has not been linked with exposure information and has been informally dismissed as reflective of exposures prior to employment at Hydro (eg. asbestos in shipbuilding trades). An increase was observed among thermoelectric power plant workers in Italy (Cammarano, Crosignani, Berrino & Berra, 1986; and Forastiere, Pupp & Magliola, 1989), with respiratory cancer showing the highest SMR (171, 90% CI 89-299). Exposures to asbestos, polycyclic aromatic hydrocarbons or silica may account for this increase but may not persist with better ventilation, work practices and respiratory protection. Unfortunately the increases in cancers have not been tied to risk estimates per GWa.

Evidence of reversible respiratory obstruction (asthma like condition) has been shown among workers cleaning out the boilers of Hydro's oil fired Lennox Generating Station (Lees, 1980). The syndrome was attributed to exposure to the trace element vanadium in bottom ash. Similarly, exposure to other trace elements such as arsenic may be partially responsible for increases in lung cancer among thermal generation workers.

Figure 6.1 from the Hydro overview document labelled "Summary of Health Impacts - Fossil Generation" is concerned with mortality rather than the range of injuries cited in the body of the text and present in the literature (see Table 4.3 above from Cohen & Pritchard, 1980) or the morbidity referred to above. Similarly, the maximum individual risk (MIR) estimates and summary of human health effects focus solely on general population cancer risks rather than on the range of effects occurring among workers and the general population. Data quality problems may have justified the heavy reliance on deaths in earlier overviews in the 1970's and the Porter Commission's report. Continuation of such an oversight must be remedied as soon as possible.

c. Emission Rates from Hydro FFGS

A PHC commissioned study by MacViro Consultants Inc. (July 13, 1992) analyses annual emissions of pollutants from Hydro FFGS for the year 1990. The study found that Lakeview, Lambton and Nanticoke generating stations used higher sulphur coal and emitted significantly more SO_2 than the remaining three stations using low sulphur fuel.

The study proceeded to compare these emission levels with proposed Federal standards for particulates, SO_2 and NO_2. These standards are to apply to new thermal generating stations built after the legislation is enacted and therefore will not apply to existing Hydro FFGS. However, the comparison illuminates the differences between levels previously considered acceptable and what the future is likely to hold in store for Hydro practice.

The study notes that the three largest stations which burn higher sulphur fuels are currently well above the proposed standard for SO_2 emission levels. These three stations could use low sulphur coal or deploy currently available flue gas desulphurization methods to meet the proposed levels.

Finally, the study notes that the five Hydro coal fired plants (Lakeview, Lambton, Nanticoke, Atikokan, Thunder Bay) meet or are close to meeting the proposed NO_2 standard. With some modification to the combustion process, and/or incorporation of state of the art NO_x reduction technology, all of the plants could be well below the proposed standard. The study also notes that all plants are below the standard for particulate emissions.

The PHC notes that these emissions, however small, will lead to health detriments whose costs must be considered in the decision to deploy any alternative to the proposed Hydro undertaking which includes additional fossil fuel capacity.

RECOMMENDATION 4.1: The PHC recommends that an alternative based on the fossil fuel option should not be approved. There are unacceptable adverse health effects and associated health costs, including respiratory diseases, arising from the fossil fuel option.

RECOMMENDATION 4.2: The PHC recommends, if an alternative based on the fossil fuel option is to be approved, that as a condition of approval Hydro be required to use low sulphur coal and install flue desulphurization methods to reduce SO_x emissions and that Hydro be required to modify its combustion process at all FFGS to reduce NO_x emissions.

RECOMMENDATION 4.3: The PHC recommends that the proposed agency develop an acid aerosol network to monitor and evaluate this pollutant and its associated environmental effects and costs.

Chapter 5
Health Effects from the Hydraulic Generating Option

Both Hydro's DSP undertaking filed in 1989 and its 1992 Update contain provisions for the addition of new hydraulic generation facilities development. Therefore, the PHC requests that this chapter be used to evaluate the hydraulic generation components of the undertaking and any alternatives to the undertaking which include said components.

5.1 Introduction

The PHC documents the impacts on worker health and safety from the hydraulic/hydroelectric generation option in this chapter (Cole; September, 1992). In addition, T.Kosatsky's report (August 12, 1991) prepared for the Moose River/James Bay Coalition [MR/JB] (and kindly transmitted for the PHC's use by P.F.Wilkinson, Scientific Co-ordinator for the MR/JB Coalition) is used to address the subject of methylmercury.

5.2 Issues of Occupational Health and Safety from the Hydraulic/Hydroelectric Option

The scope of hydroelectric worker health and safety discussions is limited to the topics of construction and operation in Hydro's report on health effects of hydroelectric development (Hydro; October, 1991); in an article based on the corporation's comparative experience (Hamilton; 1982); and in a site-specific environmental assessment (Hydro, July, 1988).

The planning and assessment process prior to initiation of construction has already caused one death for the Little Jackfish project. Impacts from material acquisition and transportation of construction materials, which are second order activities, are included by Inhaber (see Table 5.1 below) and contribute considerably to overall risks, the latter source being particularly important for remote locations.

Inhaber based his findings on Hydro dam construction experience from 1947-1977 but likely overlooked injuries and illnesses among contracted workers, as noted by Hamilton and Wilson (1982). The type of dams is not indicated. For example, concrete dams in gorges require tunneling, and so the worker health impact could be expected to be greater for these types of dams than for retaining dams on more level ground. The experience of Hydro Quebec contractors for the James Bay dams would be more appropriate evidence to cite than general Hydro construction experience. Psychosocial impacts upon workers in isolated camps (e.g. substance abuse, isolation, violence) also need to be considered.

Table 5.1
Hydro Electric Power Risk (per Gigawatt-Year net Electrical Output)[a]

RISKS	MATERIAL ACQ'N. & CONST.	OPERATION & MAINT.	TRANS PORT.	DAM FAILURES	TOTAL
Occupational:					
Accidental					
Death	0.89-2.00	0.63	-	-	0.15-0.26
Injury	340	13.0[c]	-	-	350
Man-days lost	22,000-29,000	4,400	-	-	$(26\text{-}33)\times10^3$
Disease					
Death	-	-	-	-	-
Disability	0.08[b]	-	-	-	0.08
Man-days lost	4.0	-	-	-	4.0
Public:					
Accidental					
Death	-	-	-	1.1-1.6	1.1-1.6
Injury	-	-	-	1.1-12.8	1.1-12.8
Man-days lost	-	-	-	6,600-10,000	6,600-10,000
Disease					
Death	-	-	-	-	$(1.1\text{-}3.2)\times10^{-3}$ [d]
Disability	-	-	-	-	6.0-19.0[d]
Man-days lost	-	-	-	-	40-120[d]

Notes: a. Adapted from Table K-6 in Inhaber,H.: Energy Risk Assessment. New York; Gordon and Breach Science Publishers, 1982.
b. Based on 50 man-days lost per disability.
c. Based on 72 man-days lost per disability.
d. From emissions due to steel production.

Operational impacts appear to include four worker fatalities over the last two decades. Hamilton (1982) reports one in the 1970s and Hydro's overview document cites two from falls, and one drowning in the 1980s. Figure 6 of Hydro's overview document provides lost time injury data, but these statistics are presented in relation to person hours worked rather than to electrical energy produced over the life cycle of the facilities (even in aggregate). Musculoskeletal injuries during construction, falls and electrical contacts describe the most frequent injury problems. Occupational diseases are not mentioned. A 1983 noise exposure survey, and its follow-up study in 1985, indicated dangerous levels of noise, particularly on turbine floors, and in pits and tunnels (Behar; 1982, 1985). A listing of industrial deafness claims at Hydro for 1985-1990 (response to Interrogatory 6.17.18) indicated 75 accepted health care claims and 23 accepted pensions in the Regions branch. Since hydraulic station workers are only a fraction of the workers within the Regions branch, it is impossible to say how many workers suffered noise induced hearing loss as a result of hydraulic exposure. Similarly, it cannot be determined how many of the three allowed skin disease claims or 25 other allowed occupational disease claims from the Regions for 1985-1990 were related to hydraulic generation (response to Interrogatory 6.17.15).

Rehabilitation of hydraulic stations, an important component to the revised DSP, usually involves construction work, but no general or specific literature is available on health impacts for this phase. Decommissioning is not touched upon anywhere, although injuries similar to those during the construction phase are likely to occur.

Dam failures are a catastrophic event for hydraulic stations. Workers would likely suffer injuries if present on site (as contrasted with no injuries for remote monitored small hydraulic facilities). Increased seismic activity, which can precipitate dam failures, has occurred only once in Canada during the filling of the Manicouagan 3 Reservoir in Quebec in October, 1975 (Milne; 1976) but no dam failure has occurred.

Overall therefore, the evaluation of risks to workers from hydraulic generation has advanced little since Inhaber's pioneering work (1982) despite the considerable criticisms of his approach. Table 5.1 above is drawn from his study, and is the only presently available guide to potential worker impacts despite its lack of inclusion of all risk generating activities. Evidence presented before the Board indicates that considerable confusion persists as to both the measurement and allocation of health impacts including worker injury and illness. (See Volume 93, pp. 16,502-16,535 for cross-examination by PHC counsel on the issue of confusion.)

Given the extent of Hydro's historical data on the contribution of hydraulic generation to electrical energy production, a more appropriate information system should be developed to monitor and record worker health impacts. Such a project could be conducted in conjunction with Hydro Quebec, with its more recent and applicable experience, as well as with the Manitoba Hydro authority. Under the Manitoba purchase option being pursued by Hydro, the costs of worker health effects likely to occur in Manitoba should be attributed to Hydro and its customers.

5.3 Hydroelectricity and the Methylmercury Issue

Mercury is a naturally occurring element in the environment, and is found in the form of compounds with other metals as mercury salts (also called inorganic mercury). Mercury salts can be methylated by bacteria in soil and water (thus the term "methylmercury") and, in a methylated form, can become highly concentrated in the flesh of certain fish. While all fish contain some methylmercury, fish in areas where mercury is concentrated (e.g. from the discharge of pulp mills, or in new reservoirs where submerged rotting vegetation encourages excessive bacterial methylation) contain much higher levels of this toxin. Methylmercury is bioconcentrated; predatory species have higher levels than do fish which eat plants or insects, and older fish have higher levels than younger. While its presence causes no discernible change in the fish, its level can be confirmed accurately by laboratory analysis.

Unlike mercury salts, for which absorption is limited, ingested methylmercury is almost completely absorbed. Absorbed methylmercury is bound to red cells and distributed throughout the body, easily entering the brain and other nervous tissues, unlike mercury salts. The nervous system, the kidneys and the developing fetus are body sites where methylmercury is concentrated.

The human body eliminates both mercury salts and methylmercury over time. While most absorbed methylmercury is eliminated by the intestines into the faeces, mercury salts are eliminated by the kidneys into the urine. Converted to mercury salts, this demethylated mercury is eliminated by the kidneys into the urine as are mercury salts absorbed directly from food or water.

The amount of methylmercury in the body at any time can be estimated from samples of blood and hair. Those measurements are therefore used to characterize methylmercury exposure. Blood concentrations are influenced by recent exposure to methylmercury in food; hair concentrations show less variation. An additional advantage of hair samples as a way to estimate the quantity of methylmercury in the body is that a hair measurement can demonstrate the body's level of methylmercury both prior to and at the time of the sample. Since hair grows about one centimetre per month, progressive centimetre-long segments of hair can demonstrate how much methylmercury was in the hair (and in the body) during the months when the hair was growing out from the scalp. Based on month-by-month analysis of hair segments, it is estimated that the body eliminates one-half of its content of methylmercury each 70 days. People whose exposure to methylmercury fluctuates will therefore show changing levels as measured in hair.

The human body systems which are most affected by methylmercury are the nervous, renal and reproductive systems. The most striking evidence of disease following exposure is in the nervous system. There is no evidence that methylmercury causes cancer.

The first reported outbreak of neurological disorders following the consumption of methylmercury in fish occurred around Minimata Bay in Japan. The cause was the discharge of metallic mercury, mercury salts and methylmercury itself from an industrial factory. In affected adults, this neurotoxic syndrome (since called Minimata disease) included narrowing of the visual fields, impaired recognition of visual images, tingling around the mouth and the extremities, lack of coordination manifested by the inability to write or to button, tremor, and impairment of speech, hearing and gait. While these effects were usually irreversible, some improvement of motor coordination occurred with time. Pathology studies at Minimata showed that victims had elevated levels of methylmercury in their hair and brains.

An epidemic of methylmercury-induced poisoning in Iraq followed consumption of bread from grain treated to prevent mould. Symptoms were similar to those in Minimata victims. Experience in both Japan and Iraq suggests that for ingestion over a short period of time there is a threshold of exposure to methylmercury below which toxicity is not observed. Above this threshold, an increasing dose is associated with increasing numbers of people affected and the severity of disease. Recent reappraisals of Japanese and Iraqi data suggest that for adults the threshold for neurologic disease associated with methylmercury corresponds to a level of mercury measured in hair of 60-100 mg/kg.

Concern that common lower level consumption of methylmercury as a contaminant of fish could cause severe neurologic disease arose after the demonstration of the effects of high level exposure to methylmercury over weeks or months. Neurologic assessments of fish eaters in Sweden, Samoa, Peru and Italy who over years ingest methylmercury at concentrations much lower than those which poisoned the Japanese and the Iraqis have shown no evidence of the incapacitating disease associated with long term methylmercury exposure. This data should be cautiously interpreted, considering that fewer than 10 of the total subjects in the studies had mercury measurements which surpassed the equivalent of 60 mg/kg (60 ppm) of mercury in hair. In their 1976 Environmental Health Criteria document (revised in 1990), the World Health Organization recommended:

> Several types of epidemiological study are needed. Long term studies on adults should concentrate on those areas of the dose-response relationship where the effects of methylmercury become just detectable. There are still uncertainties concerning ... the equivalent long term daily intake of mercury as methylmercury associated with the earliest effects in the most sensitive group in the adult population.
>
> So far, dose-response relationships in human populations have been based on outbreaks of poisoning in which daily exposure was high and limited to months or a few years at the most. To extrapolate these relationships to the general population, more information is needed on the potential influence of long term exposure. [World Health Organization: Environmental Health Criteria 101, Methylmercury. Geneva, 1990]

Much of the animal experimentation pertinent to the question of long term exposure to methylmercury was performed during the 1970s. It generally showed that the dose rate of methylmercury and the period of dosing influence the pattern of damage to nervous tissue. In monkeys, for example, longer term exposure to doses below those which cause rapid poisoning leads to more generalized damage than is observed following high doses given abruptly.

In some animal experiments, a latency period precedes the manifest appearance of the effects of methylmercury. A recent report by Rice (1989) described disability first evident at age 13 in five monkeys given daily doses of methylmercury chloride from birth to 6.5-6.0 years of age. Treated monkeys appeared clumsy and showed slow and inaccurate fine motor movement and insensitivity to pin prick. This finding of delayed neurotoxicity is consistent with Japanese claims that individuals exposed to methylmercury only begin to show signs of neurologic dysfunction many years after exposure.

The McGill Methylmercury Study (McKeown-Eyssen; 1983a) conducted among the Cree Indians of the James Bay region of Northern Quebec evaluated the effects of long term exposure to methylmercury. While there were several methodological problems, the McGill study did show that Crees with nervous system symptoms such as tremor and incoordination were more likely to have been exposed to higher levels of methylmercury than were people without neurologic dysfunction. As opposed to Minimata and Iraqi victims where there was a threshold of disease of about 60 ppm mercury-in-hair, the McGill study showed increased neurologic symptoms relating to exposure as low as 10 ppm.

The developing nervous system appears to be especially sensitive to the effects of methylmercury. Incidents of poisoning of the fetus during pregnancy have been reported from Sweden, Japan and Iraq. Severe brain damage followed high dose prenatal exposure, while infants exposed to lower doses showed delayed development and mild neurologic abnormalities. Similar effects were seen in Cree boys examined as part of the McGill Methylmercury Study (McKeown-Eyssen; 1983b). In the McGill study, the boys' exposure to methylmercury concentrations as low as 6 ppm as measured in their mother's hair was associated with their delayed development and abnormalities of muscular tone. No effects were seen in girls exposed during pregnancy. Similar effects in 4 year olds, both boys and girls were seen in New Zealand at levels as low as 9 ppm in their mother's hair.

Other than the nervous system, the urinary system is most likely to be affected by long term methylmercury ingestion. Among exposed persons, levels of methylmercury are higher in the kidney than in any other organ, including the brain. Nevertheless, little is known about adverse renal effects of methylmercury. In an outbreak of illness among Iraqis who consumed grain coated with the related fungicide ethylmercury, the kidneys leaked protein and were unable to concentrate urine. In rats, methylmercury in high doses causes acute spots of damage to the renal tubules including fibrous tissue formation and inflammation.

Since some methylmercury is demethylated to inorganic mercury (the salt form) and as up to 30% of mercury in fish is present as mercury salts, low dose long term intoxication by this form of mercury should also be considered for Native persons who eat freshwater fish in large amounts over the years. However, because absorption of mercury salts is low (3-5% as opposed to 95% for methylmercury) regular fish eaters would be exposed over time to much less inorganic mercury than to methylmercury.

Kidney damage has been observed among workers acutely exposed to high doses of inorganic mercury as well as in laboratory rodents exposed both acutely and long term. This damage is probably related to immune type mechanisms and can involve both the glomerulus (the kidney's filters) and the renal tubules (where water is reabsorbed). Laboratory findings include excretion of enzymes in the urine (signifying damage to cells), and indicators of dysfunction including the presence of proteins in the urine.

Information on the reproductive effects of methylmercury comes mainly from animal experiments. In rats, methylmercury reduces the number of successful pregnancies. A relationship between chromosome abnormalities and exposure to methylmercury in fish eaters has been shown in some studies of humans, although the significance of this finding to human health is unknown.

The effects of methylmercury can be more or less severe depending on personal factors (age, general state of health and nutrition, for example) and on exposure to other chemicals. The effects of age were demonstrated in the McGill Methylmercury Study, where for the same degree of exposure, people in their 60s appeared more likely to develop tremor and incoordination than people in their 40s. People who were frequent consumers of alcohol were more likely to be affected than non-drinkers, given equivalent exposure to methylmercury. In experimental rats, alcohol administered with methylmercury led to severe incoordination of the hind limbs. Other rats administered the same dose of methylmercury but without alcohol showed moderate abnormality and those receiving only alcohol showed no abnormality (Turner; 1981).

A variety of chemicals other than methylmercury can affect the kidneys. Little is known of their effect in combination with methylmercury. The influence of preexisting disease on the renal effects of methylmercury is also largely unknown. In this regard, particular concern must be placed on the effect of the kidney-toxin cadmium which is present in caribou and in moose liver and kidney (Archibald; 1991) and on diabetes which has important long term effects on the kidneys and is prevalent in many Canadian Native groups (Young; 1990).

While a large number of chemicals and health conditions are known to affect reproduction and fetal development, little is known of their capacity to interact with methylmercury. Alcohol and maternal age are clearly concerns; much research is needed.

The trace metal selenium, present in fish and other foods, may change and perhaps diminish the effects of methylmercury on the nervous and other body systems. Selenium binds to the receptors in cells which are attacked by methylmercury. While it is possible that people who are exposed to methylmercury and selenium have less severe damage it is also possible that selenium prevents methylmercury's action at some sites but not at others (especially the brain). Concern that selenium exposure might in fact worsen the neurologic effects of methylmercury limits its potential as an antidote (Berlin; 1986).

Methylmercury is clearly a poison. It is present in many foods but is found in its most concentrated form in freshwater fish. On the other hand, freshwater fish is an important nutrient, low in fat and in salt, high in protein and probably containing factors that protect the heart and cardiovascular system from disease (Holub; 1989). For Native people, fish is a traditional staple: accessible, abundant and with high nutritional and cultural significance.

How can people be protected from the harmful side of fish consumption? Medical treatments for the effects of methylmercury are not of much value given that damage often becomes evident only years after exposure and involves structural alteration of the brain and kidneys. As for treatment for intoxication, high levels of methylmercury in the body can be eliminated (in case of one time poisoning) by dialysis (a procedure for cleaning poisons from the blood with an artificial kidney), but such a measure is not appropriate for long term exposure. While selenium or perhaps Vitamin E may counteract the long term effects of methylmercury, these remedies are untried and possibly harmful (Berlin; 1986).

Can a safe level of fish consumption be set? In 1976, the WHO reviewed the question of methylmercury exposure, determining that human health consequences probably did not occur below a body concentration reflected by 60 ppm as measured in hair. They applied a "safety factor" of 10, and so set an "acceptable" adult mercury-in-hair guideline of 6 ppm. Governments took this human exposure guideline, assumed a regular consumption of one daily meal of fish, and daily elimination of about 1% of the body's content of methylmercury (corresponding to a half life of 70 days), and determined the level of methylmercury in fish that would not lead consumers to exceed the 6 ppm-in-hair guideline. This became the commercial fish mercury limit, set in Canada at 0.5 ppm of fish flesh.

In reviewing the mercury-in-fish guidelines, several points need to be mentioned:

1. Many freshwater fish, especially the predatory species such as pike and walleye, "naturally" contain more than 0.5 ppm of methylmercury.

2. Fish consumption is not constant throughout the year and for many Native groups can seasonally approach high levels, well beyond those which figured into the 0.5 ppm of fish flesh limit.

3. Some people eliminate methylmercury more slowly than others; for them the half life is longer than the "average" 70 days. These people will attain higher body levels than do faster eliminators given the same daily dose of methylmercury in fish.

4. The 6 ppm in human hair guideline, while perhaps very cautious for adults, is not at all cautious for the fetus. During pregnancy, a fetus can be affected subtly by methylmercury at levels as low as 9-15 ppm as expressed in a measurement of mercury in the mother's hair.

From the point of view of public health, encouraging consumption of less methylmercury in fish is advisable. Still, since fishing and fish consumption are also beneficial, how should a fish consumption guideline be developed and promoted?

A substantial volume of information needs to be collected in order to address such a complex question. Information on fish catches and consumption patterns by age group in the population, by fish source and fish species, is necessary to weigh the possible disadvantages of eating contaminated fish. This information can change with time. For example, people's consumption levels can go up or down and methylmercury levels in fish increase markedly after reservoir construction. Data on mercury levels in fish should be supplemented by data on mercury levels in people. Population-wide hair samples should be taken at least twice a year to determine exposure.

The advantages of eating fish should also be evaluated, to assess the nutritional value of fish compared to other foods. The social consequences to Native societies of not fishing and of not taking the traditional meal of fish together also needs to be considered.

One effect of concentrating on fish as a possible poison is to turn some people into fish-avoiders. Others continue to eat fish but come to distrust health advice as a result of their disbelief in advisories for saying not to consume a traditional food (Lepage; 1991). Review of hair mercury patterns in the Quebec James Bay Cree indicates a high degree of sensitivity to advice that they should not eat contaminated fish. Rejection of fish seems most widespread among the Quebec Cree under 40, a group whose hair mercury levels have declined markedly over the past 10 years (Kosatsky; in press).

The identification of mercury as a possible health risk and the development of approaches to evaluate and mitigate that risk pose problems to a community for which balance with the environment has always been a central theme. The effects of calling into question that environment can be significant as recently described among the Quebec Cree (Inskip; 1985). The Quebec experience teaches that judgement and sensitivity are crucial in the entire question of methylmercury beginning with interpretation of the scientific literature, to assessing exposure, to developing and promoting programs to prevent unwanted health effects.

RECOMMENDATION 5.1: The adverse health effects and associated health costs arising from the hydraulic option are less costly than options based on either nuclear or fossil fuel. However, the cost is borne disproportionately by affected native populations. The PHC supports recommendations made by Native groups to mitigate adverse health effects and recommends that alternative energy options be explored.

RECOMMENDATION 5.2 : The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that Hydro be required to monitor the health effects on all workers whether directly or indirectly employed by Hydro and to assess the health costs, including the health costs to the public respecting the effects of methylmercury, actually incurred as a separate identifiable cost source.

RECOMMENDATION 5.3 : The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that Hydro obtain worker health data and costs from other utilities including Quebec Hydro and Manitoba Hydro so that a more accurate assessment of costs can be obtained and included in assessing the cost of power purchases.

Chapter 6
Health Effects from the Transmission and Distribution of Electricity

In both its original 1989 undertaking and in its 1992 Update, Hydro has proposed a Manitoba purchase of hydraulically generated electricity involving the construction of an 1,100 km 500 kv transmission line across Northern Ontario. Since all of the options involve transmission and distribution components, the PHC requests that the material in this chapter on health impacts from the construction, operation and maintenance of new and existing transmission and distribution lines for electricity be used by the Board to evaluate all corresponding aspects of the undertaking and alternatives to the undertaking.

6.1 Introduction

This chapter considers issues of health effects arising from the use of the herbicide 2,4-D (or 2,4-dichlorophenoxyacetic acid) as a defoliant along Hydro transmission corridors; the topic of non-ionizing radiation (for which electromagnetic field or EMF radiation is one component); and issues of occupational health and safety arising from Hydro electricity transmission and distribution activity.

The material in this chapter is drawn from the following reports by PHC experts (GlobalTox: 10/02/92; GlobalTox: 09/24/92; D.Cole: September, 1992).

6.2 Health Effects and the Herbicide 2,4-D

a. Introduction

Dr. Mark Goldberg of GlobalTox International Consultants Inc. reviewed the toxicology of 2,4-dichlorophenoxyacetic acid (2,4-D), a herbicide used by Hydro to control the growth of broadleaf weeds along its power line rights-of-way (GlobalTox: 10/02/92). Although not exhaustive in scope, Goldberg's report concentrated on the most sensitive endpoints reported in the literature. Both human and animal studies were reviewed to give the broad spectrum of effects.

Human toxicological information is usually limited to acute exposures and epidemiological data, which is often incomplete and insensitive. This provides little information about mechanisms by which effects are produced. For this reason, human data is used to confirm or reinforce conclusions derived from more sensitive and better controlled studies of laboratory animals.

b. Regulatory Status of 2,4-D

2,4-D is under special review by the U.S. Environmental Protection Agency Carcinogen Assessment Group. Health and Welfare Canada classifies 2,4-D as a Group III chemical (i.e.

possibly carcinogenic to man). 2,4-D was no longer available for use in Sweden as of December 31, 1990.

c. Use of 2,4-D by Ontario Hydro

Table 6.1 estimates Hydro's usage of herbicides containing 2,4-D or related compounds.

Table 6.1
2,4-D Usage by Ontario Hydro[a]

Product Name	2,4-D Content (%)	Quantity of 2,4-D Applied (kg), by Year		
		1985-1988[b]	1989	1990
Desormone Diphenoprop Silvoprop Weedone CB	50	25,996.0	10,877.9	6,986.5
Tordon 101	80	6,869.6	9,725.6	10,652
2,4-D amine	100	593	217	215
Killex	62.8	994	463	198
Killex 500	38.5	73.9	539.4	435.4
Atra-Pell	5	13.6	27	33.2
TOTAL		**34,540.1**	**21,966.5**	**18,520.1**

Notes: a. Developed from Undertaking 142.75
b. Average for years 1985 - 1988 inclusive

Further, it has come to the PHC's attention that private contractors are hired by Hydro to conduct additional spraying of Hydro transmission and distribution corridors, and that Hydro does not maintain records of herbicide usage by such contractors or of any reported (or unreported) health effects to workers in their employ. Consequently, the above annual estimates of usage underestimate the true extent of environmental and human impact.

d. Toxicology of 2,4-D

The literature on the health effects of 2,4-D is particularly confusing because 2,4-D was often marketed in formulation with other herbicides, or contaminated by trace chemicals. Therefore, Goldberg's review took care to consider the purity and formulation of the 2,4-D used in studies where this information had been reported.

One common formulation contained equal parts of the *n*-butyl esters of 2,4-D and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), marketed by one manufacturer under the name "Agent Orange". This combination was contaminated with trace amounts of dioxins, in particular

2,3,7,8-tetrachlorodibenzo-*p*-dioxin [TCDD], introduced in the manufacture of 2,4,5-T. TCDD and other dioxins have adverse health effects at very low doses. The early literature on the adverse health effects of 2,4-D often included reports of effects which were later attributed, at least partially, to exposure to dioxins in formulations containing 2,4,5-T. TCDD has not been found in technical grade 2,4-D (WHO, 1984). Other much less toxic dioxins have been reported at concentrations of less than 10 μg/kg (Cochrane et al., 1982).

Another contaminant, N-nitrosodimethylamine [NDMA], has been detected in samples of 2,4-D at concentrations up to 300 μg/L (Cohen et al., 1978) when nitrite has been added to the amine formulation. It is unlikely that NDMA would be found in other formulations or that this concentration of NDMA in the amine formulation would have acute effects (NAS, 1981).

Another potential source of confusion is that most studies report results obtained using the 2,4-D acid, while amine and ester formulations are commonly used in the field. It is reasonable to assume that results from the acid are applicable to 2,4-D esters and amines, since they are readily metabolised to the acid (Ibrahim et al., 1991).

d.1 Toxicokinetics

The absorption, distribution, metabolism and excretion of 2,4-D have been studied. Only 4.5% - 6.4% of the 2,4-D applied to the skin is absorbed. Dermal exposure is responsible for 90% of the total absorbed dose in workers who spray 2,4-D (WHO, 1984; Fisher et al., 1985; Feldmann and Maibach, 1984; Harris and Solomon, 1992) although it can be absorbed via all routes of administration.

Using C^{14}-labelled 2,4-D, Khanna and Fang (1966) showed that the highest concentrations in rat tissues were reached 6 to 8 hours after ingestion. Half-times for urinary excretion were 3 hours in the rat, 8 hours in cattle and 12 hours in pigs (Erne, 1966). Small doses of 2,4-D are rapidly excreted in sheep, with 96% appearing in the urine unchanged after 72 hours (Clark et al., 1964).

d.2 Acute Effects

Acute oral LD_{50} (i.e. the Lethality Dosages necessary to achieve a kill rate of 50% in the animal population within a prescribed interval of 24-96 hours) values for rats, mice and guinea pigs range from 350 to 666 mg/kg (RTECS, 1992).

There are several reports of humans ingesting lethal doses of 2,4-D. In suicides, the dosage tends to be excessively high and consumption of 6 to 13.5 g (approximately 86-193 mg/kg) have been reported as lethal doses (WHO, 1984). Non-lethal acute effects include coma, drowsiness, slurred speech, abnormal electrocardiogram, peripheral nerve dysfunction, skeletal muscle stiffness and damage, vomiting and diarrhoea, haematological abnormalities, abnormal liver and kidney function, skin irritation, and decreased libido and impotence (WHO, 1984).

d.3 Subchronic Effects

2,4-D (97.5% pure) was added to the chow of Fischer 334 rats at varying doses in a 91 day study. Rats receiving 5 mg/kg/day or more after 7 weeks had significantly reduced levels of blood cells. Animals receiving 15 mg/kg/day had significantly increased kidney weights and significantly decreased liver enzymes. Histopathology of the kidney showed damage to the renal cortex (Hazelton Laboratories, 1986). B6C3F1 mice (20/sex/group) were fed 97.5% pure 2,4-D in their chow for 91 days in a related study. At 5 mg/kg/day, increased weight of the adrenal glands was reported in females. Effects reported at 15 mg/kg/day dose included altered organ weights and haematologic effects. Kidney weights were not affected below 45 mg/kg/day (Dow Chemical, 1983). In another study, renal tubular necrosis was found in mice fed very high levels (5,200 mg/kg/day) for 3 weeks (NTP, 1989). Mice fed 325 mg/kg/day or more 2,4-D for 13 weeks show dose related increases in liver necrosis (Borzelleca et al., 1985).

Repeated dermal exposure in forestry workers applying phenoxyacetic herbicides has resulted in severe contact eczema. Polyneuritis has also been reported (Hayes, 1982).

d.4 Reproductive and Developmental Effects

In twelve studies of rats, mice and hamsters, maternal exposure to 2,4-D during the critical stage of pregnancy when formation of the organs is taking place in the fetus results in a number of documented effects, including abnormally high incidences of fetotoxicity and fetal death. Developmental abnormalities of the blood and lymphatic systems, musculoskeletal system and urogenital system were reported. Craniofacial malformations including the nose, tongue, eyes, ears and central nervous system were also found. Fetal growth retardation was induced in a dose-dependant manner in a study on mice in which 2,4-D was administered with picloram (a formulation called Tordon 202c) during the organogenesis period (Blakley et al., 1989a). (Ontario Hydro has used Tordon 101 extensively. It applied 13,315 kg (representing 18% of all herbicide applied by the utility) in 1990. Tordon 101's formulation is 65 g/L picloram and 240 g/L 2,4-D while Tordon 202c, reported in this study as a fetal growth and development retardant in mice, is formulated similarly as 12 g/L picloram and 200 g/L 2,4-D.) These authors also demonstrated that paternal prenatal exposure to the same agent could result in fetal growth retardation in mice (Blakley et al., 1989b).

A recent review of a collection of human studies have implicated the phenoxyacetic herbicides, of which 2,4-D is a member, as teratogens (Schardein and Keller, 1989). Many involve studies on Vietnamese populations exposed to Agent Orange. A study by Meselson and co-workers (1970) reported an increase in birth defects in Saigon between 1964 and 1968. A joint Japanese-Vietnamese study found double the incidence of congenital malformation in South Vietnam compared to other Southeast Asian countries (Masazumi, 1990). These effects may not be attributable to 2,4-D, since exposure to TCDD, 2,4,5-T and other herbicides confounds the interpretation. There is one case report in the literature (Casey and Collie, 1984) in which a child was born with malformations of the skull and severe mental retardation after both parents had prolonged occupational exposure to 2,4-D.

d.5 Mutagenicity

Short-term assays of genetic toxicity indicate the potential of an agent to cause cancer. There are over 100 different types of assays which can be carried out on bacterial cultures or cultured mammalian cells (*in vitro*) or in living animals (*in vivo*). Positive results obtained in the latter type of study are more suggestive of carcinogenic potential than those obtained in the former, since they reflect the agent's ability to be absorbed from the site of application, metabolized to a reactive form, transported to its site of action and interact with the tissue of interest. Similarly, studies on the mutagenicity of an agent done in mammalian species are stronger indicators of human carcinogenic potential than those done on bacterial or non-mammalian species.

In 1987, the mutagenicity of 2,4-D was reviewed by the International Agency for Research on Cancer (IARC, 1987). At that time 51 studies of 2,4-D's genotoxicity had been published representing 30 different assay types, of which 14 showed positive results (47%). Several other genotoxicity assay results with 2,4-D have since been published. The breakdown of positive assay results by assay type is shown below in Table 6.2.

Table 6.2
Summary of the Mutagenicity Assay Results of 2,4-D

Assay Type	Positive Results / Assays Performed			Positive Assays (%)
	IARC	IRIS	Other	
Non-mammalian, *in vitro*	8/15	2/2	3/3[a,b]	65
Mammalian, *in vitro*	4/6	3/3	1/1[b]	80
Non-mammalian, *in vivo*	2/4			50
Mammalian, *in vivo*	0/5		1/1[c]	17
TOTAL	14/30	5/5	5/5	60

Notes:
a. Kappas, 1987
b. Pavlica et al, 1991
c. Schop et al., 1990

d.6 Carcinogenicity

Animal Studies

Prior to 1986, three studies of the carcinogenicity of 2,4-D had been published. All of these are considered to be inadequate as they do not meet the guidelines for performing bioassays published by the International Agency for Research on Cancer (1982) and by the US Environmental Protection Agency (USEPA, 1988). Two new studies were commissioned by an Industry Task Force. In the first, Fischer 344 rats were chronically fed 0, 1, 5, 15 or 45 mg 2,4-D/kg/day for 2 years (Hazelton Labs, 1986). A pilot study had determined that 45 mg/kg/day was the Maximum Tolerated Dose; at doses of 60 mg/kg/day, rats developed kidney damage. Male rats fed 45 mg/kg/day had a statistically significant increase in the incidence of astrocytoma (a brain tumour). Male rats fed 14 mg/kg/day also had a statistically significant increase in astrocytomas, but had fewer than the high dose group. In the second study (Hazelton Labs, 1987), $B6C3F_1$ mice were treated with the same doses of 2,4-D for 2 years. No increase in tumour incidence was seen. A panel convened by the Harvard School of Public Health (Ibrahim et al., 1991) concluded that the Maximum Tolerated Dose was probably achieved in rats but not in mice. They were puzzled by the apparent sex difference in the rat study in that only male rats developed brain tumours.

A case-control study done by the National Cancer Institute in the U.S. (Hayes et al., 1991) found that incidence of canine malignant lymphoma, a disease analogous to non-Hodgkins lymphoma in humans, was related to dog exposure to 2,4-D. Owners of dogs diagnosed with malignant lymphoma applied 2,4-D to their lawns a third more often than owners of control dogs. When owners applied 2,4-D four or more times per year the risk of lymphoma in their dogs doubled.

Vainio et al. (1983) found that 2,4-D and a related compound, MCPA, induced proliferation of peroxisomes in the liver, a response which can occur during tumour promotion. Peroxisomes are microbodies present in vertebrate animal cells, especially liver and kidney cells, which are rich in certain enzymes and which participate in certain metallic oxidations.

Reddy and Rao (1987) have suggested that an increase in the numbers of peroxisomes could be related to high levels of hydrogen peroxide generation, which can have a genotoxic effect, damaging DNA. This type of damage can lead to initiation of carcinogenesis.

Table 6.3 summarizes Goldberg's findings from his review of animal studies of health effects from 2,4-D.

Table 6.3
Health Effects for 2,4-D in Animal Studies

Effect and Species	Threshold Dose (mg/kg/day oral)	Reference
REPRODUCTIVE AND DEVELOPMENTAL EFFECTS		
Growth Retardation:		
Rat	75	Schwetz et al., 1971
Mouse	177	Courtney, 1977
Embryolethality:		
Rat	100	Khera and McKinely, 1972
Mouse	177	Courtney, 1977
Malformation/Teratogenicity:		
Mouse	221	Courtney, 1977
Hamster	100[a]	Collins and Williams, 1971
SUBCHRONIC EFFECTS (91 day feeding studies)		
Increased kidney weights; decreased liver enzymes		
Rat	15	Hazleton Laboratories, 1986
Increased adrenal gland activity		
Mouse	5	Hazleton Laboratories, 1986
CARCINOGENESIS (2 year feeding study)		
Astrocytoma		
Rat	14	Hazleton Laboratories, 1986

Notes: a. No Observed Adverse Effect Level (NOAEL).

Human Studies

This type of study is done when exposure to a specific agent is suspected to be a cause of a certain disease. The methodology involves identifying confirmed cases of the disease and then gathering data on their exposure to the suspected agent either by interviewing them or their surviving relatives, or by examining records. A control population is constructed by finding people of the same sex, age, etc. who were in hospital at the same time as the cases or who lived in the same neighbourhood, or by selecting people from a databank such as a cancer registry. The incidence of a disease among the cases divided by the incidence in the control population is referred to as the odds ratio [OR].

Studies by Hardell and colleagues (Hardell and Sandstrom, 1979; Eriksson et al., 1981; Hardell, 1981; Hardell et al., 1981) in Sweden first suggested that exposure to 2,4-D might be associated with an increased risk of Soft Tissue Sarcoma [STS], Hodgkin's disease [HD] or non-Hodgkin's lymphoma [NHL]. Since this initial series of papers, there have been several other case-control studies of the association between 2,4-D and STS, HD, and NHL. These are summarized in Table 6.4.

Table 6.4
Case-Control Studies on 2,4-D

Reference	Study Population	Odds Ratio			Comments
		STS[a]	HD[b]	NHL[c]	
Hardell and Sandstrom, 1979 Eriksson et al., 1981 Hardell, 1981 Hardell et al., 1981	Sweden	4.2			
Vineis et al., 1986	Northern Italy	2.7			
Smith et al., 1984 Pearce et al., 1986 Pearce et al., 1987 Pearce, 1989	New Zealand			1.4	All herbicides. No 2,4-D specific exposure data. 2,4,5-T is the main phenoxy herbicide used in New Zealand.
Hoar et al., 1986a Hoar et al., 1986b	Kansas	No assoc.	No assoc.	2.6	Stronger association for farmers with backpack sprayers who did not use protective equipment.
Woods et al., 1987	Washington State	No assoc.		1.07 1.71	Lower Odds Ratio was for all farmers. Higher Odds Ratio for those with at least 15 years exposure.
Zahm et al., 1990	Kansas			1.5 5.3	Lower Odds Ratio was for all farmers. Higher Odds Ratio was for men who mixed or applied 2,4-D for more than 21 days/year. Odds ratios were lower for farmers who changed clothes immediately after contact with 2,4-D. Odds ratios decreased when data corrected for organophosphate use. No cases where there was a 2,4-D exposure for 21 or more days without exposure to organophosphates.

Notes:
a. Soft tissue sarcoma
b. Hodgkin's disease
c. Non-Hodgkin's lymphoma

Case-control studies investigating the link between 2,4-D exposure and cancer have some common problems. First, since people are interviewed about their exposure to herbicides in previous years, the accuracy of the exposure data is related to the accuracy of the subject's recall. The Harvard study group (Ibrahim et al., 1991) concluded that if the degree of accuracy in the recall of cases and controls is equal, then the net effect is to decrease the OR, resulting in an underestimation of the association between exposure to 2,4-D and disease. Second, NHL and STS are not specific diseases, but rather are groups of similar diseases.

Thus, it is possible for misdiagnosis to occur. If it occurs randomly, the net effect will be to decrease the ORs. Finally, it must be noted that exposure to 2,4-D does not occur in isolation from other chemical exposures. 2,4-D is often formulated with other herbicides or fertilizers. Farmers who apply 2,4-D often are also exposed to pesticides, like organophosphates. As mentioned in Section 5.2.d above, 2,4-D can be contaminated with polychlorinated dibenzodioxins other than TCDD. Therefore, the association seen between 2,4-D and NHL may be attributable to exposure to other chemicals associated with 2,4-D use.

In spite of these caveats, there appears to be an association between exposure to 2,4-D and NHL. The strongest evidence comes from studies like those of Hoar et al., (1986a) and Zahm et al. (1990) which show the risk of NHL increases with higher exposure levels.

In cohort studies, the disease-specific mortality of a group who are known or suspected to be exposed to the agent in question, 2,4-D, is compared to the mortality from the same disease in the general population. The number of deaths observed in the cohort divided by the number of deaths expected in a group that size, based on the general population data, gives a standard mortality ratio [SMR] from which the relative risk [RR] can be estimated. The cohort studies on 2,4-D are summarized in Table 6.5.

The studies of Axelson et al., (1980), Riihimaki et al., (1982) and Green (1991) were considered by the Harvard panel to have cohorts that were too small to yield meaningful data. With the exception of the Bond et al. (1988) study in which the RR is calculated on the basis of 2 cases, the RRs in these studies are not strikingly high. The study by Wigle et al. (1990), which was not considered by the panel, shows a relationship between the acreage sprayed with herbicide (which was between 75-90% 2,4-D) and the mortality from NHL. This is the strongest evidence from the cohort studies that exposure to 2,4-D is linked to NHL.

Table 6.5
Cohort Studies on 2,4-D

Reference	Cohort	Exposure	Observed/Expected			Comments
			STS[a]	HD[b]	NHL[c]	
Axelson et al., 1980						Considered by Ibrahim et al., (1991) to be unacceptable due to small cohort size.
Riihimaki et al., 1982						Considered by Ibrahim et al., (1991) to be unacceptable due to small cohort size.
Green, 1991						Considered by Ibrahim et al., (1991) to be unacceptable due to small cohort size.
Lynge, 1985	Danish phenoxy chemical workers	Phenoxy herbicides, no TCDD	2.72 3.67		1.3	STS significant. Higher relative risk for STS found with 10 year latency.
Wiklund et al., 1987	Swedish pesticide workers	More MCPA than 2,4-D or 2,4,5-T		1.2 1.45	1.01 1.16	Higher relative risks occurred with > 10 years exposure.
Bond et al., 1988	U.S. chemical workers	TCDD, PCDDs and 2,4-D		1	2/0.5 = 4	The cases of NHL had moderate exposure to 2,4-D for 3 years in one case and 10.5 years in the other.
Wigle, 1990	Saskatchewan farmers	All herbicides, 75 - 90 % 2,4-D			1.0 - 1.47	Relative risk increased with acreage sprayed with herbicides.

Notes: a. Soft tissue sarcoma
b. Hodgkin's disease
c. Non-Hodgkin's lymphoma

e. Conclusions

1. Acute Toxicity: 2,4-D can cause death in humans at doses of approximately 86-193 mg/kg, while the LD_{50} ranges from 350 to 666 mg/kg in rodents.
2. Subchronic Toxicity: Animal studies indicate that doses as low as 5 mg/kg/day fed for 7 weeks can alter haematological parameters in rodents while high doses of 2,4-D fed over short periods of time can result in kidney and liver toxicity. Reports of effects on humans are anecdotal. However, it can be concluded that some individuals may be at risk of liver disease, kidney damage, cardiovascular disease, skin irritation and nervous disorders if exposed to 2,4-D, especially if exposure occurs in these sensitive individuals at a high dosage over a short period of time.
3. Teratogenicity and Reproductive Toxicity: Results in animals and humans suggest that 2,4-D is a teratogen causing embryolethality, retardation of fetal growth and fetal malformations in several different organ systems.

4. Mutagenicity and Genotoxicity: Sixty percent of the 40 published genetic toxicity assays on 2,4-D have shown positive results. It is likely that there is some reporting bias in these results since it is easier to publish positive results. However, the reported results clearly indicate the potential for 2,4-D to induce mutation.
5. Carcinogenicity in Animals: 2,4-D appears to be an animal carcinogen in at least one species: a 2 year feeding study on rats found a dose-related increase in the incidence of astrocytomas. This finding was not confirmed in a mouse study, but that study may not have fed levels of 2,4-D sufficient to produce tumours.
6. Carcinogenicity in Humans: Human case-control studies show a weak but consistent association between exposure to 2,4-D and increased incidence of non-Hodgkin's lymphoma (NHL). Higher odds ratios were seen among cases who were more heavily exposed or exposed for longer durations. Cohort studies do not lend strong support to this association, but at least one study shows an exposure-related increase in the risk of NHL.

6.3 Health Effects of Non-Ionizing Radiation

a. Introduction

Material for this section was prepared by Dr. R. Brecher of GlobalTox International. Consultants Inc. and provides information concerning Non-Ionizing Radiation [NIR], as related to impacts of power transmission (GlobalTox: 09/24/92).

Brecher's report addresses the following questions:

1. What is NIR?
2. What forms of NIR are associated with power generation and distribution?
3. How does NIR interact with living systems?
4. What are the human health consequences of NIR exposure?
5. What are the limitations of the database?

While points 1 to 3 can be answered pragmatically and objectively, information on certain adverse human health impacts requires a subjective assessment of what constitutes health and disease. For other suggested effects, objective classification of health and disease is possible, but the data is not adequate to make definitive statements about the presence (or absence) of causal relationships between NIR and disease. This is especially true for NIR associated with power production and transmission.

Brecher reports on several comprehensive reviews of the literature on NIR health impacts, supplemented by examination of some key primary references.

b. Overview of Non-Ionizing Radiation

Radiation can be categorized as either *ionizing radiation* or *non-ionizing radiation*, and comes from both natural and man-made sources. Ionizing radiation includes X-rays, gamma rays and other high-energy forms of radiation. Ionizing radiation interacts with matter primarily by dislodging electrons from atoms. This process is called *ionization* and leads to the formation of highly reactive chemical species. When these reactive materials are formed in living tissue, their presence leads to chemical reactions which would not otherwise take place. NIR includes all types of radiation which interact with matter primarily by mechanisms other than ionization. There are two main types of NIR:

1. *electromagnetic radiation* [EMR] includes ultraviolet, visible, infrared, microwaves, radio waves and Extremely Low Frequency [ELF] fields. Static electric and magnetic fields may also be included in this category.

2. *pressure waves* include sound (frequencies of 20 - 20,000 Hz), infrasound (frequencies less than 20 Hz) and ultrasound (frequencies > 20,000 Hz). Pressure waves require a medium, such as air or water, for transmission.

b.2 NIR Associated With Power Production, Transmission and Distribution

All different types of NIR are associated with electricity use. However, this report focuses only upon NIR associated with power generation, transmission and distribution. It does not consider NIR associated with electricity use, for example, in domestic appliances or industry.

In North America, electricity is provided as an alternating current [AC] operating at 60 Hz (1 Hz = 1 cycle per second). Throughout much of the rest of the world, electricity is provided as a 50 Hz AC supply. This 60 (or 50) Hz AC current is the source of electric and magnetic fields associated with power production, transmission and distribution. A 60 Hz AC current changes direction, or alternates, 60 times every second, producing electric and magnetic fields around the conducting wire, which vary with time. These time-varying fields can induce electric currents within nearby conductors, including animal tissue.

The principal sources of electric fields associated with electric utilities are high voltage transmission lines and generating stations. The electric field strength at the edge of high voltage transmission line (500 kV) rights-of-way may be up to around 10 kilovolts per metre (kV/m). The field strength associated with power generating stations may be as high as 16 kV/m. By contrast, the earth's natural electric field associated with 50-60 Hz frequencies is about 10,000,000 times lower.

Power production and transmission also produce magnetic fields. The magnetic flux density (which is directly related to the magnetic field strength) for generating stations is of the order of 20 - 40 microtesla (μT), but may have peak levels as high as 270 μT. High voltage transmission lines have associated average magnetic flux densities of 10 - 30 μT, with peak levels of up to 400 μT, 800 times lower. The earth's natural time-varying magnetic field in the ELF range has an associated magnetic flux density of 10^{-6} μT (0.000001 μT). During severe thunderstorms, magnetic flux densities of 0.5 μT can be produced. Certain appliances, such as hair dryers and electric shavers, can produce magnetic flux densities of up to 1000 μT (about 2.5 cm away from the appliance as the appliance is turned on). Nuclear magnetic resonance devices used as diagnostic tools in medicine can expose patients to peak magnetic flux densities as high as 2 T (2,000,000 μT).

c. Field Interactions with Living Systems

Since organisms are relatively good electrical conductors compared to air, their presence changes an electric field. There are two principal mechanisms by which electric fields interact with living systems:

1. Increased field strength on the surface of the organism, and consequential charge redistribution on the body surface.
2. Production of currents within the organism.

The first of these types of interactions may lead to vibration of hair shafts, as well as a prickly sensation between skin and clothing (partly due to the strong electric field on the body, and partly due to direct stimulation of nerve cells in the skin). Electric current densities produced in the body at a field strength of 10 kV/m can be up to 4 milliamperes per square meter, which is in the range of natural current densities due to electrical activity in brain and heart.

Like electric fields, magnetic fields effect living systems by inducing currents within the body, although these currents are much weaker than those produced by an electric field. Magnetic fields also exert a force on electric charges in motion, changing the direction of motion of these particles. This force, known as the Lorenz force, can polarize substances in solution, alter patterns of blood flow, and affect the assembly of anatomic structures at the molecular level. Magnetic fields can also have direct effects, as evidenced by induction of magnetophosphenes. Magnetophosphenes are the flickering lights perceived when the eye is exposed to magnetic fields greater than 10 mT and with frequencies over 10 Hz. It is believed that the effect occurs through a direct magnetic field interaction in the retina, but the exact mechanism is not known.

d. Health Consequences of 60 Hz Electromagnetic Fields

Human health risk from a given toxicant (generally a chemical), is usually determined through quantitative risk assessment. This is the foundation for regulations designed to limit exposure to levels which are considered to have zero risk (for non-carcinogens) or an acceptable risk (for carcinogens). The quantitative risk assessment process consists of four major components:

1. Hazard identification
2. Dose-response assessment
3. Exposure estimation
4. Risk characterization and quantification

The hazard identification process for NIR associated with power production and transmission is well under way, but there is limited knowledge in steps 2 and 3, making quantitative risk assessment highly speculative. An important limitation in the database is that researchers have not yet identified the appropriate measure for dose. The type of NIR discussed in this report is an extremely complex phenomenon, having both electric and magnetic components, and causing indirect and direct effects on molecular, cellular and anatomic structures.

There are three principal types of information on human health effects. First, there are a number of epidemiological studies of children and adults in residential exposure settings, and of adults occupationally exposed to NIR. There are also laboratory studies which describe effects of NIR on whole animals or plants, or on cultures of cells or tissues. Finally, there are predictions concerning the potential health implications of observed interactions between living systems and NIR. Based on the available information, it is not yet possible to complete steps 2, 3 and 4 of the quantitative risk assessment process. However, in spite of the difficulties associated with reproducibility of laboratory experimental conditions, and the limited power of epidemiology to detect small differences in small populations, all of the information when taken together is sufficient to warrant public concern over, and extensive further research into, NIR.

While the vast majority of the scientific community would concur that EMR can affect biological systems, the health significance of these effects is far less clear. Much of the available literature focuses on a possible role of EMR in human cancer, with limited information concerning its other possible human health effects. These are discussed separately below.

d.1 Cancer

A number of studies have explored the possible link between certain types of cancer and exposure to 60 Hz electromagnetic fields in both residential and occupational settings. These have been comprehensively interpreted in several recently published review articles (Savitz et al., 1989; Bates, 1991; Bernhardt, 1992). Various government bodies and advisory panels have also prepared reports describing the state of knowledge concerning health effects of EMR related to power production and transmission (US Environmental Protection Agency, 1990; Department of National Health and Welfare, 1989; Stather, 1991). Other unpublished reviews have also examined health effects of EMR associated with power generation, transmission and use (Bridlewood Hydro Line Research Committee, 1987; Milham, 1992). Clearly, identification and management of human health effects from environmental toxicants (chemical or physical) is an emotional issue, and this is reflected in the diversity of conclusions which have been drawn from the existing database.

By far the most heavily studied and hotly debated issue with respect to health effects of 60 Hz EMR is the putative link with cancer. The strongest associations have been suggested for cancers of the central nervous system, leukaemia and male breast cancer. However, the role, if any, of EMR in observed cancer excesses is as yet unclear for the following reasons: the inherent limitations of epidemiology studies, the difficulties in developing appropriate animal models, and the lack of knowledge concerning the relevant measurement of dose for EMR (in other words, which of the many possible parameters which can be measured might be correlated with cancer incidence). Magnetic fields appear more important than electric fields; however, it is not known whether the determinant of health impacts is magnetic field strength, flux density, duration of exposure, or exposure spikes (or perhaps some combination of these parameters). Moreover, it is widely reported in the literature that other factors are probably involved in EMR-induced cancer promotion. Hill's criteria (1965), which determine the degree of association between suspected causes and resultant effects are the most pragmatic way to approach the limitations of the database (see Section 2.3). Although they were originally proposed for investigation of occupational diseases, they can be extended to diseases caused by exposures to chemicals and other toxic agents, such as ionizing and non-ionizing radiation, in non-occupational settings. Information relating to Hill's principal criteria, and the conclusions based on consideration of these criteria, are discussed below.

Strength of Association

To suggest that disease is caused by exposure to an agent, the rate of disease in the exposed group must be higher than that in an appropriate control group. Statistical significance of an increase in the rate of disease ordinarily means that the observed increase would be expected to occur purely by chance in less than 5 out of 100 similar experiments (referred to as "the 95 percent confidence level").

Several case-control studies of cancer associated with EMR have satisfied this requirement for establishing causality, assuming that indicators such as substations within 150 m of a residence or occupation (i.e. "electrical workers") are good predictors of exposure (for example, Wertheimer and Leeper, 1979; Demers et al, 1991). However, these assumption concerning indicators of exposure have not been validated.

Consistency of Association Upon Replication

The same exposure-disease relationship must be shown for different populations, in different geographical locations, under different circumstances, or at different times. That is, the association should be reproducible.

This criterion is not well satisfied for most cancers associated with EMR. One reason for this is the difficulty inherent in replicating an epidemiological study using surrogate exposure indicators. In laboratory studies, geometry of the test animal relative to the EMR field and experimental designs have not been standardized, and interlaboratory comparison of results is difficult. In the case of certain central nervous system tumours the association has been relatively consistent upon replication. For leukaemia, the association is weaker. For example, although studies in Sweden (Tomenius, 1986) and Colorado (Wertheimer and Leeper, 1979) have found an association between surrogate measures of EMR exposure and childhood leukaemia, others have not found such associations using direct field measurements (for example, London et al., 1991). It has been suggested that there may be a publication bias in the EMR-leukaemia studies, with positive results being more frequently published. In the case of male breast cancer, the database is not sufficiently complete to draw conclusions.

Specificity of Association
The uniqueness of a disease strengthens the confidence of causality. For example, Minimata (cf. Section 5.3) disease occurs specifically following mercury poisoning. However, with ubiquitous agents, including some environmental pollutants, such specificity may be difficult or impossible to observe. Furthermore, different materials may produce similar responses. No effects unique to EMR exposure have yet provided enough evidence to satisfy this criterion. However, male breast cancer may ultimately satisfy this requirement, since male breast cancer is very rare.

Time-Order of Association
Exposure to the hazard must precede the disease. In some cases, disease may not occur until long after exposure. Some effects may manifest themselves only in generations subsequent to that exposed. Although the relationship between exposure duration, frequency and level, and health outcome is unknown for EMR, case control studies have shown exposure and disease to be temporally related. For example, Demers and coworkers (1991) showed that the odds ratio for male breast cancer was elevated in workers who had been exposed for 30 or more years prior to diagnosis than compared to workers exposed less than 30 years prior to diagnosis.

Dose-Response Relationship
For chemical toxicants, increased exposure must result in increased incidence of disease, on at least an interval scale. However, this criterion may be modified by, for example, competing causes of death. For example, a high dose of radiation which causes death will not subsequently cause a cancer in the same animal.

For resonance-related phenomenon, such as EMR, the dose-response relationship may be an oscillating one depending upon frequency of radiation or field strength. As discussed above, determination of "dose" in the case of 60 Hz fields associated with power generation and transmission is a problematic issue at this point in time.

Biological Plausibility of Association
Establishment of disease mechanisms usually requires studies from disciplines other than epidemiology to demonstrate the plausibility of the proposed association. In the case of EMR associated with power production and transmission, some biologically plausible mechanisms of interactions have been proposed, and were discussed in Section 6.3.c. A biologically plausible mechanism for EMR involvement in male breast cancer was recently suggested, involving changes in melatonin and prolactin levels (Demers et al., 1991 and references therein).

Coherence of Relationship
There should be similar studies confirming the relationship as well as studies in other branches of science and bioscience which support the relationship, such as studies of animals

in the wild. This criterion is not well satisfied in the case of EMR. Although there are a number of biological effects which have been noted in various test systems, including humans, their significance in the context of human health implications is generally unknown.

Experimental Confirmation

Laboratory studies on animals are used to test causal relationships between hazards and disease. This is not always possible, since animal models may not be available for certain responses. For EMR, experimental confirmation of carcinogenicity is weak. As already pointed out, this is due to the difficulty in obtaining a suitable animal model, a lack of knowledge concerning the relevant measure of exposure to EMR, and the problems of achieving results which are reproducible in different laboratories.

Conclusion

On balance, the evidence for EMR having a role in human cancer is weakly positive, at least for central nervous system cancers. For leukaemia, the link is weaker still. The suggested link between male breast cancer and EMR warrants further study and, if borne out, would go a long way to satisfy the specificity of association and to provide important public health information: primary male and female breast cancers are derived from the same tissues, and a positive finding in men may have important ramifications for health protection in women. Demers et al. (1991) correctly note that some other factor related both to breast cancer in men and occupational exposure to EMR may contribute to their findings. Taken together, the data for EMR having a role in cancer is suggestive, though not yet conclusive.

In the absence of clear scientific data demonstrating (or refuting) a link between a suspected toxicant and an adverse health effect such as cancer, society must be guided by other, non-scientific principles. Several states in the U.S. have adopted policies of "prudent avoidance" as regards 60 Hz fields (Microwave News, 1992, and references therein). This is consistent with erring on the side of caution, and allows positive and cost-effective action to be taken to mitigate preventable exposures, while at the same time encouraging research to more clearly define the link, if any, between EMR and human cancer.

d.2 Non-Cancer Health Effects

A number of non-cancer health effects have been observed or suggested on the basis of experiments in animals or limited human information. Some of these are summarized in an unpublished review by the Bridlewood Hydro Line Research Committee (1987), and include:

1. generalized non-specific stress and high infant mortality rates in laboratory animals,
2. behavioural changes such as decreased reaction times in monkeys,
3. sluggishness, irritability, sleeplessness and lack of libido in humans,
4. vascular system effects, including change in the threshold for ventricular fibrillation induced by a 50 Hz AC current, and
5. changes in blood chemistries, hormone and neurotransmitter levels in animals.

A few studies have also suggested links between human disease, such as polycythemia, and exposure to EMR. In most cases, it is impossible to assess the public health significance of these findings due to either a lack of experimental or epidemiological evidence, or due to a lack of understanding as to how an "effect" relates to "health".

Kavaliers and Ossenkopp (1992) review information concerning the effect of magnetic fields on circadian rhythmicity, (that is daily, time-specific rhythms of behaviour), and the link to the opioid system. Their article highlights experimental data which may prove relevant to human health, noting that the opioid system appears to be involved in a number of important functions in vertebrates, including neurologic and psychiatric disorders, immune system function, carcinogenesis, feeding behaviours, memory and spatial learning. Little information is available on the human health significance of effects observed in animals, on which most of the opioid-EMR interaction database is built. However, if the mechanisms postulated for animal species are confirmed and are shown to operate in humans, the involvement of the opioid system may provide a mechanistic basis to explain the largely anecdotal evidence for non-cancer effects of EMR in humans thus far. Identification of the opioid system as an important "target organ" of EMR toxicity would also help to guide investigators in experimental design and interpretation.

The opioid system - EMR link in animals may have immediate relevance to chronic pain patients. The best known role of the opioid system is involved with nociception (perception of pain), and magnetic fields have been demonstrated to reduce the analgesic (pain relieving) properties of administered opiates, such as morphine. In animals, this has been demonstrated for 60 Hz fields and for fields produced in magnetic resonance imaging (MRI) devices.

Chernoff et al. (1992) assessed studies investigating potential reproductive effects of EMR. The authors reviewed over 100 studies encompassing avian and non-human mammalian species, and epidemiological investigations. Although several studies noted statistically significant differences between exposed and control animals or human populations, these results were generally not reproducible by other investigators. Some results could not be reproduced even within a single laboratory. The most interesting work, from a human health perspective, were studies of women exposed to EMR from working with video display terminals (VDT). Chernoff et al. (1992) concluded that there was "no substantial evidence to suspect that ... [EMR] ... at the VDT is a risk factor for pregnancy outcome.". In experiments in non-human mammalian species, a variety of statistically significant effects were observed, but did not seem to follow any biologically plausible pattern, and were not replicable. It is impossible to assess the biological significance of these results without further study.

e. Emerging Epidemiological Data

The report to the Native Groups' Intervenors (Milham, 1992) states that "a growing body of human epidemiologic data indicates a positive association between certain site-specific cancers (leukaemia, non-Hodgkin's lymphoma, brain tumours, malignant melanoma, and male breast cancer) and EMF exposure". The report continues: "This association is supported in different locales in children and adults in many populations, jobs, and situations where there is a high probability of EMF exposure."

These early findings suggest that public policy should take the direction of prudent avoidance.

6.4 Occupational Health and Safety Issues

The PHC expert report by D.Cole provides advice on occupational health and safety issues related to Hydro's transmission and distribution of electricity. Hydro's data on worker health impacts for the transmission of electricity excludes the planning phase but includes decommissioning (Ontario Hydro: Materials Relating to Environmental & Health Effects of Transmisssion Facilities; December, 1991). Such impacts distribute across the generation options but may be offset via reductions in demand/consumption.

Injury data for construction of transmission lines and the operation and maintenance of the transmission and distribution system are presented in aggregate form in Figure 3 of Hydro's overview document. The denominator is person-hours worked. Few if any transmission line injuries could be attributed to any specific generating option (viz. the lines coming directly out of a generation facility; or from other grids, as in Manitoba or U.S. purchases). Most are a consequence of overall electricity generation and consumption requirements.

Relating injuries to kilometres of transmission via person-hours worked for all phases of the life of a system until replacement is another pertinent denominator for analysis. This analysis would require project specific data, particularly for the construction phase. Table 6.6 shows the transmission line risk per 1,100 km per year over the transmission system's lifetime. The figure of 1,100 km is based on the estimated length of the 500 kV, single circuit transmission line for the Manitoba purchase of 1,000 MW of hydroelectric capacity.

Table 6.6
Transmission Line Risk (Based on 1,100 km per Year Over System Lifetime)[a]

RISKS	MATERIAL ACQ'N. & CONSTR'N.	EMISSIONS[b]	OPERATION & MAINTENANCE	TRANSPORT'N.	TOTAL
Occupational:					
Accidental:					
Death	0.0429	-	0.0023	0.012-0.037	0.057-0.083
Injury	4.07	-	0.072	0.10-0.35	4.29-4.51
Man-days lost	374	-	22	88-286	484-682
Disease:					
Death	c	-	c	-	c
Disability	0.202	-	0.002	-	0.205
Man-days lost	11.11	-	0.097	-	11.2
Public:					
Accidental:					
Death	-	-	-	0.006-0.014	0.006-0.014
Injury	-	-	-	0.012	0.012
Man-days lost	-	-	-	37-87	37-87
Disease:					
Death	-	0.015-0.046	-	-	0.015-0.046
Disability	-	94-281	-	-	94-281
Man-days lost	-	583-1,760	-	-	583-1,760

Notes:
a. Adapted from Inhaber, 1982, Table L-3. Estimates are based on reported data for 500 kV, two-circuit transmission line rather than 500 kV, one circuit line (for which no data was reported). Note, however, that estimates for 765 kV, one-circuit lines are higher than the above information. Estimates are scaled up to 1,100 km, the reported length of the new transmission line required for the Manitoba purchase (Hydro DSP, 1989, Ch.14, p.14-9).
b. Reported risks under emissions are attributable to associated steel production for towers, etc.
c. All deaths assigned to accidents.

According to Hydro's documentation (Overview report; p.29), construction data for Hydro's Lines, Stations and Miscellaneous projects over the 1986-90 period show one fatality (in 1990) over about 9 million exposure hours. This corresponds to 1 fatality in about 960 person years of risk [PYRs] or about 2.08 fatalities per 10,000 PYRs of risky construction work on transmission line projects. Similar calculations yield about 1.20 fatalities per 10,000 PYRs of risky operations and maintenance work for Hydro transmission lines.

The Regions Branch, who are primarily responsible for line maintenance, continue to deteriorate in safety performance (page 10 in Ontario Hydro 1990 Document, HSD-91-19). Forty percent of disabling injuries in 1990 were among power line maintainers. The hazards of such work have long been known and of concern to the workers involved (CUPE 1977), to health and safety personnel at Hydro (Wills & Henville; 1982) and to governmental bodies in other jurisdictions (NIOSH 1989). Musculoskeletal injuries among foresters and lineman are related to awkward positions, high forces and adverse environmental conditions. No documents address the psychosocial impacts of such tragedies on co-workers although these impacts are common knowledge among high risk occupations such as linemen. Psychological follow up is provided by Hydro Health Services Department (CUPE 1000, personal communication).

Exposures of concern include noise, vibration, pesticides, PCBs and electromagnetic fields (the first two of which are not discussed in the overview document).

A noise exposure assessment conducted in 1983 found that 73% of foresters and 24% of ground maintainers had exposures in excess of 85 dBA, a level above which noise induced hearing loss [NIHL] can be expected to increase (Behar; 1983). As with hydraulic system workers, the extent of NIHL actually caused among such workers has not been reported.

Vibrating tools, such as chainsaws, nut drivers and pneumatic breakers are also a concern (Behar; August, 1990). Twenty-four claims for vibration-induced whitefinger disease have been made for the period 1982-1988 with 10 allowed and 13 pending. This condition may increase as manual brush clearing displaces herbicide applications on transmission rights of way [ROW].

The issues of herbicide exposures to workers and concerns over cancer in the long term as well as Hydro's participation in international studies (IARC) are dealt with in the overview document, although it does not refer to the acute effects experienced by foresters and ground maintainers. These have included increased headaches, acne, weakness, drowsiness, irritability, eye irritation, pain or tightness in the chest, sore throat, nasal congestion and loss of appetite as compared to linemen in a cross-sectional study of Hydro employees (Choi & Nethercott; 1987). Such symptoms occur but may not be counted in the usual workers' compensation statistics if they do not result in lost time or are not reported.

Health impacts of PCBs and EMF exposure are of potential concern and considerable controversy. The Hydro overview document briefly covers these controversies and the Risk Assessment Program for EMF radiation in which Ontario Hydro is playing a major role. Less well represented is the consistency across worker studies for increases in leukaemia, particularly acute myeloid leukaemia, associated with work in electrical occupations (see reviews by: Coleman and Beral, 1988; Bates, 1991; Theriault, 1991). Exposure determination has remained the weakest component of these studies and is being improved considerably in "second generation" studies. Occupational studies of this sort have yet to be analyzed and presented and so we must await such work to understand the particular role of EMF.

Local municipal utilities distributing electricity have some similar exposure concerns and are participating in the EMF studies. They also have widely ranging accident rates, in both frequency and severity (see Cole: Figures 4 and 5). These would need to be aggregated by year and put over a denominator of power distributed in order to be added to the overall injury impacts of transmission and distribution. The majority of "public" electrical accidents are occupational and deserve inclusion among the worker impacts of electricity generation (Ontario Hydro, 1987). Such a product custodian approach is taken by Hydro via its interface with municipal and industrial distributors/consumers and its programs aimed at reducing "public accidents".

RECOMMENDATION 6.1 : The PHC recommends that Hydro be required to practice "prudent avoidance" in the location of new transmission lines as well as in the location of transmission and distribution lines of Hydro's associated ~~municipal utilities~~ and other customers.

The current and emerging evidence respecting the adverse health effects of EMFs is sufficient to justify the adoption of a policy of prudent avoidance in the location of transmission lines, shielding, breadth of transmission line corridors and land use in the vicinity of transmission line corridors.

RECOMMENDATION 6.2: The PHC recommends that Hydro and its associated municipal utilities and other customers establish work practices which minimize the exposure of their workers to EMFs.

RECOMMENDATION 6.3: The PHC recommends that Hydro be obliged to minimize its use of herbicides in transmission line corridors and to replace herbicides by manual clearing wherever feasible.

RECOMMENDATION 6.4: The PHC recommends that the proposed agency conduct ongoing research programs to evaluate health effects associated with EMFs.

Chapter 7
Health Effects From Energy Efficiency Improvement Options

Since demand management (or the energy efficiency improvement option) is a major component of Hydro's proposed undertaking in both its 1989 DSP submission and the 1992 Update to that submission, the PHC requests that the Board consider the material in this chapter in its evaluation of the undertaking and any alternatives which deploy this conserver society strategy.

7.1 The Conserver Society and Hydro

Material for this chapter has been drawn from reports by PHC experts T.Hancock (10/05/92) and D.Cole (September, 1992).

Hydro's DSP strategy (March, 1989) acknowledges the value of demand management and conservation. Pursuit of these options will ensure low cost electrical services and will reflect the corporation's commitment to maximizing overall benefit to the community and customer value over the long term.

The DSP Update (1992) examines alternative energy options such as small hydraulic and gas-fuelled NUGs (Non-Utility Generation). Further, the Alternative Energy Review (Ontario Hydro, 1991a) suggests that certain alternative energy systems - notably fuel cells, photovoltaics and biomass - will have a contribution to make, while a study on fuel switching (Ontario Hydro, 1991b) indicates substantial potential for fuel switching (primarily conversion from electric to gas space heating and water heating in residential and commercial buildings) of some 3,000 megawatts by the year 2000. However, Hydro has not yet produced a serious, comprehensive, detailed DSP based on a high conservation scenario, making it difficult for the PHC to evaluate its health impacts.

The Ministry of Energy has produced an outline of a high conservation scenario. This scenario yields a 1.6% per year growth in electricity demand for Ontario to the year 2005 (Ministry of Energy, 1991), and is based on the following assumptions: demand management policies which achieve electricity savings 50% more than targeted at the time by Hydro; a 50% increase in the target for NUGs to 3,300 MW, full development of planned hydro electric potential (2,000 MW); the Manitoba Purchase of 1,000 MW; and improved performance of nuclear generating stations. Under that scenario, coal fired generation could be reduced by more than half. The DSP Update goes beyond the Ministry of Energy's supposedly optimistic high conservation scenario, anticipating a 1.0% growth in demand, a 77% increase in electricity savings through demand management, and a 100% increase in NUG supply to 4,200 MW while the hydro electric potential is only slightly less than proposed by the Ministry of Energy.

The next section uses a possible conserver society scenario for electricity (originating with the Coalition for Environmental Groups [CEGs]) to make a preliminary assessment of some of the resulting health impacts. Uncertainties around the details of an alternative scenario, such as the remaining operational Hydro fossil and nuclear stations given a high conservation scenario, make it impossible to perform a detailed health impact assessment.

7.2 A Conserver Society Electrical Energy Scenario

This section draws on the following scenario and assumptions:

1. The CEG's draft revision of Hydro's basic load forecast predicting 37,000 MW of demand by 2014;
2. The CEG's position that demand management can save 15,000 MW (This compares to the almost 10,000 MW assumed by Hydro in the DSP Update, in itself an increase from the 5,570 MW of the original DSP; since Hydro has itself almost doubled its estimate for demand management, a further 50 percent increase seems modest, especially given that Hydro estimates that fuel switching to gas alone (i.e., not to direct solar space and water heating) combined with electrical efficiency improvement (EEI) has a potential of reducing demand by 8,480 MW by the year 2000 (Ontario Hydro, 1991)).
3. A resulting primary load forecast of 22,000 MW, to which a reserve capacity of 20% (Hydro in its DSP assumed 24% but most of the utilities cited in the report (Figure 4-17) used 22% and the CEG proposes 20%) or 4,400 MW yields a required capacity in the year 2014 of 26,400 MW.

To meet this capacity requirement, the following assumptions are made:

1. Hydraulic meets 7,300 MW (the existing 6,500 plus an additional 800 MW proposed in the plan update, but excluding 1,000 MW of Northern Ontario hydraulic);
2. Independent sources of generation provide 8,405 MW based on the Independent Power Producers Society of Ontario [IPPSO] estimates of market potential assuming a value of power (or buy-back rate) of 6.0 cents/kwh (IPPSO, August 20, 1992). This market potential is almost all (99%) cogeneration.
3. The Manitoba purchase is excluded.
4. Renewables meet 4,400 MW (this assumes the upper range of the optimistic scenario 3 outlined in the Alternative Energy Review (Ontario Hydro, 1991) for photovoltaic and fuel cells and the IPPSO estimates for wind and biomass.

This leaves a balance of 6,295 MW to be provided by fossil or nuclear in 2014.

Table 7.1 provides details of this conserver society scenario and compares it to Hydro's DSP Update.

Table 7.1
Conserver Society and Hydro DSP Update Scenarios for Electricity Demand and Supply: 2014

Demand/Supply Components	Conserver Society Scenario	Hydro DSP Update Scenario
DEMAND:		
Revised Basic Load Forecast (1)	37,000	39,800
Demand Management (2,3)	15,000	9,860
Fuel Switching	6,000	3,120
- direct solar	(1,000)	
- natural gas or oil	(5,000)	
EEI (4)	9,000 (4)	5,360
- insulation of buildings		
- lights		
- appliances		
- motors		
- other		
Load Displacement		1,380
Primary Load Forecast	22,000	29,940
Reserve capacity (5)	(20%) 4,400	7,186 (24%)
Required Capacity	**26,400**	**37,126**
SUPPLY:		
Hydraulic (6)	7,300	8,300
NUG (7)	8,405	4,200
Manitoba purchase	-	1,000
Renewables:		
Photovoltaic (8)	100	-
Wind (9)	2,000	-
Fuel cells (10)	800	-
Biomass (11)	1,500	-
	20,105	**13,500**
Balance to be provided:	6,295	23,626
Option [a] - Fossil	6,295	
Option [b] - Nuclear	6,295	
Hydro's DSP Update: (12)		
Fossil		12,514
Nuclear		15,040

Notes:
1. Approximate CEG estimate.
2. CEG estimate. (Since Hydro's forecast for demand management has increased from 5570 MW to 9860 MW between the DSP (1989) and the update (1992) a further 50 percent increase seems reasonable, even modest. Hydro's estimate for demand reduction from fuel-switching to gas is for 3120 MW and for total EEI and FS is 8480 MW by the year 2000 alone.
3. The CEG estimate ignores load shifting, since the energy (and thus it's health and environmental effects) are still produced. If load shifting were included, demand reduction would be even greater.

4. CEG estimate.
5. CEG estimate is for 20% reserve capacity. Hydro's 24% estimate is at the high end of the range for North American utilities. (Figure 4-16, Plan Report).
6. 1993 hydraulic capacity of 6,500 MW (Plan Report, Figure 4-2) plus 800 MW addition to Adam Beck only - no new northern Ontario hydraulic.
7. Approximate amount based on IPPSO estimates, includes:
   - 7,081 MW industrial cogeneration, 90% natural gas, 10% biomass plantation and/or wood waste) at 60-70% efficiency.
   - 1,256 MW load displacement cogeneration, much of it in hospitals, mostly gas, at 70-90% efficiency.
   - 16 MW small hydraulic, much of it on aboriginal lands.
   - 51 MW landfill gas - "obligatory use"

   Hydro estimate is assumed to be completely cogeneration, also 90% natural gas, 10% biomass.
8. Optimistic (scenario 3) forecast from Ontario Hydro Alternative Energy Review.
9. Estimate from IPPSO.
10. Optimistic (Scenario 3) forecast from Ontario Hydro Alternative Energy Review.
11. Estimate from IPPSO, includes 1000 MW from wood waste, 300 MW from peat and (from Optimistic Scenario 3) 200 MW from mini-rotation plantation biomass.
12. The Plan update identifies 9,514 MW from fossil, 12,040 MW from nuclear and a further 6,000 MW unspecified. It is assumed here that this is split evenly between fossil and nuclear.

7.3 Health Implications of the Conserver Society Scenario

The conserver society scenario has several characteristics that distinguish it from the Hydro DSP. These include a greater reliance on demand management, renewables and alternatives (principally gas-fuelled NUGs) and a sharp reduction in fossil and nuclear.

The first three elements are reviewed here in terms of their potential health effects. The health effects of reduced use of fossil and nuclear are extrapolated from previous sections of this report.

a. Demand Management

> "...conservation is the best strategy for minimizing environmental and health impacts, at least in the medium term until more benign technologies become available." (Porter Commission, Vol. 6, Pg. XV)

Electricity production in Ontario in 1988 consumed 734 PJ or 28% of primary energy, while providing only 467 PJ or 20% of secondary energy (Smith and Torrie, 1991, Pg. 7). In other words, 36% of the energy inputs to electricity production are lost in the production and transmission process. Moreover, analysis of end use electricity markets suggest that a more appropriate use of electricity in Ontario would reduce the figure of 20% to 13% of secondary energy overall. That is, 35% of current electricity usage is inappropriate (Smith and Torrie, Pg. 16). For example, electricity has approximately 32% of the residential secondary energy market whereas more appropriate electricity-specific end uses would only require approximately 18%. A substantial portion of the saving, particularly in the residential market, comes from electricity's share of space and water heating.

In other words, there is considerable potential for reducing demand for electricity both by switching to more appropriate and efficient fuels for space and water heating and by upgrading electrical energy efficiency at the point of end use (e.g. installation of insulation; more efficient lighting, appliances, motors and other electrical end-uses; etc.).

a.1 Fuel Switching

An indication of the relative efficiency of electricity and gas can be found in the Ministry of Energy's high conservation scenario which indicates that total electricity consumption in 1988 was 503.5 PJ while total energy used for electricity generation (fossil, hydro and nuclear) was 1,449.8 PJ. This gives a fuel conversion efficiency of 34.7%. However, the fuel conversion efficiency of natural gas is given as 80%, and of natural gas cogeneration, 60%.

In this scenario, the health effects from fuel switching are the difference between the avoided health effects from reducing electricity demand by 5,000 MW (which will depend upon the estimated fuel mix of the avoided generation) and the additional health effects from acquiring and transporting the materials for constructing and installing gas furnaces and the necessary duct work for space heating and gas heaters for water heating, together with the health costs of the gaseous and other emissions. In a study of fuel switching for space heating in Ontario, Passmore Associates (1992) noted that 60-90% of the electricity required for space heating is from fossil (primarily coal) -fuelled generation at 30-60% efficiency, and that high efficiency gas furnaces operate at up to 93% efficiency. Since gas emissions are cleaner than coal emissions, the public health benefits can be considerable, with roughly three-fold reductions in CO_2 emissions, six-ten-fold reductions in SO_2 and a ten-fold reduction in nitrogen oxide emissions. There may also be health effects from the disposal of electric base-boards and water heaters, and health costs resulting from the increase in production, distribution and supply of natural gas.

The fuel switching under consideration here is to natural gas; the results would also be positive, through less dramatic if the switch were to oil (Passmore Associates, 1992). There are other options, including switching to direct solar space and water heating in the residential and commercial sectors. Here, the health gains would be analogous to those from fuel switching to gas, but the health costs would only be for the construction and installation of the solar panel, ducts, pipes and any associated fans or pumps. Once installed there would be no emissions and thus no health costs from operation, although there might be some health costs from maintenance.

Perhaps the most important, direct benefit from the deployment of Hydro fuel switching programs is the impact on employment in the province.

a.2 Electrical Efficiency Improvement

Fickett, Gellings and Lovins (1990) summarize the issues with respect to efficient use of electricity. They identify four areas of progress including advanced technologies for using electricity more productively, new ways to finance and deliver those technologies, expanded and reformulated roles for electrical utilities and innovative regulation that rewards efficiency. According to their review, the use of advanced technologies could save anywhere from 24% to 75% of current electricity use. In the area of advanced technology, for example, some 55% to 90% of electricity used for lighting could be saved, or from 1/7 to 1/5 of total electricity now used in the U.S. Moreover, better lighting might increase productivity in an office and reduce maintenance costs. Better motors can yield 10% to 40% in savings, while efficient appliances can save anywhere from 50% to 90% of electricity currently used to power them.

The technologies must be used to be effective. As Fickett, Gellings and Lovins state: "the potential for safe electricity will not be realized until - like power plants - electricity savings programs are planned, designed, financed, built, commissioned and maintained."

In their view this will require: electric utilities or the government to both push and pull the market through such measures as rebates, leases (including leases on lightbulbs); the provision of efficiency services and the setting of efficiency standards; and mechanisms to ensure an adequate payback horizon. They suggest that while "utilities are the logical organizations to expedite the use of energy efficient products...at present...they have little motive to expedite energy efficiency...why spend money to reduce sales?" They suggest that the appropriate role of utilities is "the profitable production of customer satisfaction" through the application of "least cost utility planning" or "integrated resource planning".

As Davis comments (1990): "in a sustainable world, the balance of new initiatives would shift from producer to consumer, from energy supply to energy services and from quantity to quality of energy."

The health effects of electrical energy efficiency [EEI] improvements are related to: improved ceiling, floor, wall and basement insulation; air sealing window and door upgrades; more energy efficient new houses (e.g., R2000); water heater insulation and heat traps; heat pumps; low flow shower heads; energy efficient lights; energy efficient appliances; energy efficient motors; etc.

As for fuel switching, the net health effect of EEIs would be the difference between the health gains as a result of not having to generate and supply electricity less the health costs of the materials, acquisition, construction, installation, operation, maintenance and disposal of the more efficient technologies, together with any health costs associated with the removal and disposal of the replaced technologies. These health effects would also include the net health effects of additional employment.

In their review for Hydro, Haites and Mauldin (1990) conclude that the environmental impacts of a variety of EEI technologies "are generally less than the impacts that would be experienced in the absence of those measures, given that suitable mitigation efforts are implemented."

The first EEI technologies to consider are those concerned with improved insulation, which includes window and door upgrades and air sealing. The first health effect of concern is with the materials used for insulation. A review of the health effects of energy conserving materials (Levin and Purdom, 1983) reviewed such materials as asbestos, urea-formaldehyde foam, polyvinyl chloride, cellulosic insulations, fibrous glass, mineral wool and vermiculite. (Asbestos and UFFI are no longer used, but their continuing presence and - particularly in the case of asbestos - the hazards involved in their removal and replacement - are of concern. However, since they are not used in new insulation, their effects cannot be considered to be an additional effect of electrical efficiency improvements undertaken today.)

Cellulose - in the shape of old newspapers and similar materials - proved to be a fire hazard, particularly when in contact with recessed lighting fixtures. Polyurethane and wood chips or sawdust are also a concern in fires, the former due to release of such toxic products of thermal decomposition as carbon monoxide and hydrogen cyanide, the latter due to release of cresols. No toxic effects of the vermiculite were noted, but its use is limited by its low density and relatively high cost. Mineral wools and fibrous glass are generally the materials of choice from the standpoint of health hazards. The health hazards of both are primarily in their production, due to the effect of small particles on the skin, eyes, upper respiratory tract and lungs. Their effects are primarily irritant, but the review noted that there was little evidence at the time to support the concern with respect to carcinogenicity or pulmonary fibrosis. (Note that a recent study by Prof. Harry Shannon of McMaster University using Ontario data has shown a non-significant increase in lung cancer among glass fibre production workers). The occupational and public health hazards of insulating materials in terms of their production, installation and life-time presence in the walls, floors and ceilings of buildings should be the subject of a health impact analysis.

A second concern related to insulation and the sealing of buildings is indoor air quality - the so called "sick building syndrome". Haites and Mauldin (1990) address this topic in their review of the environmental impacts of demand management options for Hydro. Radon is the pollutant of most concern with respect to residential indoor air quality due to its contribution to lung cancer. Research at the Lawrence Berkeley Laboratory indicates that "standard weatherization programs appear to have only a small effect on indoor air quality." This problem can be mitigated by insuring adequate ventilation rates (they note that the City of Boston requires .5 to .8 air changes per hour upon completion of weatherization work) or if necessary other more expensive systems involving equalizing soil pressure with air pressure in the home.

They also review indoor air quality in commercial buildings, noting that the major sources of indoor air pollution include building and furnishing materials (e.g. insulation, pressed wood products, floor and wall coverings, carpet, paints, glues, etc.); everyday activities (e.g., use of photocopiers and other office machines, cleaning agents, printing, secondhand smoke, etc.); and outdoor sources brought in by poorly designed ventilation systems. As with radon, the best answer appears to be adequate ventilation, particularly when a new building is first used or after renovations or the installation of new materials, when it may take some months for the outgassing of chemical contaminants to substantially decrease. Finally, they note that buildings with high moisture content or improperly cleaned and maintained humidification systems have the potential of microbial contamination which can cause respiratory diseases. Properly designed, operated and maintained HVAC systems should solve the problem. Haites and Mauldin also suggest that "by encouraging the use of non-CFC insulation products, Hydro's demand management measures could decrease CFC emissions."

The production and installation of more energy efficient windows and doors is only likely to have additional health effects if more toxic materials or processes were used in their manufacture, or if they entailed more dangerous operating procedures or produced more toxic wastes than is the case with conventional doors and windows. This too would need to be evaluated. The installation of energy efficient doors and windows is unlikely to have additional health effects compared to the installation of ordinary doors and windows.

The health effects of energy efficient showerheads appear to be no greater than the effects of regular showerheads; in both cases, the thermostat regulating water temperature should be correctly set to prevent scalding (Haites and Mauldin, 1990).

While it is generally reasonable to assume that the hazards of production and use of more energy efficient products (such as lights, appliances and motors) are not any greater than the production and use of energy inefficient products, there are certain instances where the materials used in the former products are or may be more hazardous to health. For example, fluorescent lamps contain mercury while incandescent lights do not. Moreover, as the Haites and Mauldin report notes, a relamping program which replaces lamps which are not yet at the end of their useful life would result in an annual mercury release of 8 tons; however they also report that, according to Competitek, the annual use of mercury in lighting represents 0.02 percent of annual mercury emissions from all sources and that using fluorescents saves an order of magnitude of mercury due to the fuel savings (i.e., not burning coal, which contains mercury that is lost to the environment in the emissions.) Finally, there are occupational health hazards in the disposal of fluorescent tubes, particularly those in which mercury vapour is still present (i.e., if the light is replaced before the lamp burns out). Radioactive isotopes such as krypton-85, present in some compact fluorescent lights are another potential health effect (Earth Island Journal, Summer 1990).

It will be important to determine whether other more energy efficient products also involve the use of more toxic products than are used in the energy inefficient products currently on the market, and whether the hazards posed are more than offset by the hazards avoided through reduction of fossil fuel emissions.

Other potential environmental and health effects of energy efficient products include: a potential increase in HCFC emissions resulting from the use of heat pumps; and potential reductions in the escape of CFCs through the use of non-CFC insulants in appliances (Haites and Maudlin, 1990).

The largest health impact arising from EEI improvements is likely to be the beneficial health effects of increased employment as a result of domestic and commercial insulation programs, as indicated earlier.

b. Renewables

The renewables of concern here are hydraulic, photovoltaic, wind and biomass.

The health impacts of the hydraulic option will arise from two sources in this conserver society scenario: an additional 800 MW from expansion of the Niagara generating station and 16 MW of small hydraulic NUG, much of it on aboriginal land. According to Holgren et al (1983) the health effects of the hydraulic expansion include the occupational health hazards of materials acquisition, transportation and construction; there are likely to be few if any additional occupational health costs of operation and maintenance. Public health hazards are primarily the result of transportation of materials for construction.

Occupational and public health hazards arising from small hydraulic NUGs are difficult to estimate without more detailed knowledge of the specific sites and the hazards that they involve. Among the health effects to be considered (and addressed in the reports of the aboriginal peoples intervenor group) are the health effects of mercury and the social/employment and economic development effects.

The occupational and public health effects of solar photovoltaic electrical generation arise from the use of toxic materials in the manufacture of solar cells (and in their subsequent disposal). Some occupational and public health hazards may arise from other manufacturing effects and from the installation and maintenance of photovoltaics. The latter will depend upon whether the photovoltaic strategy is primarily a decentralized one involving installations in individual residential, commercial and industrial premises or community "solar" farms. The more decentralized strategy will generate more jobs but at the same time may result in more occupational health problems.

A WHO report (1987) considered some of the health consequences of solar power. It noted that: "all solar technology will require the large scale fabrication of solar conversion materials, the manufacture and ultimate disposal of this material and will increase the exposure of both workers and the general population. Silicon, cadmium, germanium, arsenic, complex organic coating compounds and other materials may be used in large quantities. More information of their effects on health and their transport in the environment will be required."

Boeniger and Briggs (1980) reviewed the health hazards from the production of silicon photovoltaics, the hazards of cadmium sulfate photovoltaics and touched upon gallium arsenide photovoltaic cells. In practice, only silicon is being used in solar cells to any significant extent at present (Szeless, 1991).

One hazard of silicon photovoltaics is the health threat to workers during the mining of ore-bearing rock and its subsequent refinement, when they may be exposed to crystalline free silica which can result in silicosis. Exposure to silica particulates may also occur in the processing, while additional hazards may result from exposure to chlorosilines, methyl chloride, exposure to heat from furnaces and hot materials, and other toxic materials including hydrofluoric acid, phosphine, nitric acid, epoxy fibreglass and formaldehyde. Phosphine in particular will be used in large volumes, and since 70-90% remains unreacted after the deposition process, handling and disposing of these unreacted portions will be a problem (Argonne National Laboratory, 1991).

Additional occupational hazards from manufacture arise from the use of electrical equipment and high intensity currents, with associated risks from electro-magnetic field effects and sparking or arcing igniting explosions in the presence of inflammable gases (Argonne National Laboratory, 1991).

The major hazard in production of cadmium sulfide cells is exposure to cadmium, which causes chronic cadmium poisoning and may be a carcinogen. Other toxic materials here include thiourea, another suspected carcinogen. The authors noted that "although the numbers of workers are expected to increase in future years, the number of hazardous processes may decline because of the elimination of the need for those steps or through the automation of the process."

The health hazards associated with wind power are those involved in the manufacture of windmills, their installation, operation and maintenance. These are the occupational hazards associated with light industry and engineering in general, together with potential public health effects arising from the operation of windmills, primarily noise, local climate effects and accidents arising from breakdown or failure. Evidence from the extensive experience in California and Denmark in the construction, installation and operation of windmills indicates that they have a relatively good safety profile and that the only obvious public risk from their operation, blade throw, is rare (Beurskens, 1991).

Biomass energy in this scenario is assumed to come from wood waste, peat and mini-rotation plantations. Wood waste, in particular, will be from cogeneration. There are little or no additional health effects to be imputed to the production of wood waste, since that will occur whether or not the material is used to produce electricity. The health costs of concern are those involved in the processing of wood waste that would be required over and above the processing already undertaken (since much wood waste is already burned to provide heat anyway), together with the additional costs over and above existing furnaces/heating plants to adapt them for electricity production. Depending upon how much wood waste is currently burned, (and this will require additional specific information from IPPSO who are the major proponents of NUGs together with additional information from Hydro on NUG wood waste cogeneration proposals), there may be little or no additional air emissions or waste production from the use of wood waste fuel for electricity generation. Thus the net health effects of wood waste electricity cogeneration are likely to be minimal.

In the case of peat or biomass plantations, there will be a range of health effects that require quantification. The WHO review (1987) notes that biomass production will require cultivation and harvesting (with associated hazards similar to those experienced in agriculture and forestry) while Hydro's Alternative Energy Review notes that plantations would likely require the application of fertilizers, pesticides and herbicides and could have an effect on land and water.

The occupational health costs may exceed that of coal mining: Holdren et al. (1983) cite 34-41 fatalities and 140-160,000 work days lost per 1018 J for biomass forestry compared to 35 fatalities and 35-60,000 lost work days for coal mining, while Argonne National Laboratory (1991) suggests fatality rates 25-70 times as high for tree removal as for underground coal mining per trillion Btu. However, biomass cultivation using future automated clear cutting and field chipping technology may result in a 25-200 fold reduction in occupational fatalities and a 25-35 fold reduction in occupational injuries per GWe - Year when compared to present harvesting methods (Cox, 1985, Tables 4.1, 4.2).

In addition to the occupational and public health hazards of production and harvesting of biomass and its transportation to a generating station, there are the public and occupational health hazards associated with the construction of the generating station (inherently no different from the health hazards resulting from the construction of other fossil fuelled plants) and the emissions and wastes produced, which will be similar to those produced by coal fired generating stations. The Hydro Alternative Energy Review notes that wood fired power plants may produce fugitive dust emissions, odours and leachates from fuel storage piles, SOx, NOx, carbon dioxide, trace organics, carbon monoxide, bottom ash and fly ash. Trace organics will include volatile organic compounds and polycyclic aromatic hydrocarbons. A detailed analysis of the health effects of biomass fuelled plants is required.

Many of the same concerns with plantation biomass apply to peat, although peat is not strictly speaking a renewable fuel, or only renewable over the very long term. IPPSO anticipates 300 MW from peat, primarily on aboriginal lands. The public and occupational health hazards resulting from large scale harvesting/mining of peat, its transportation, processing and combustion will be similar to that of strip mined coal or plantation biomass (detailed information is required and should be available from Finland and Ireland.)

The Alternative Energy Review notes that peat production will involve the disruption of the peat land ecosystem and that peat slurry from thermal treatment and peat fuel-pile and ash leachates will require treatment. The emissions from peat fired generating stations are similar to those from coal fired stations, but up to twice as much ash is generated per kilowatt of power of generation from peat firing compared to coal firing... They note that "in Finland, most peat fired stations also provide district or process heating, thereby making better use of the energy content of the fuel..."

The employment generation effects of several of these technologies are considerable. In the case of small hydraulic and peat, much of the employment generation would be in northern or eastern Ontario and/or in aboriginal communities, thereby providing local economic stimulus. A photovoltaic industry would likely generate considerable employment and, as with insulation, a decentralized industry would result in a more equitable distribution of jobs across Ontario. Again, detailed information from IPPSO and Hydro is required before a full health impact assessment can be undertaken.

c. Alternatives

The alternatives considered here are large and small cogeneration plants - mostly gas fired -, fuel cells (also mostly gas-fired) and landfill gas.

The health effects of cogeneration will depend upon whether or not the heat generating plant was to be built anyway. The only additional health costs for building the plant as an electrical cogenerator are the construction, installation, operating, maintenance and disposal of any additional material or equipment that will be needed over and above that needed for heat generation. If the plant is a new plant to be built for both purposes, only a proportion of the health costs should be attributed to electricity generation.

Perhaps the largest single health effect of cogeneration will be the health benefit from avoided health costs due to the more efficient use of primary energy (primarily gas) that results from cogeneration. According to IPPSO, large cogeneration is 60-70 percent efficient, while small cogeneration is 70-90 percent efficient. Thus there is a net reduction in health effects due to the increased efficiency. However, a full health impact assessment of cogeneration must await a detailed scenario from either IPPSO or Hydro.

Although landfill gas is only a small electrical energy source, it is, in the words of one commentator an "obligatory use". Since the gas is being produced anyway, it should be used, rather than merely burned as waste. Health costs are those associated with the manufacture and installation of the plants.

7.4 Preliminary assessment

Table 7.2 shows the major elements of a comparison of the health effects of the conserver society scenario (CSS) and the Hydro DSP Update. The major elements of the CSS are shown in column 1. Column 2 shows the main health costs to be considered for each element of the CSS and column 3 shows the main health benefits (principally increased employment). Column 4 shows the avoided health costs of not implementing certain elements of the DSP, principally northern Ontario hydraulic, the Manitoba purchase and fossil and nuclear plants.

The fifth column provides details on any specific differences between the CSS and the DSP health benefits.

A health effects assessment of the various technologies in both the conserver society alternative scenario (or any genuine alternative energy scenario Hydro cares to provide) is needed. The total health costs of one scenario should be compared to another, including health costs and benefits associated with environmental and employment impacts.

Table 7.3 shows some typical health impact data from the literature.

Table 7.2
Differences Between Conserver Society Scenario and Hydro DSP

DEMAND/SUPPLY OPTION	HEALTH COSTS OF CSS	HEALTH BENEFITS OF CSS	AVOIDED HEALTH COSTS OF DSP	DIFFERENCE IN HEALTH BENEFITS OR COSTS BETWEEN CSS & DSP
1. <u>Fuel switching:</u> - direct solar - natural gas	- acquisition of materials, construction, installation & disposal of flat plate collectors, ducts, etc. - acq'n. of materials, construction, installation & disposal of high eff'y. furnaces, ducts, etc. - acq'n., transportation and distribution of gas - emissions from gas or oil combustion	- employment generated - employment generated	- costs associated with major supply options that are displaced.	
2. <u>Electrical eff'y. improvements:</u>	- acquisition of materials, construction, installation, operation, maintenance and disposal of insulation, windows, doors, lights, appliances, motors, etc.	- employment generated	- costs associated with major supply options that are displaced.	- additional costs only for add'l. insulation, doors & windows & for any extra health hazards of energy efficient lights, appliances, motors, etc., compared to non-energy efficient versions
3. <u>Hydraulic:</u> [Not using 1000 MW of Northern Ontario supply]	- employment and other benefits lost in Northern Ontario in construction and development		- acq'n. of materials, transportation, construction, installation, operation & maintenance of 1000 MW Northern Ontario hydraulic, incl. environmental & social costs	

Table 7.2 (cont'd)
Differences Between Conserver Society Scenario and Hydro DSP

DEMAND/SUPPLY OPTION	HEALTH COSTS OF CSS	HEALTH BENEFITS OF CSS	AVOIDED HEALTH COSTS OF DSP	DIFFERENCE IN HEALTH BENEFITS OR COSTS BETWEEN CSS & DSP
4. NUG: - Cogeneration - Small hydraulic - Landfill gas	- additional costs (over and above costs for non-cogeneration plant (if it were to be built anyway) of materials acq'n., transportation, construction, installation, operation, maintenance and decom-missioning - add'l. costs of emissions - employment lost from construction & maintenance of power lines and rights of way - acq'n., transportation, construction, operation & maintenance of dams, incl. social & environmental costs - construction & installation of equipment	- employment generated	- occupational health costs of line & right of way construction & maintenance. - costs associated with major supply options that are displaced.	
5. Manitoba purchase: [A=-1,000 MW]	- employment & other benefits lost in Manitoba in construction & economic development - ditto for lines & rights of way in Ontario		- occupational costs of dam construction in Manitoba & line & right of way construc-tion in Manitoba & Ontario - environmental & social costs of the same	

Table 7.2 (Cont'd)
Differences Between Conserver Society Scenario and Hydro DSP

DEMAND/SUPPLY OPTION	HEALTH COSTS OF CSS	HEALTH BENEFITS OF CSS	AVOIDED HEALTH COSTS OF DSP	DIFFERENCE IN HEALTH BENEFITS OR COSTS BETWEEN CSS & DSP
6. Renewables: - Photovoltaic	- acq'n. of materials, construction, installation and disposal of solar PV arrays	- employment generated	- costs associated with major supply options that are displaced.	
- Wind	- As above	- As above		
- Fuel cells	- As above, plus costs of acq'n. & transportation of fuel plus operation and maintenance of fuel cells (including emissions - mainly from gas)	- As above		
- Biomass: . Wood waste . Peat . Plantation	- As above, plus costs of operating & maintaining plantations and peat	- As above		
7a. Major Supply: Fossil & Nuclear	- employment lost in operation & maintenance of plants and associated power lines & rights of way - employment lost in acquisition, processing and transportation of fuel		- oper'n. & maintenance of fossil & nuclear stations: . occupational . environmental (emissions, wastes) . social & health costs of acq'n., processing & transportation of fuel	Assumes all existing nuclear is shut down and only the cleanest fossil is kept (or vice versa) (N.B. decommissioning costs are not avoided).

Table 7.3
Some Selected Health Effects of Demand Management & Alternative Electrical Energy Alternatives Compared to Coal and Nuclear Power

Demand/ Supply Alternatives	Deaths			Injuries		Emissions			
	Worker deaths per 10^{18} J (1)	Occupational deaths per GWe Year (2)	Public deaths per 10^{18} J (1)	Lost work per days per 10^{18} J (1)	Injuries per GWe Year (2)	CO_2 metric tons per GWh(3)	Particulates x 10^3 MT per 10^{18} J (1)	SO_x x 10^3 MT per 10^{18} J(1)	NO_x x 10^3 MT per 10^{18} J(1)
Solar flat plate collectors	18-28		0.5-6.0	55-109			0.37-150	0.093-1.9	0.26-1.5
Solar photovoltaic(4)	12-31	0.45-6.25	0-60	47-160	216-777	5.4	190-1000	2.5-9.7	0.36-1.8
Wind	2.9-12	0.26-2.7	1-8	13-43	35-69	7.4	5.8-140	0.3-11	0.0032-1.7
Biomass, cultivation (5)	16-67	20.3-22	Potentially large	45-190	103-180		69-8300	150-430	300-2200
Gas fuel cell		0.26-11			35-168				
Coal - Surface mine - Underground	35	 0.29-0.99 0.73-3.0	17-100	58-60	 36-72 81-150	750-964	140-1300	350-1200	410-820
Nuclear	4.8-5.0	0.28-0.54	1-2	14-16	15-57	7.8	7.0-23	2.7-6.2	1.0-2.2

Notes:
1. Holdren et al., 1983;
2. Cox, 1985;
3. Beurskens, 1991;
4. Worst case estimate from Cox
5. Future technology (automated clear cutting & field chipping) in the Cox data

Clearly, the alternative technologies (except biomass cultivation) do as well as or better than coal in terms of worker and public deaths but may be as bad or worse with respect to worker injuries; generally, they do not do as well as nuclear power. However, these figures are based on energy output; given that there are more workers involved in alternative technologies such as solar collection, solar photovoltaics and wind power, the deaths and injuries per worker year are less (Holdren et al, 1983; Cox et al, 1985). Society as a whole needs to weigh worker deaths and injuries against the health benefits of the extra employment, and its dispersed and long term nature.

Clearly, renewable alternative technologies have a substantial benefit over coal when it comes to CO_2 and sulphur oxide emissions, as they do (with the exception of biomass) when it comes to particulate and nitrogen oxide emissions.

RECOMMENDATION 7.1 : **The PHC recommends that the conserver society option is the best alternative to Hydro's undertaking in the short term. In the long term, the best alternative is investment in sustainable life compatible technologies.**

RECOMMENDATION 7.2: **The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that as a condition of approval Hydro be required to conduct a more extensive review of sustainable life compatible alternative technologies and the conserver society options for both the short and long term.**

RECOMMENDATION 7.3: **The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that Hydro be required to undertake a health impact assessment of sustainable life compatible alternative technologies and the conserver society option for both the short and the long term.**

Chapter 8
Estimating the Health Costs of Alternative Electricity Demand/Supply Scenarios

8.1 Introduction

This chapter calculates some preliminary and incomplete estimates of the external dollar costs to human health associated with the options outlined in Chapters 3 through 7.

The material in this chapter is drawn from the report of P.Coyte, as reviewed by G.Torrance.

8.2 Health Costs and the Nuclear Generating Option

In Chapter 3, the PHC developed a range of estimates for the number of fatal and non-fatal cancers which would result to workers and society at large from the operation of nuclear generating stations by Hydro during the DSP planning period (1993-2014). The PHC also examined the effects of ionizing radiation on reproduction and development, but did not attempt to estimate the possible intergenerational adverse health effects which would thereby be associated with Hydro's nuclear power (although considerable discussion and some data from international studies estimating generational health effects from radiation exposure are provided for the reader).

Hydro's plans to generate an average of 11 GWa of electricity from its nuclear generating stations in each of the 22 years (1993-2014) remaining in the DSP planning horizon lead to an estimated range of 316 to 2,518 excess cancer fatalities and an estimated 14 deaths due to conventional accidents during this time period.

During the same planning horizon, the PHC estimates the following ranges of non-fatal cancers: for all non-fatal cancers except skin cancer, the range is 155 to 1,333 cases; and for skin cancers alone, the range is 532 to 5,036 cases. The PHC will not attempt to estimate the health costs associated with such non-fatal cancers. In some instances such as skin cancers, the costs may amount only to direct health care costs (for medical diagnosis and treatment) alongside some indirect costs (lost employment, etc.). In more debilitating situations, the cancers may lead to permanent disability. The subject is complex and beyond the scope of the PHC's submission.

The PHC will also not attempt to estimate the health costs associated with reproductive and developmental health effects associated with radiation exposure since it is not yet possible to estimate the size of these effects.

Instead, the health costs of fatalities associated with the nuclear option arising from cancer and accidents will be determined as follows. From the Chapter 2 discussion on health costs resulting from different adverse health effects, the total estimated costs associated with the loss of the life of an adult aged 35 due to neoplastic disease (including lifetime direct costs, indirect cost of foregone earnings and quality of life losses) range from $3,161,800 to $5,912,800 1990 Canadian dollars. The corresponding range for death from injuries is $3,251,100 to $5,479,400 dollars.

As a consequence, the PHC estimates the total health costs resulting from cancer and conventional accident fatalities and associated with the operation of Hydro's nuclear stations during the planning period 1993-2014 will range from $1.0 to $15.0 billion dollars ($1990).

To facilitate comparison with other components in the undertaking, the PHC notes that the above ranges can be expressed in normalized units of GWa^{-1} of electrical energy output. On that basis, the estimated health costs of cancer and accidental fatalities range from $4.0 to $61.7 million dollars ($1990).

8.3 Health Costs and the Fossil Fuel Generating Option

Chapter 4 presents several ranges of estimates of adverse health effects which would and do result from electrical energy production from fossil fuel generating stations [FFGS]. The health effects are a consequence of SO_2 and Total Suspended Particulate [TSP] emissions from FFGS and are expressed in terms of annual numbers of: respiratory hospital admissions; respiratory hospital days; respiratory mortality; and total non-accident mortality. Table 8.1 lists the ranges of annual estimated health effects for both the years 1989 and 2014 (with the lower and upper bounds taken respectively from the Concord and Pengelly studies) and the associated health costs using the health economic cost data from Tables 2.1, 2.2 and 2.3.

Table 8.1
Ranges for Estimated Adverse Health Effects and Associated Costs In the Year 2014 from SO_2 and TSP Emissions of FFGS

Health Effect	Annual Incidence (Number)	Annual Cost (millions of $1990)	Cost per GWa (millions of $1990)
In 1989 from SO_2 emissions:			
Respiratory hospital admissions	247-1,104	0.6-4.6	0.15-1.2
Respiratory mortality	8-51	26.5-276.2	6.8-71.0
Total non-accident mortality	0-233	0.0-1,261.7[a]	0.0-324.3
In 1989 from TSP emissions:			
Respiratory mortality	0-1	0.0-5.4	0.0-1.4
In 2014 from SO_2 emissions:			
Respiratory hospital admissions	1,057-2,798	2.7-11.8	0.4-1.5
Respiratory mortality	38-129	126.1-698.5	16.2-89.8
Total non-accident mortality	0-590	0.0-3,194.8[a]	0.0-410.7
In 2014 from TSP emissions:			
Respiratory mortality	0-3	0.0-16.2	0.0-2.1

Notes: a. Assuming the same total estimated health cost as for respiratory mortality.

The calculations suggest that, for SO_2 emissions, the upper bound on the envelope of costs for hospital admissions will grow from $4.6 million in 1989 to $11.8 million in 2014 ($1990). For premature deaths from respiratory disease, the comparable growth is from $276.2 million in 1989 to $698.5 in 2014; and for total non-accident mortality, the costs grow from $772.9 to $3,194.8 million. For respiratory mortality, the upper bound on costs associated with TSP emissions grows from $5.4 to $16.2 million.

On a per GWa basis, the upper bounds of estimates of the annual cost of adverse health effects in the year 2014 are as follows. For SO_2 emissions, the cost of hospital admissions will be $1.5 million ($1990); for premature death from respiratory disease, $89.8 million; and for total non-accident mortality, $410.7 million. For respiratory mortality from TSP emissions, the estimate is $2.1 million. On a normalized basis (i.e. GWa^{-1}), these costs range from $7.0-$397.9 million in 1989 to $16.6-$504.1 million in 2014.

The upper bound of these normalized projections is derived from the assumptions that there are no pollution abatement initiatives between 1989 and 2014, and that population growth (and hence subgroups at risk) averages 1% per year over this time period (and hence urban density and exposed populations in southern Ontario).

Pengelly advises that FFGS health effects and associated health costs would be significantly higher were SO_4 emissions to be included in these estimates.

8.4 Costing Occupational Health Effects from the Fossil Fuel Generating Option

Ranges for occupational and public health effects arising during the mining, transportation and operation steps in the coal fuel cycle are reviewed by Cole (September, 1992). Cole cites a study by Cohen and Pritchard (1980) providing relevant information on numbers of casualties per GWa of coal fired electricity production. These data are summarized in Table 4.3 of this submission and reproduced below in Table 8.2 which also attaches ranges of economic costs to this information. Based on incomplete information, the PHC estimates total health costs over the entire coal fuel cycle arising from the production of 1 GWa of coal fired electricity to range between $44.3 and 972.4 million in 1990 Canadian dollars. It should be appreciated that most of these costs (about 89% of the upper bound of costs) are related to injuries and not to deaths.

Table 8.2
Range of Estimated Costs of Deaths and Injuries Over the Coal Fuel Cycle Based Upon 1 GWa of Electricity Production

HEALTH EFFECT	NOS. OF CASUALTIES	ESTIMATED COST[a] (millions of 1990 $ Can.)
Fuel extraction:		
Accidental deaths	0.44-2.84	1.43-15.6
Accidental injuries	32.8-1,385	15.7-664.8
Pneumoconiosis deaths	0-9.3	0-50.4
Pneumoconiosis cases	0.55-64	0.26-30.7
Fuel transport:		
Occupational deaths	0.073-5.0	0.24-27.4
Occupational injuries	0.44-315	0.21-151.2
Public deaths	0.4-2.5	1.3-13.7
Public injuries	1.56-28	0.75-13.4
Operation:		
Accidental deaths	0.01-0.2	0.03-1.10
Accidental injuries	1.2-8.5	0.6-4.1

Notes: a. Estimated costs for deaths include losses of investment and consumption benefits while, for all injury and pneumoconiosis cases shown, figures are based on loss of consumption benefits only.

8.5 Health Costs and the Hydroelectric Generating Option

Chapter 5 contains a table of estimates of occupational and public deaths, disabilities and man-days lost from accidents and disease associated with the production of 1 GWa of net electrical output (Table 5.1). The range of incompletely estimated health costs totals some 181-201 million in 1990 Canadian dollars.

Table 8.3
Estimated Adverse Health Effects and Their Associated Costs From Production of 1 GWa of Hydroelectric Power[a]

CATEGORIES OF ADVERSE HEALTH EFFECTS	ADVERSE HEALTH EFFECT ESTIMATES	ASSOCIATED HEALTH COSTS[b] (millions of $1990)
Occupational:		
Accidental		
Death	0.15-0.26	0.5-1.4
Injury	350	168
Man-days lost	(26-33)x10^3	4.4-5.6
Disease		
Death	-	-
Disability	0.08	0.004
Man-days lost	4	6.8 x 10^{-4}
Public:		
Accidental		
Death	1.1-1.6	3.6-8.8
Injury	1.1-12.8	0.53-6.1
Man-days lost	(6.6-10)x10^3	1.1-1.7
Disease		
Death	(1.1-3.2)x10^{-3}	(3.5-18.9)x10^{-3}
Disability	6-19	2.9-9.1
Man-days lost	40-120	(6.8-20.3) x 10^{-3}

Notes: a. See Table K-6 in Inhaber,H.: Energy Risk Assessment. New York; Gordon and Breach Science Publishers, 1982.
b. Death cost estimates include both foregone investment and consumption benefits while injuries and disabilities include only loss of consumption benefits (and assuming a severe degree of injury or disability). Person days lost are calculated only for men aged 35-44.

8.6 Health Costs associated with the Transmission/Distribution System

Chapter 6 of this submission discussed the possible health effects from exposure to herbicide 2,4-D as well as from non-ionizing radiation (including EMF radiation).

Occupational health and safety issues were also raised by drawing material from the Cole (1992) report. In particular, Table 6.6 provided estimates of annual transmission line risk associated with all aspects of the system's lifetime (i.e. material acquisition and construction, emissions, operation and maintenance and transportation). The figures are based upon the 1,100 km reported length of the 500 kV, single circuit transmission line for the Manitoba purchase of 1,000 MW of hydroelectric capacity. Table 8.4 below provides PHC estimates ranges of health costs for man-days lost, injuries and deaths associated with the transmission line required for the Manitoba purchase. These ranges are based on incomplete health cost information but nonetheless aggregate to 48-139 million in 1990 Canadian dollars.

Table 8.4
Estimated Transmission Line Risk (per 1,100 km per Year Over System Lifetime) and Associated Costs

CATEGORIES OF ADVERSE HEALTH EFFECTS	ADVERSE HEALTH EFFECT ESTIMATES	ASSOCIATED HEALTH COSTS[a] (thousands of 1990 $ Can.)
Occupational:		
Accidental		
Death	0.057-0.083	185.3-454.8
Injury	4.29-4.51	2,100-2,200
Man-days lost	484-682	80-120
Disease		
Death	b	b
Disability	0.205	100
Man-days lost	11.2	1.9
Public:		
Accidental		
Death	0.006-0.014	19.5-76.7
Injury	0.012	5.8
Man-days lost	37-87	6.3-14.7
Disease		
Death	0.015-0.046	48.8-252.1
Disability	94-281	45,000-135,000
Man-days lost	583-1,760	100-300

Notes: a. Estimated death costs include losses of investment and consumption benefits while injuries and man-days lost include only foregone consumption benefits. Costs for man-days lost are based on males aged 35-44.
b. All deaths assigned to accidents.

8.7 Costing Issues and Worker Health and Safety

For consideration within a monetarized framework of demand/supply planning, costs must be assigned to various worker health impacts. However, Cole (1992) did not find any reference to worker health costs in Hydro's overview documents (the various Hydro reports on "Materials Relating to Environmental & Health Effects" by generation option) or in National Energy Board submissions. A response to a PHC Interrogatory (No. 2.17.17, Section [d]) noted that the U.S. "FERC system of accounts for major electric utilities" included non-occupational as well as occupational costs implying a contrast to Canada where non-occupational health care costs are covered through provincial insurance mechanisms based on direct employer contributions but not tied to corporate specific illness and injury experience. Cross-examination by M. Campbell of Hydro witnesses for the Hydraulic Panel indicated that occupational health and safety costs are incorporated into ongoing capital and operating costs (pp.16,506-16,511 of Volume 93 of transcripts).

Cole notes that some confusion apparently exists within Hydro about the composition of occupational health and safety costs as well as the importance of annually reporting these cost breakdowns. Earlier Hydro Occupational Health and Safety Performance reports (1985, 1986) included "minimum estimated accident costs" of $3,599,531 for 1985 and $4,312,513 for 1986 but these estimates have been dropped in recent years.

Hydro must accept the basic principle that human health impacts deserve separate, identifiable costing, making sure to avoid double counting. As noted in economic evaluations of occupational health services, compensation costs are only part of the resource impact on corporations and workers (Atherley; 1976). Nor do they measure the full societal impact of worker injury and illness (Ashford; 1991). This is due in part to a reluctance of physicians, workers and employers to deal with the recognition process when universal health insurance or negotiated sickness benefits are available, particularly when it comes to occupational illnesses and diseases. As well, it is due to a lack of knowledge of the linkages between work and health or an unwillingness to recognize them (Yassi; 1987). This becomes increasingly important as psychosocial stressors and work organization factors are shown to account for substantial morbidity commonly thought of as non-occupational such as heart disease (Karasek; 1990).

Nevertheless, a system of linking workers' compensation claim costs with specific generation options over the life of generation facilities would be a first step in assigning costs to worker health impacts. This is not possible either from annual data alone or from Hydro construction, operation and maintenance experience alone. These data would not include valuations of the quality of life changes experienced by workers and their families (Sinclair; 1987) except as these are partially reflected in "non-economic loss" awards under recent changes in workers' compensation law in Ontario. This submission provides a health economic framework for estimating such costs.

Chapter 9
The Nuclear Regulatory Environment and Other Nuclear Issues

9.1 Introduction

This chapter addresses a number of issues arising from the PHC's examination of Hydro's nuclear generation program. These issues set an important context within which the nuclear option must be examined, although they do not give rise to direct cost estimates of health effects and thus are not included in Chapter 3.

The first section of this chapter contains an overview of Hydro's regulatory environment prepared by legal consultant A. Orkin. In the second section, Dr. P.Rosenberg (Head of Emergency Medicine, Etobicoke General Hospital) and Dr. P.Lane (Head of Trauma Medicine, Victoria Hospital and University of Western Ontario) address the state of Hydro's preparedness in the face of a nuclear accident (Sections 9.3 and 9.4).

9.2 Ontario Hydro's Nuclear Regulatory Environment

a. Introduction

A. Orkin was commissioned to review aspects of nuclear regulation in Canada relevant to the environmental assessment of the Hydro DSP (September, 1992). See also the paper by K.Z. Morgan respecting the role of the International Commission on Radiological Protection [ICRP] in standard setting.

Orkin points out that the nuclear industry and its regulation are of profound importance to Ontarians and Canadians: as participants in all "peaceful" aspects of the nuclear fuel cycle from uranium mining through nuclear power generation to nuclear waste management, we are wedded to nuclear technology, effectively forever. Our safety and health depend on the effectiveness of our nuclear regulatory regime; if we fail to regulate the nuclear fuel cycle effectively, "the result could be social chaos, environmental disaster, and profound health problems."

Over the past fifteen years, many public inquiries and a number of studies have examined the question of nuclear regulation in Canada. They have repeatedly identified significant structural, standard-setting and practice-related shortcomings in the way that the nuclear industry in Canada is regulated.

The importance of nuclear regulation dictates the need for an ongoing, critical and independent examination of both the industry and its regulators. Two official examinations of nuclear issues provide a basis for evaluating the radiation-exposure standard setting process: the [Bates] Royal Commission of Inquiry into Uranium Mining in British Columbia of 1979-1980 (hereinafter the "Bates Commission"), and the 1977 Canadian Law Reform Commission report on the Atomic Energy Control Board [AECB]. With these and related findings, Orkin critically examines the international nuclear radiation exposure standard-setting process and the structural aspects of nuclear regulation in Canada.

Orkin's report excludes any in-depth examination of public participation and accountability, impact assessment, licensing and approvals, and monitoring/enforcement issues of nuclear regulation in Canada. These important issues were reviewed effectively by the Canadian Environmental Law Association (CELA; September, 1987).

b. The Bates Commission

The Bates Commission was appointed by the Government of British Columbia in January, 1979 to, *inter alia*:

1. examine the adequacy of existing federal and provincial requirements for the protection of the health and safety of workers associated with exploration, mining and milling of uranium in British Columbia, and for the protection of the environment and of the public;
2. receive public input on these matters;
3. make recommendations for setting and maintaining standards for worker and public safety and for the protection of the environment as a result of the exploration for the mining and milling of uranium ores.

Although the Bates Commission focused on the protection of workers and the public from the dangers of uranium mining, its recommendations are relevant to the present proceedings for three principal reasons. First, all phases of the nuclear fuel cycle are inseparable with respect to their potential harm in terms of radiation exposure. Accordingly, all activities engendering radiation exposure are subject to standards or limits based on the same general standards and approach. Second, the same regulatory framework that governs the extraction and processing of uranium in Canada also governs all other phases of the nuclear fuel cycle, including nuclear power generation. Third, and most importantly, the Bates Commission paid some attention to the regulation of the nuclear fuel cycle in Canada, and particularly to the standard-setting process involving the AECB and the ICRP.

Among the Bates Commission's recommendations was the following (No. R-5): "We recommend that the *process* of setting radiation standards at the national level should be reviewed and revised.... [emphasis added]." The considerations leading to this conclusion included the following:

1. The Canadian body responsible for setting standards in Canada, the AECB, relied *heavily and uncritically* on the recommendations of the ICRP; [emphasis added]

2. Members of the ICRP responsible for determination of recommendations were *internally appointed and responsible to no one.* Limited funding ensured that the bulk of

appointments to the ICRP would be sponsored governments; [emphasis added]

3. The ICRP principle that radiation doses be kept as low as reasonably achievable, economic and social factors being taken into account (hence "ALARA") demanded a political and social determination of the "reasonable" standards to be applied to a given area or activity. In short, the *ICRP was no substitute for a national standard setting process*; [emphasis added]

4. The advisory committees of the AECB were appointed by the AECB and the AECB alone. There was no mechanism by which other interested groups might name or even participate in the naming of members of these committees;

5. Divided jurisdiction between the provinces and the federal government had resulted in confusion over responsibility for regulation and inspection. It was still unclear where the initiative necessary to deal with problems was to be taken.

The Bates Commission reported that the functioning of the AECB as a national standard setting and enforcement agency did not "inspire confidence" and, as a result, called for significant reforms to the standard setting and licensing process, worker health protection and enforcement procedures. Given that the standard setting process necessarily involved important value judgements, the Commission advised that a province (in that case, British Columbia) should no more blindly assume that the AECB regulations were suitable for its particular context than the AECB should simply adopt those set down by the ICRP. By its recommendation, the Commission raised the issue of the AECB's delegation to the province of certain aspects of regulation, inspection and enforcement. The issue of jurisdiction division aside, the recommendation highlights the important issue of public involvement in the standard-setting process.

c. From ICRP to AECB Standards

c.1 The ICRP

The International X-Ray and Radium Protection Committee, that had functioned since 1928 and which had published the first set of international recommendations for protection from ionizing radiation, was exclusively concerned with medical exposure to radiation. It was restructured and renamed as the ICRP in 1950 to take stock of the budding nuclear industry. The ICRP's function is to review the available scientific data and to make recommendations on the strength of the expertise of its members.

The Commission consists of twelve members chosen every four years by the International Congress on Radiology. Membership in the ICRP is select and controlled; prospective members must be approved by the ICRP International Executive Committee. With respect to ICRP Committee structure, the Bates Commission noted that "[m]embers appear to be

internally appointed by the Commission and there is no independent membership of any of its committees; that is, nobody is put on a committee of ICRP by some other body."

ICRP Committees undertake much of the work leading to ICRP recommendations. For example, ICRP Committee 2 undertook the crucial extrapolation of recommended annual limits on intake of radionuclides by workers from the 1990 (ICRP Publication 60) recommendations.

Of the fewer than 50 scientists who have been named to the Commission since the end of the Second World War, the vast majority have been physicists and medical radiologists in the employ of governments and their agencies. All members of the main commission, and many members of the four 15-person ICRP standing committees, are also national advisors on radiation safety. These members are thus in the position of both formulating and then evaluating and recommending the adoption of ICRP recommendations.

On this and related issues, the Bates Commission's Final Report quoted from the testimony of Dr. E. Radford, then chair of the U.S. National Research Council's Committee on the Biological Effects of Ionising Radiation (the "BEIR" Committee):

> The ICRP is a self appointed group of twelve scientists whose terms of appointment have varied; they are responsible only to the International Congress of Radiology. In the early years after World War II it served an outstanding function in providing scientific reviews and recommendations concerning radiation hazards. Within the past decade, however, as the nuclear controversy has sharpened, I have noted a change in the ICRP publications, in that instead of reviewing scientific evidence they have been more concerned with defending previous recommendations. This process is especially noticeable with ICRP Publication 26 issued in 1977... this is essentially a social and political document, with no new scientific evidence in it.

Radford's testimony signals the ICRP's entry into the realm of nuclear policy-making: rather than conducting its own research, the ICRP bases its recommendations on the review of existing data and the assembled expert opinions of its members, two thirds of whom had served the ICRP for 10 years or more (in 1989).

By its composition, financing and mandate, Orkin concluded that the ICRP is a self-perpetuating international body with extraordinary influence over nuclear radiation but responsible to no-one. The recommendations of the ICRP are indeed adopted with little or no modification by most world nuclear jurisdictions, including the AECB in Canada. As a consequence, nuclear regulators such as the AECB are able, on the one hand, to point to "international standards" to assuage public concern about nuclear risks or the adequacy of standards, and on the other hand, are able to dismiss ICRP standards as being "only recommendations" when it is expedient to do so.

c.2 The ICRP Standards

ICRP standards were consistently adjusted downwards until 1958. The ICRP itself estimates that "[i]n broad terms...the annual limit for occupational exposure of the whole body was reduced by a factor of about 3 between 1934 and 1950, and by a further factor of 3, to the equivalent of 50 mSv, by 1958". In 1990, ICRP Publication 60 once again adjusted the occupational exposure limit downwards to 20 mSv annually. The corresponding limits for members of the public were 5 mSv in 1958 and 1 mSv in 1990.

However, Orkin notes that scientific appreciation of standards of radiation protection did not remain constant from 1958 to 1990. On the contrary, the same dose limits that were in 1958 held to be declaratory of safe limits to exposure had become, by 1990, legal limits "just short of unacceptable for continued exposure as the result of deliberate practices the use of which is a matter of choice" and imposed in the knowledge that no amount of radiation is absolutely safe.

The genius of the ICRP has in fact been its ability "...to maintain stability in its recommendations..." and "to provide a consistent basis for national and regional regulatory standards...". Frequent changes, or changes which would have considerably lowered limits "too soon", would clearly have been expensive for industry, unsettling for regulators and unnerving to an increasingly sceptical public. The 1977 recommendations (ICRP Publication 26) thus explicitly embodied the aim of setting a ceiling on risk without imposing undue costs to industry.

Orkin reports the ICRP's decision that radiation work should not impose risks of more than one death per 10,000 workers, being approximately equivalent to the risks run by workers in "safe" industries. Yet, according to the ICRP's own calculations, on the basis that 1 million person rems will cause 125 cancer deaths, the existing standard of 50 mSv implied a 6 in 10,000 chance of cancer mortality plus a 4 in 10,000 chance of serious genetic defects in future generations. To bring the risks of radiation work to equal those of other industries, it would have been necessary to divide the 50 mSv limit by 10, a measure thought to be impracticable by many within the nuclear industry.

In the end, the ICRP proposed the compromise that 50 mSv would remain the legal dose limit but should no longer be an acceptable level of exposure. Considerably more emphasis was placed upon the ALARA principle in order to reconcile this position. The ICRP made it clear that it expected the industry to comply with the 5 mSv standard where this was "reasonably achievable"; or, in other words, that all exposures be avoided so long as it was not too expensive to do so.

This introduction to a cost-benefit mode of analysis is explicit throughout recent ICRP publications. The commission makes clear that its standards are only recommendations which must be adapted with care into any particular domestic context and that ALARA must be the dominant principle: "Authorities...need to develop their own structures of legislation,

regulation, authorizations, licences, codes of practice and guidance material in line with their usual practices and policies".

Orkin makes the following brief observations about the ALARA principle. First, in legal or regulatory terms, the concept is vague and requires the exercise of momentous judgements about economic and social factors ("...economic and social factors being taken into account"), known as the ALARA-EASFBTIA principle. What standards or exposures are "reasonable"? Who determines these standards? Or are they universal? How will the cost-benefit calculation inherent to the ALARA concept be undertaken? What economic and social factors? Are these factors stable, or do they change, for example, according to unemployment levels? Who decides, and with what input, especially from the public? The answers to these questions, and thus the ALARA-EASFBTIA principle itself, are unquestionably political and social.

The ALARA-EASFBTIA principle of reasonable achievability opens the regulatory apparatus, purportedly driven by scientific considerations, to political control. In the view of a former senior U.K. government scientist (Orkin: Footnote 35): ""Reasonably achievable" has to be interpreted, so long as one is in government service, as being whatever level of contamination is compatible with the economic well-being of the industry responsible for the pollution under scrutiny."

A 1984 study for the Law Reform Commission of Canada concludes that the politico-economic capture of regulatory apparatus is a dominant model of regulation of Canadian industry with environmental impacts (Orkin: Footnote 36). On the other hand, "industry representatives fear that ALARA will trigger an expensive pointless downward spiral of exposure limits, necessitating increasingly burdensome administrative arrangements." (Orkin: Footnote 37)

The ICRP position with respect to the "home-grown" development of regulatory standards, policies and practices is, purportedly and on its surface, wholly consistent with the critical recommendations of the Bates Commission and with an ethical position which insists that individuals be free to choose or reject certain risks (even permitting that their representatives may, under certain circumstances, justifiably make that decision for them). Orkin argues that this position raises the problem of delay in implementing new knowledge that affects current and possibly inadequate, standards.

The Bates Commission observes that radiation standards "should be developed within a process of full public participation". The Canadian Environmental Law Association study on nuclear regulation notes some recent reforms with respect to regulatory openness which still fall short of current standards for full participation (witness the present impact assessment process under Ontario legislation), including adequate public notice of proposals for standards, mandatory public hearings before an independent tribunal, and full and adequately funded participation of employer and public interest groups. Different views exist on "accountability" in standard-setting processes, ranging from a fully open model as described above, through a participatory model involving the political process, to the paternalistic view that these are highly technical matters that simply cannot be entrusted to the public. The Porter Commission chose a path towards the latter end of this spectrum (Orkin: Footnote 39):

> We believe that although the details of experts' decisions may be comprehensible to only a few, many of the uncertainties of risk analysis and many of the choices to be made can and should be more fully *explained to the public*. But caution should be exercised in our expectations of public participation. Decisions will still require technical and scientific data and recognizing this fact, there must be a *careful development of the appropriate purposes, timing and procedures for public participation...* [emphases added]

The Bates Commission, on the other hand, stated that the standard-setting process, particularly with respect to the subjective factors of ALARA, must fully involve "industry, labour unions, disinterested members of the public and civil servants together". The Royal Commission concluded that the necessary scientific data is complex but can be "laid out in comprehensible form."

Orkin argues that regulators' lengthy "consultations" with affected stakeholders prior to formulation and revision of standards may, paradoxically, adversely affect the public interest. This describes the current situation regarding the new findings of 1987 and the resulting ICRP recommendations of 1990, although consultation may itself be less to blame than institutional lethargy. These revisions of standards have been in the "BEIR-ICRP-AECB pipeline" for some years since the scientific findings that gave rise to them were first published, and it may be some time yet before Canadians "enjoy" the benefit of apparently necessary further downward revision of exposure standards.

This paradox may, in the end, only be satisfactorily addressed through a reversal of the operating paradigm of nuclear regulation from the present "innocent until proven guilty" model to the "guilty until proven innocent" model of pharmaceutical regulation. Adoption of this model, brought about by the thalidomide and other disasters, would allow the public to enjoy the benefit of the knowledge that all radiation is harmful; and that delays inherent in the process of standard-setting result in continued *protection* rather than perpetuated *exposure*.

c.3 The 1990 Standards

ICRP Publication 60 lowered recommended annual exposure limits for workers to 20 mSv. It "held" annual exposure standards for the general public at the suggested 1985 level of 1 mSv. (See the paper by K.Z. Morgan for a discussion of the implications of single organ dose and whole body dose.)

The present reduction, after 30 years with no changes in standards, results from a re-estimation of dosimetry data for Japanese A-bomb survivors and the consequent upward revisions of risk from low dose ionizing radiation. The revised risk estimates now range from two to ten times the old ICRP level of 125 fatal cancers in a million person-rems. The revisions led the BEIR Committee to undertake a new study of radiation risk incorporating the new dosimetry which was published in 1990 as the BEIR V report. BEIR V concluded that cancer risk from low level ionizing radiation was 2-3 times more serious than previously determined by its 1980 committee, BEIR III. The publication of BEIR V, three years after the dosimetry revisions, prompted ICRP's revision of its dose limits. The 20 mSv figure neatly splits in two the ambiguity of the BEIR report by reducing occupational dose limits by a factor of 2.5.

Orkin notes that the 1 mSv figure for public exposure was not changed because of "the widespread acceptance of the previous annual limit of 1 mSv" and ~~because of "the~~ increased use of much lower dose constraints for individual sources of public exposure...which virtually ensure that individual members of the public will not receive doses from controlled sources approaching the limit" (Orkin: Reference 45). He adds that the ALARA doctrine "permits" the rationalization of 5 mSv for different nuclear fuel cycle facilities, certain medical technologies and nuclear weapons facilities. He asks why the same reasoning would not equally apply to occupational exposures.

c.4 AECB Reaction to New Standards

The AECB has yet to adopt the ICRP's new recommendations, although it did indicate an intention to "revise...the <u>Atomic Energy Control Regulations</u> to reflect the new risk estimates developed by the ICRP" (Orkin: Reference 46) by proposing new regulations which are identical to the ICRP dose limits. These proposals reflect a shift in the AECB's approach from its previous reaction to the ICRP's 1985 changes to the limits for public exposure. At that time, the AECB chose not to respond but rather to propose (in April, 1986) that the ALARA principle be incorporated into the regulations, leading to harsh criticisms from Greenpeace, the environmental group. The AECB replied that the ICRP value was a recommendation, not a national limit and that, in any case, it had "assessed this recommendation and decided it was not necessary for protection of the public since the actual exposures under the existing limit and licence conditions were already so small (much less than 1 mSv)" (Orkin: References 47,48).

Orkin questions why the legal dose limits are not lowered if all facilities are already complying, and wonders when an ICRP recommendation is merely to be evaluated, and when is it actually to be acted upon. He quotes from the 1991 AECB Consultative Document C-122 on the proposed changes to standards which touch on the matter of radon and thoron progeny (mainly affecting uranium mining):

> The new ICRP recommendations do not provide revised radon-and-thoron-daughter exposure limits although new recommendations on this topic are being developed. Meanwhile the ICRP has stated that the recommendations in ICRP 47 remain valid. ICRP 47 includes the annual limits for radon and thoron daughters, 4.7 WLM and 14.1 WLM respectively, which are the same as those in the General Amendments, and so there will be no change.

Orkin notes that this paragraph is indicative of the AECB's approach: ICRP recommendations are, almost without exception, still adopted uncritically. This excerpt highlights the inherent ambiguity in the AECB's policy proposals. Recommendations (whether issued by the ICRP or any other constituted body) can be interpreted as "valid" because of their basis in impartial, scientific knowledge. As the recommended radiation exposure standards of the ICRP or AECB (or both), the proposals can also be interpreted as "valid" because they appear in an official publication. Finally, the last sentence in the paragraph quoted above confirms the AECB's continuing, uncritical (and delayed) adoption of ICRP recommendations as an acceptable basis for nuclear standard setting in Canada.

One telling criticism of the AECB by the Bates Commission centered on the fact that, given the value-laden and non-technical nature of the standard setting process, inadequate efforts were made to determine the opinions of the general public and affected populations. In response to the 1987 Hiroshima data revisions, the AECB has initiated a consultation process on the proposed changes and invited comments by "licensees and any interested members of the public". The adequacy of the public consultation process is open to question. Orkin notes that formal hearings with appropriate notice, and adequately funded public interest participation and open decision-making of the variety that occurs under Ontario environmental assessment legislation, is not the practice.

The Bates Commission noted that the AECB has declared its dependence on international organizations for the formulation of Canadian radiations standards:

> [The AECB] has to rely on the international community, the UNSCEAR has the task of reviewing the world literature, collecting all the information on risks available, and the ICRP uses those risk estimates plus any other information they can find and we rely very heavily on the work that is done there at the international level.

Finally, Orkin notes that all nuclear fuel cycle facilities are given until January 1, 1995 to comply with the 20 mSv requirement, admittedly "irrespective of the cost" (Orkin: Reference 56). It is hard to imagine that a new scientific consensus regarding the increased mutagenic or teratogenic effects of a pharmaceutical agent would be followed by eight years of regulatory perambulation before coming into force as a revision of standards. Current nuclear standard-setting practice, surrounding significant reductions in the ICRP recommendations, surely does not measure up to a national standard setting process as called for by the Bates Commission, either in substance or in implementation.

c.5 The Hare Report on Nuclear Safety in Ontario

A finding of the 1988 Hare Commission into the Safety of Ontario's Nuclear Power Reactors must be referred to in light of the foregoing in this section (Orkin: Reference 57):

> In spite of many ill-informed allegations, the ICRP remains the best available body for the determination of radiological dose limits. AECB should continue to base its regulations on ICRP guidelines, although not necessarily according to its timetable. Provincial practice should follow suit.

This recommendation from the Hare report confirms the central role that ICRP determinations play in standards' setting. The Bates Commission accepted testimony that the AECB "does review the [ICRP] standards and on occasion departs from them, but in general the standards recommended by ICRP have usually been adopted by AECB"; but concluded that the present process of standard-setting in relation to radiation exposure is "unsatisfactory". In this regard, Bates observed: "It is a criticism of the AECB that it has not, to this point, realized the importance of structuring such a procedure in Canada, but has generally been content to accept the views of other agencies." (Orkin: Reference 59)

The Hare conclusions regarding the ICRP are clearly questionable in light of the concerns and conclusions expressed about this issue by the Bates Commission, and elaborated upon in Orkin's review. Most importantly, AECB practice remains unchanged, as evidenced by the Hare recommendation above and the AECB's current Document C-122.

An integral part of the ICRP process is the ALARA principle, which (as the Bates Commission concluded) is a social and economic construct that necessarily involves a wide range of subjective and political judgements. This principle led Bates to observe that it was

> clear that an international body structured in this way [the ICRP] could not make decisions on maximal acceptable exposure levels taking into account social and economic factors for different countries. In our view it might have been more prudent for the ICRP to limit its role to establishing, as accurately as possible the level of risk associated with given levels of exposure. The risk of maximal permissable exposure limits and judgement on risk acceptability would then be left to national bodies. In the contemporary context, it cannot be argued that the ICRP is an effective substitute for a national standard-setting process. (Orkin: Reference 61).

Orkin questions the Hare Review's conclusion that the ICRP is the "best available body" for determining radiological dose limits for two reasons. First, the ALARA principle, which is central to the conclusion, is a subjective principle which should be evolved if judged appropriate, and then applied in a rigorous and open process in Canada. Second, the structure, makeup and some of the workings of the ICRP organization remain questionable, as Bates has noted more than a decade ago.

d. Nuclear Regulation in Canada: Players and Approach

d.1 The Regulator: the AECB

The AECB is, pursuant to the Atomic Energy Control Act, the regulator of the nuclear industry in Canada and a wholly federal jurisdiction (Orkin: References 62,63).

In response to greatly increased public concern about the nuclear fuel cycle and its regulation, several commissions of inquiry and other studies have examined the structure, mandate and performance of the AECB and the nuclear industry in general in the years following the mid-1970s. The 1978 Law Reform Commission of Canada's report on the AECB is representative in its principal conclusions that the AECB was neither independent from industry nor government, that its resources were inadequate, and that its deliberations and operations were too secretive and should be subject to a more public process - most notably with respect to the licensing procedure.

Bill C-14 of 1977 attempted to address some of these problems and would have completely altered the 1946 Act by providing strong new guidelines for the fulfilment of the Board's public information mandate and by making a bold attempt to separate the functions of control and safety from the commercial, promotional and research activities which are of interest to the nuclear industry and to governments charged with responsibility for energy. Unfortunately, the bill died on the order paper and the AECB continues to operate on the basis of a statutory and mandate structure conceived in 1946.

Since the mid-seventies, the AECB has made efforts to reform its procedures and operations in the spirit of Bill C-14. Its staff has been increased from 38 in 1970 to over 300 today and, as noted above, recently proposed changes to the regulations have been made available to the public for comment. In Orkin's opinion, however, important structural difficulties remain.

The fundamental conflict of interest between the functions of regulation and promotion of the nuclear industry in Canada remains starkly unresolved. In 1980, the Porter Royal Commission on Electric Power Planning recommended, inter alia, as follows (Orkin: Reference 65):

> To ensure that the people of Ontario can have confidence in the process that regulates nuclear power, we recommend that:
>
> ...
>
> 5.27 The Government of Canada should ensure the separation of the promotional and regulatory aspects of nuclear power by drafting appropriate legislation to replace the Atomic Energy Control Act *as a matter of the highest priority.* This would ensure that the AECB and AECL would report to separate ministers, reflecting their very different roles, thereby avoiding public confusion and possible conflicts of interest of the sort that have in the past strained public confidence in the regulatory process. [emphasis added]

To this date, the AECB continues to report to a Minister whose statutory duty is to both regulate and promote atomic energy in Canada. Orkin notes that this is a conflict of interest with continuing and profound implications, if not for atomic regulation itself, than for public confidence in that regulation. His concern is exacerbated by the fact that a number of recent ministers in this portfolio have been highly enthusiastic promoters of the nuclear industry.

d.2 The Regulatory Environment: AECB's "Clients"

d.2.1 AECL

The major clients of the AECB have always been the nuclear power industry and the uranium industry, both dominated by the federal government. In the early days, the AECB had only ostensible administrative control over Atomic Energy Canada Ltd. [AECL] and none over Eldorado. In fact, in significant ways, it was AECL which controlled (or had "captured") the AECB. The following examples are illustrative: the quasi-entirety of Canadian atomic scientists and engineers were trained by AECL; AECL executives chaired the Reactor Safety Advisory Committees [RSACs]; until 1976, the president of AECL, along with Eldorado's president, sat on the AECB as a matter of course; the research budget of the AECB, in accordance with its statutory mandate, was spent on basic research in atomic energy as opposed to applied research in support of its regulatory function, or "mission-oriented research." Such facets were unsurprising so long as strategic secrecy and public trust characterized the industry. Yet, with the development of civil nuclear power on a large scale and a corresponding public awakening to its dangers, the professional closed-shop that Doern (Orkin: References 29,67) describes was unnecessary and undesirable. Even so, without clear and fresh legislative direction, old habits die hard; it was not until the mid-seventies that the beginning of reform was noticeable within the AECB.

Today, it appears that the most flagrant examples of a captured regulator have been corrected. The serious public scrutiny the Board received in the late seventies did much to force it to reevaluate its profile and procedures, and it is now much more independent vis-à-vis AECL than before.

Yet, within Canada, Orkin notes that the AECL has been replaced as the major player in the nuclear industry by Hydro, and many of the original structural problems of dependency which plagued the AECB in its relationship with a federal crown corporation, AECL, appear to plague it today with respect to a provincial crown corporation, Hydro. In terms of structure, little has changed; the basic picture is still one of state regulators regulating state entrepreneurs in a market which, already subject to extremely fierce competition, is as likely as not to remain moribund for years to come, notwithstanding the occasional reactor deal or two, in Canada or abroad.

The Canadian government has expended significant moral and financial capital on the industry and its development in Canada over the past forty-five years; and, if it is ever to see more than an amorphous strategic return on its investment, it has a considerable interest in the industry's continued existence. As Orkin states, it is impossible to totally separate regulation and government control of an industry that is similarly owned by governments; yet, short of privatizing the industry, more could be done. As discussed above, the governments continue to both own and promote, and regulate, central aspects of the nuclear industry in Canada.

d.2.2 Ontario Hydro

The province of Ontario (Quebec and New Brunswick have one operating reactor each) has been the almost exclusive support for the nuclear industry in recent years. Indeed, Orkin reports that the AECL is today considered no more than a sub-contractor for Hydro which is in a position of monopsony power vis-à-vis that portion of the nuclear power industry not already on its salary rolls.

Hydro, Canada's largest non-financial corporation, is a strong proponent of "big science" and of the nuclear industry in particular. In 1993, with Darlington at full power, approximately 60% of Hydro's electricity will come from nuclear reactors. This makes Ontario the most heavily nuclearized grid in North America. This distorted interest in nuclear power is not alien to the AECB whose personnel regulate the industry for, Orkin surmises, the industry's own good (much as the AECL found it in its best interest, indeed the very survival of the industry depended on it, to develop safety regulation in the early days after the first accident at the NRX in 1952). The AECB, in short, is a necessary part of the nuclear industry. While it is expected to exercise a measure of control over the industry, it is (by virtue of the ALARA principle, and perhaps also by the two hats worn by the federal minister responsible for nuclear regulation and promotion) simply not expected to impose "unreasonable" costs on the industry which would make its operation uneconomic. The resulting regulatory model is that of a family working together to provide the best results for all concerned, a regime that can only be described as permissive.

Yet, as with most families, Orkin notes that some members are more powerful than others. In the opinion of John Ahearne (Orkin: Reference 68), former Chairman of the United States Nuclear Regulatory Commission, "Hydro is swamping the AECB" in terms of manpower and resources. The AECB is stretched too thin and needs many more staff to perform independent review and "to keep Hydro on its toes". In the view of Ahearne, Hydro is so dominant that it is "close to having *no* independent reviewer" (emphasis in original). The Ahearne study was published in December of 1987 in the second great flurry of studies, this time following the accident in Chernobyl. Since that time the AECB has added some 60 staff and has increased its "Professional and special services budget" by 50% to 6.5 million dollars.

The President of the AECB addressed the critical need for increases in the financial and staff capacity of the AECB in the 1988 Annual Report. (By 1989-90, the Annual Report notes that the funding problem had been satisfactorily resolved.) It should be noted, however, that during the same approximate period, two of the four Darlington reactors came on line.

d.3 Canadian Approach to Regulation

Orkin's report has explored some of the implications for the industry of having the regulator, the designer and the utility owned by the taxpayer and in close co-operation with each other. This tripartite relationship is made possible by the typically Canadian approach to government regulation.

In the nuclear field the licensee is generally the primary entity responsible for safety. The AECB regulations furnish broad requirements, but do not provide prescriptive norms of construction or operation. A completed design or procedure is submitted for approval to the AECB where it is reviewed on the basis of the expertise and past experience of the Board staff as there are few hard and fast written guidelines. The means of attaining regulatory goals are thus left largely to the discretion of the licensee. This system has the benefit of being quite flexible from an engineering point of view. It may produce cheap and innovative solutions to problems without charging the typically more cumbersome bureaucracy with the task of elaborating extensive codifications of approved practices. Yet, it is impossible to ignore the old problems of dependency on the licensee for expertise or the development of technical standards due to lack of resources. In the words of one Hydro official "ultimately, a lot of the Control Board approach is based on trust that Ontario Hydro is doing the job correctly" (Orkin: Reference 77), or, as Orkin adds, that they are all doing what they or their specifications say they are doing.

Systems of inspection are designed to ensure compliance with norms. The nature of those norms conditions the character of the inspector's work. At one end of the spectrum, extremely formalistic and detailed rules make for a similarly ritual checklist inspection. At the other end, where rules are more open ended, larger amounts of discretion and power must be given to an inspector to ensure that the essence of the rule as he or she sees it is complied with. In this second case, to which the Canadian model tends, significantly more qualified and capable personnel are needed to properly do the inspector's job. In Canada, as elsewhere, it is a basic fact of the nuclear industry that such qualified personnel are scarce and costly.

Orkin notes that the absence of a wide array of formal penalties available to the inspector to ensure compliance or punish the lack of it. The single formal tool available to the AECB is the refusal to renew operating licenses. Such licenses are usually granted for periods of two years once a reactor is operating. Given the costs of shut-down, this is a drastic measure and is used extremely rarely, though, as a threat, it is a helpful lever of compliance around renewal time. On one occasion, Bruce A Reactor was shut down for a period of days to force Hydro to install safety devices which were a condition of its license.

Under the present legislation, the AECB does not control any of the more subtle pressure points such as fines, suspensions of personnel, or forcing shutdowns between renewal periods. The AECB depends upon trusting Hydro to promptly and honestly report problems, when, at least between renewal periods, there is little incentive to do so. Ahearne reports that the AECB staff believe that "Ontario Hydro tends to find the solution before they tell the AECB of the problem." (Orkin: Ref.78)

Another facet of the collegial regulatory environment in Canada reported by Orkin is the absence of prohibitions against the "the revolving door" phenomenon through which administrators and scientists move between Hydro, AECL and the AECB. Although this movement probably results from the lack of technically-trained personnel available to the AECB, Orkin urges it be avoided in the interests of maintaining AECB staff objectivity. Shortages of qualified personnel should be addressed in the universities rather than in relying upon the ability of employees to switch employers and adopt different attitudes in mid-stream.

Finally, he notes that an informal approach to regulation causes problems when the knowledge amassed by the regulator must be passed on to younger regulators, to courts or to foreign countries (e.g. prospective CANDU purchasers). If little is documented or if there is less-than-complete technical recording of the results of past agreements and practices, it is inevitable that disagreements will arise as to the Board's requirements (see in particular Orkin: Ref.79).

It is impossible to weigh the costs and benefits of such a system in any definitive fashion.

Orkin writes that it is probably not desirable to wholly adopt a rigid and formal system such as that which exists in the U.S. The Canadian regulatory approach may work as long as the quantity and quality of its personnel is high enough. He notes this to be as true of the CRTC as it is of the AECB. Yet, given the nuclear industry's awesome potential for causing harm and its almost exclusively governmental participants, it is essential to err on the side of caution and to set extremely cautious thresholds and procedures in order to prevent problems before the fact. In other fields, such as telecommunications, this may be looked at as an inefficient way to handle regulation. For the nuclear industry, however, Orkin notes that the unimaginable consequences of a Canadian Chernobyl merit separate and special considerations.

The optimal balance can obviously never be definitively decided; yet the image of a family working together, proud of its collective achievements, is no more reassuring to us now, Orkin notes than it was at the time of the Bates Commission.

e. Conclusions

Orkin's thematic review of nuclear standard setting in Canada began with the findings of the Bates Royal Commission into Uranium Mining in B.C., which found that the process was, in 1978, "unsatisfactory", and "has not been such as to inspire confidence." He noted that the following areas were among the principle reasons for these conclusions:

- an uncritical reliance by the AECB upon, and substitution of judgement in favour of, the ICRP in relation to nuclear standard setting in Canada;
- the operating assumptions of the ICRP, and in particular, the ALARA principle;
- questions regarding the membership, funding and accountability of the ICRP;
- structural and operational shortcomings of the AECB;
- an inherent conflict of interest between the regulatory and promotional roles of the single minister responsible for both of these areas of nuclear energy in Canada.

Orkin notes that some progress has been made in recent years with respect to the structural and operational shortcomings of the AECB. There are nevertheless important weaknesses in the approach of the AECB to public involvement in nuclear standard setting in Canada including its relationship with its most powerful client, Hydro. In addition, the conflict of interest at the ministerial level remains a significant, and potentially harmful, barrier to public confidence in the nuclear regulation in Canada, and arguably to effective regulation itself.

With respect to the setting of actual radiation standards themselves, he notes that the AECB continues, explicitly, to rely unquestioningly on ICRP "recommendations", including the highly questionable ALARA principle. ICRP recommendations continue with virtual certainty to become law in Canada, but any changes involving major downward revisions of exposure levels appear to take effect with unjustifiable delay. In Orkin's view, the conclusions and recommendations of the Bates Royal Commission in this regard remain as valid today as they were in 1980, namely that this critical aspect of nuclear standard setting in Canada is seriously deficient and in need of reform in the interests of public confidence, safety and health.

The PHC recognizes the jurisdictional conflicts which exist in relation to the monitoring of the nuclear industry in Ontario. There is ample scope for problems to fall between the cracks because of unclear, poorly coordinated and inadequately funded provincial and federal Ministries which share some portion of the overall responsibility for monitoring and regulating Hydro's nuclear performance.

In Ontario, there are at least four Ministries with some responsibility for the nuclear industry. Thus, the Ministry of the Environment [MOE] monitors the environment beginning at the boundaries of Hydro's nuclear facilities. However, it employs only one professional to maintain its radiological database and has never conducted any analyses for secular trends in the database. The MOE has no answer to the question of whether or not the environment is better, worse or the same this year as compared with ten years ago as a result of the existence of Hydro nuclear facilities in the province. The Ministry of Health has jurisdiction over "public health" but there are little or no funds earmarked to address local issues and concerns. The Ministry of the Solicitor General has responsibility for nuclear emergency preparedness, but efforts and funding to realize planning in this area are only now beginning to materialize. This latter problem is addressed in PHC commissioned reports by Dr. Paul Rosenberg and Dr. Peter Lane appearing in succeeding sections of this chapter. Finally, the Ministry of Labour has responsibility for nuclear worker health and safety.

The PHC is not empowered to investigate the issue of coordination between these ministries and the federal AECB regulator. But there is anecdotal evidence to suggest that serious problems do exist. To complicate matters still further, Health and Welfare Canada maintains some interest in and facilities to monitor the health of residential communities around Hydro nuclear facilities. However, this federal ministry lacks the funds even to publish the results of its own monitoring activity (its last annual report appeared in 1988).

As a result of this interjurisdictional confusion, Hydro with its technical mastery in all matters nuclear is essentially left with a free hand to conduct its business.

The PHC maintains that all these systemic issues must be addressed in a coherent, open and responsible manner which is fully consistent with the social and cultural values of a democratic society.

9.3 Report Assessing Emergency Preparedness for Nuclear Accidents in Ontario

a. Introduction

Dr. P. Rosenberg (Chief of Emergency Department, Etobicoke General Hospital) evaluated the state of emergency preparedness for a nuclear accident in Ontario focusing on the adequacy and cost of these preparations. He studied disaster planning at the level of the province, the municipality (for municipalities contiguous to nuclear stations), Hydro, and for Pickering Nuclear Generating Station [NGS] from which review he generalized his findings to other Hydro NGSs. He also met with officials of Pickering NGS and of the Government of Ontario's Office of Nuclear Emergency Preparedness as well as Hydro's Emergency Planning, Nuclear Generating Division and Emergency Operations Centre groups; and had discussions with physicians and nurses at Ajax Pickering, Oshawa General and The Toronto Hospital [TTH] and at Hydro.

Rosenberg documents his findings in the following report. By focussing on emergency preparedness planning connected with both the Maximum Planning Accident [MPA] and the Worst Credible Radiation Emission Accident [WCREA] scenarios, he highlights certain current deficiencies and makes associated recommendations on the cost of emergency preparedness for nuclear accidents.

b. The Maximum Planning Accident

Pickering NGS (with 8 reactors) is on the outskirts of east Toronto on the shores of Lake Ontario and Darlington (with 4 reactors) is 25 km further to the east and also on the lake. Many people live close to these stations and would be threatened by a severe accident.

While very unlikely, a severe accident in an Ontario reactor, with releases of damaging amounts of radioactive substances could occur. Emergency measures planning requires that estimates be made of the range of credible accidents.

The risk of any accident is the product of the associated probability of occurrence and its consequences. While calculations show this probability to be low, the consequences are significant, and the public expects a greater degree of safety and emergency preparedness for NGS accidents than for conventional accidents. Accordingly, the MPA scenario for planning purposes was chosen to be one with a likelihood of occurring once in a million years of reactor operation; and involving a simultaneous loss of coolant and a failure to shut down accident; or a loss of regulation and failure to shut down accident. In this type of accident, there is only a brief failure of containment, and the maximum radiation exposure to any one member of the public at the facility boundary (1 km) is estimated to be 25 rem during the first twenty-four hours. Workers in the plant would receive higher exposures of radiation.

The MPA scenario assumes no short term morbidity nor injuries to the public. Public health concern, therefore, would focus on long term effects including cancer fatalities (and non-fatalities) and reproductive and developmental damage at (or below) the high dose levels associated with morbidity (50 rem) and mortality (150 rem). Emergency measures such as sheltering, evacuation, food and water control will be required to decrease long term health effects.

In the MPA scenario, NGS workers would be exposed to higher levels of radiation than would members of the general public and may suffer trauma or burns. However, few immediate casualties are anticipated in this scenario, and Hydro training exercises are limited to a maximum of three workers.

In the event of an MPA accident, an established set of measures will be taken by Hydro within the station and at Hydro's Emergency Operations Centre established in downtown Toronto. Responsibilities for these measures have been established and procedures are rehearsed at least annually. If a serious accident occurs, emergency measures will be required not only inside the plant but in surrounding municipalities as well. Hydro engages in regular drills, and provides facilities and information to the surrounding municipalities. Its program is well formulated and costs about six million dollars annually (Hare, 1988). Hydro crews are well equipped in terms of self-contained breathing apparatuses, disposable suits, ambulance equipment, personal dosimeters, whole body counters, and the like.

Overall responsibility for public safety rests with the Solicitor General. The Ministry published an Nuclear Emergency Plan in 1986 and is working to effect this plan following a Cabinet decision to arrange for its financing by Hydro. Although the Ministry of the Solicitor General is responsible for the annual exercise of the whole Emergency Management Organization, this has not happened, and there remain problem areas within the preparations.

When the nuclear facility notifies provincial and municipal authorities that an off-site emergency exists, a Provincial Operations Centre is set up in downtown Toronto which assumes overall operational control. The plan clearly defines the Centre's responsibilities and actions. During the initial phase of the disaster, decisions are made on protective measures. After the immediate threat subsides, ingestion control and restoration is directed by the Centre.

In the event of an accident, the municipality also declares an emergency, warns the public, and takes appropriate protective measures. Rosenberg reports that, while Durham Region has recently developed a Nuclear Disaster Plan with Hydro's assistance, the required training exercises have not occurred.

For the MPA scenario, specific areas of disaster planning need improvement. These include evacuation plans, monitoring and decontamination centres, prophylaxis, public notification and medical treatment of injured or irradiated workers. Evacuation plans for the primary zone (to 10km from station) and especially the contiguous areas (to 3km from station) require more detailed planning of transportation and appropriate destination facilities for special groups such as hospitalized patients, nursing home residents, handicapped persons, and school children. These plans must be rehearsed. For example, the hospitals do not have prearranged evacuation plans or dependable transportation arrangements (based upon discussions at Ajax-Pickering and Oshawa General Hospitals in 1992). Evacuation proceeds via monitoring and decontamination centres to reception centres funded by host municipalities. Problems include traffic tie-ups caused by voluntary evacuation, inadequate police manpower to carry out described evacuation plans, and lack of readiness and staffing of reception centres. Hydro has procedures in place but would have some difficulty staffing all monitoring and decontamination centres with trained and practised radiation control personnel during an actual disaster. Further, there are no arrangements to provide physicians or nurses to staff the decontamination centres.

Evacuation centres for populations within a 10 km radius will have to be staffed to provide reception, feeding and sheltering services. For populations west of Pickering station, the associated evacuation centres will be located at York University and the Canadian National Exhibition grounds, and will be serviced by Metro Toronto Social Services. However, funding and training to provide these services has yet to be put in place.

There are about 200 nuclear workers on any given shift at the Pickering A station and about 1,000 support workers. As a result of an accident at a nuclear facility, workers could suffer two major types of injuries: sustained physical injury including burns and radiation contamination; or no apparent physical injury with radiation health effects. At present, Hydro's preparedness for the initial response for such injured workers in the station is well planned. The primary hospital (Ajax-Pickering General Hospital) has limited capabilities for the initial stabilization of injured workers and decontamination. They could treat only a few seriously injured patients. Referral arrangements for traumatized and contaminated, or burned and contaminated patients are not established. Transportation to a tertiary care hospital is also a problem if the patient is contaminated. There are arrangements in place for the care of workers suffering from radiation syndrome at the Toronto General Hospital which is jointly funded by the Ministries of Health and Labour ($150,000 annually).

There is a need for annual exercise programs so that every nuclear facility plan is exercised both on site and off-site, as required by the Solicitor General.

c. The Worst Credible Radiation Emission Accident

The accident on April 26, 1986 at a nuclear generating station in Chernobyl resulted in large emissions of radiation with loss of lives and exposure of the public to significant radiation. Thirty-one persons, mostly fire fighters and plant operators, died from exposure to intense radiation or from burns within the plant. This accident differed from the U.S. Three Mile Island accident of March 28, 1979 and the U.K. Windscale accident in 1957 in that there were early deaths and the potential for numerous premature deaths due to radiation exposure to the public. There is a need to revise the basis of Ontario's planning in order to prepare for accidents which are lower in frequency or whose frequency cannot be quantified, such as those due to gross human error as at Chernobyl and Three Mile Island, or due to hostile action. Provincial Working Group No. 8 has looked at the upper limit for detailed nuclear emergency planning and described the worst credible radiation emission [WCRE] scenario in their report (June, 1988). The release of a significant portion of a reactor's core radioactive inventory was studied for Ontario CANDU reactors. The aim of this scenario is to protect the public from early morbidity or mortality, and is not designed to protect from longer term genetic or latent cancer effects. This scenario requires several changes in nuclear emergency planning for the Bruce, Darlington and Pickering NGSs and their communities.

Calculations show a 50 rem whole body dose for the WCRE scenario in the first twenty-four hours after an accident at Darlington or Bruce as far as 13 km from the plant, which extends the primary zones as well to 13 km. This requires changes in monitoring, evacuation zones, and primary hospitals (Oshawa General and Bowmanville Hospitals). As well, pre-distribution of potassium iodide tablets is necessary for such a large early exposure in the contiguous zones around the plants. An early warning system for the public is required and needs to be practised. Restriction of new housing construction near nuclear facilities, especially in the three kilometre contiguous zone, follows from this accident scenario. The need for adequate medical facilities for exposed subpopulations must be addressed by plans to screen about one thousand persons and to treat fifty persons for radiation syndromes (as recommended by Provincial Working Group No.9).

Revisions to the Nuclear Emergency Plan (as recommended by Working Groups 8 and 9) await Provincial Cabinet approval. A Cabinet decision must weigh the costs and public alarm generated by such revisions against the possibility that resources are better used to prevent accidents by improving security, operator training, operator procedures and fire prevention. Increased resources for security as well as for emergency preparedness are an integral requirement of the nuclear option, but revisions to existing plans to accept the WCREA as the planning basis are also necessary.

d. The Cost of Nuclear Emergency Preparedness

At present, the costs of planning for nuclear accidents are borne largely by the utility. Hydro allocates $6M annually for nuclear emergency preparedness which covers half of the $0.5M budget for nuclear emergency preparedness by Emergency Planning Ontario. As well, Hydro has funded renovations to the primary designated hospitals and has agreed to fund the municipalities, to a limited extent, for their nuclear preparations.

The major costs involved are for the planning staff and the employees participating in the exercises. These drills can involve 1,500 people (mostly NGS employees during regular working hours) for one day each year, a cost absorbed by the station's operating budget. Some drills involve Hydro employees from other than the Nuclear Branch and when they participate in the exercises, their salaries should be attributed to Nuclear Emergency Preparedness.

A significant cost arises from the annual exercise and more frequent small scale drills due to the salaries of non-Hydro personnel. These costs are currently being absorbed by their employers, generally the municipality or the province (e.g. police, ambulance, firemen, municipal employees, hospital personnel).

Planning for the WCRE accident scenario would require increased staffing for Emergency Planning Ontario, Hydro's Nuclear Emergency Preparedness division, and associated municipalities. Arrangements with primary hospitals would need change, and their capabilities enhanced. An early warning system would be required for each station, potassium iodide tablets would have to be pre-distributed, and exercises involving the public would need to take place on a regular basis.

There are hidden costs associated with the preparedness for accidents in nuclear generating stations. Those places that have rejected the nuclear option, such as British Columbia, incur no costs for nuclear emergency preparedness planning and exercises and for regulatory surveillance. While these costs yield certain benefits to Ontario, such as readiness for other hazardous material accidents and for disaster planning in general, they arise from the presence of NGSs in the province. All such costs should be attributed to "the nuclear option", as other means of generating electricity do not require these expenditures.

In Illinois, a U.S. state with a nuclear capacity similar to Ontario's, the Department of Nuclear Safety has a staff of two hundred and five persons, and additional staff in the Emergency Services and Disaster Agency as well as the federal Nuclear Regulatory Commission involved in the state's preparedness for nuclear accidents (Hare, 1988). The cost of the state organization to provide for nuclear emergencies is borne by the utility, and the state has the capability to monitor public safety and related aspects of the performance of state nuclear utilities. This contrasts with the Solicitor General's Office of Nuclear Emergency Preparedness' staff of six and its limited responsibilities.

Another hidden nuclear cost in Ontario is the AECB's presence as an on-site regulator at each Hydro NGS. The Board's staff salaries are not paid by Hydro.

The annual costs of adequate nuclear emergency preparedness based upon the WCRE planning scenario should include all costs incurred by Hydro and responsible provincial and municipal groups. Major ongoing costs will be for training and exercises, after adequate plans are formulated and equipment and supplies procured. Hidden costs should also be included. These arise from: the participation of persons not employed by Hydro; planning and exercises; and AECB, municipal and provincial employees' salaries. Rosenberg estimates this additional annual cost to be in the range of ten million dollars.

e. Conclusions

Rosenberg recommends that the province base its nuclear emergency planning on the maximum credible release of radioactive material. This was the recommendation of the Hare Safety Review, and awaits Cabinet approval.

Planning is required to enhance the current emergency response to deal with this scenario. While Hydro is currently well prepared for a MPA at one of their reactors, the province's plans are not adequately implemented, and the municipality of Durham is unprepared. All three levels of planning are inadequate for the WCREA scenario.

There are significant costs associated with nuclear emergency preparedness. The major ongoing costs are for the salaries of planners and participants in training and exercises. Some of the costs are hidden, while others are already incorporated into Hydro operations' budget. The additional costs are estimated to be ten million dollars annually.

What emerges from this review is a dilemma in meeting the public health requirements for nuclear emergency preparedness. That dilemma is that any action by Hydro, the Solicitor General's Office of Nuclear Emergency Preparedness or the associated municipalities contiguous to nuclear stations to fully activate any plan will increase public awareness and anxiety concerning its safety. Adequate preparations have socioeconomic impacts (such as depreciated property values in the vicinity of nuclear stations) whose costs will have to be added to the real costs of nuclear generated electricity. This has led to a reluctance to plan appropriately for a nuclear emergency.

9.4 Report Assessing Medical Preparedness for a Nuclear Emergency in Ontario

a. Introduction

Dr. P.Lane (Medical Director, Trauma Services, Victoria Hospital, London) prepared an assessment of medical emergency preparedness in the event of a radiation accident at one of Hydro's NGSs, evaluating the medical aspects of the provincial plan and the preparedness of the Bruce Nuclear Power Development for a radiation incident involving contaminated casualties.

b. Provincial Master Plan

b.1 General Comments

This remarkably detailed plan (even down to planning the establishment of a "rumour desk") is striking in its lack of health considerations. The Ministry of Health [MOH] is not even listed as a "key ministry or agency", whereas at the federal level, the "Federal Nuclear Emergency Response Plan" identifies the Minister of National Health and Welfare as the designated Minister responsible and the Department as the lead federal agency.

This lack of consideration, or downplaying of the role and responsibilities for health agencies, is pervasive throughout the provincial master plan and through other phases of provincial and site-specific planning. It is telling that after almost two decades of nuclear power generation in Ontario, there is still no tertiary hospital designated, funded, equipped, or trained to accept and care for contaminated injured patients. Similarly, there is no provincial organization or network within which hospitals and their staff can interact to share and find solutions for common problems.

The plan assumes that the most serious accident for which detailed planning shall be done is one producing an effective dose of 25 rem at 1 km. Indeed, one of the guiding assumptions is that "the more severe a postulated accident, the less likely it is to occur." This may be a valid assumption in other settings of emergency planning, but is probably inappropriate here.

The document makes no clear distinctions regarding the handling of those who are contaminated and those who are contaminated and injured. The "severity" of any incident must be thought of not only in terms of the amount of radiation released, but also in terms of how many people may be exposed, and whether or not any of them are injured and/or contaminated. A small number of contaminated injured casualties is much more likely than large numbers of people on and offsite being exposed to radiation.

There are clear statements in the master plan outlining MOH responsibilities in terms of research, planning and preparation, provision of personnel, operations and training. The MOH appears to fall far short in most of these areas - indeed, Hydro has stepped into the void in terms of supporting training, assisting with hospital costs, assisting in training of ambulance personnel, etc.

b.2 Medical Input and Content

There is a consistent and worrying lack of medical input and content in the plan. MOH personnel are relegated to purely advisory roles in both the planning structure as well as the command structure in the event of an incident. Clearly, the primary interest of all concerned is the health and safety of the population.

This plan is well thought through in terms of communications, information control, and, if necessary, evacuation plans. Yet the lack of medical input in the planning phases means that there is really no articulation of any preparedness for the medical aspects of such an emergency situation. How would the ongoing and emergency health needs of the population be met? Would emergency departments stay open? How would the emergency needs of those in an area of contamination/exposure be met, if the emergency departments of the primary hospitals were overwhelmed by caring for casualties from the incident? What plans exist to evacuate/clear wards of the hospitals to make room for the casualties? What plans exist to care for and/or evacuate the ill and infirmed in nursing homes, chronic care facilities, etc.? What plans exist to mobilize the necessary material and human resources required to care for the expected casualties - physicians, nurses, ambulance attendants, volunteers, ambulances, extraordinary hospital supplies and equipment, etc.?

In the event of an incident, the lack of medical input and authority in the command structure is a serious deficit. Again, the health of the population is the primary concern. Medical and/or MOH personnel need to have the authority and responsibility to decide when an area is unsafe, when the water and food supply are unsafe, when to evacuate or close health facilities, when to suspend normal operating procedures for hospitals and ambulances, when to second staff and resources from other facilities to meet the immediate emergency. These

considerations should not be simply relegated to a MOH representative on an advisory committee.

b.3 Hospital Designation

b.3.1 Primary

A primary hospital has been designated for each of the province's NGSs. The actual terms of this designation were not available at the time of the consultation, and neither the staff at the Bruce site, nor the medical staff at Kincardine were aware of the contents of such an agreement or contract. Presumably, such an agreement or contract must exist.

Hydro appears to have been relatively forthcoming with the primary hospitals, in terms of supporting the costs of minor renovations, some support for equipment purchase and maintenance, and even the costs of sending a few staff away for training. Strictly speaking, according to the provincial master plan, these could be seen as MOH responsibilities. This lack of a clear definition of responsibilities has meant that much of the planning and training at the primary hospital level has been on an ad hoc basis.

Much of this activity in the primary hospitals depends on good will and volunteerism. The physicians, nurses, administrative staff and others volunteer their time and expertise to the effort. This is in distinct contrast to other endeavours such as the base hospital programs for prehospital care, the lead trauma hospital programs, the air ambulance programs, and the critical care transport programs. In these examples, the MOH specifically funds the hospitals and their staffs for the effort, including identifying and funding a medical director for the program. The lack of such a relationship with the primary hospitals means that planning and preparedness activities are significantly compromised. The primary hospitals have done remarkably well despite this, but their ability to call on staff to engage in exercises and other activities is dependent upon this volunteerism.

The first meeting of the staffs of the primary hospitals to discuss common problems and issues and to attempt to identify solutions occurred in 1992. That this has taken almost two decades since the beginnings of nuclear power generation in the province is directly attributable to the lack of defined responsibilities and support. One of the consequences is that there are no standards or guidelines for the care of casualties or for the necessary training and equipment. The development of such standards and protocols was one of the principal recommendations of this first workshop on medical preparedness in June 1992, and should be accepted and implemented without delay, as should the recommendation for regular meetings of the primary hospitals and ambulance services in the province. These are not large cost items, but are rather a reflection of the ad hoc and volunteer approach that has characterized much of the provincial approach to medical preparedness.

b.3.2 Tertiary

The Toronto Hospital, Toronto General Division, was apparently designated some time ago as the tertiary care facility in the province for the care of victims of exposure and acute radiation syndrome. The hospital is funded for this role. Again, the terms and conditions of that agreement or contract were not available at the time of the consultation. Whether this responsibility extended to the contaminated and exposed patient is unclear. It has been made clear to those involved that TTH is not prepared to accept contaminated injured patients. It is telling that the staff at Bruce NPD felt that the only hospital in the province that had agreed to accept contaminated injured patients was Victoria Hospital in London. However, no formal written agreement or undertaking exists, no funding has been received, and no training of staff or renovation of facilities has been performed. In fact, other than rudimentary plans for decontamination in the morgue, Victoria Hospital has no specific procedures to guide it in this role. Again, that there is no such designation or agreement this far into our "nuclear history" is reflective of the attitude to medical preparedness, and unnecessarily places the health of Hydro workers and the citizens of Ontario at risk.

The provincial plan also contains no details regarding the extraordinary tertiary care issues that would result from an incident. Would wards of TTH need to be cleared to care for casualties, and how would that be accomplished? How would Ontario mount the large scale bone marrow transplant effort necessary after the incident at Chernobyl? How many victims of acute radiation syndrome could TTH care for before exceeding its resources, and is there any backup hospital? Is TTH prepared to maintain a number of patients with pulmonary insufficiency as a result of exposure on ventilators for a prolonged period of time? Throughout the plan, and through discussions with Hydro staff, there appears to be an overwhelming and pervasive attitude that "it could never happen here" , an attitude that is neither reassuring nor the basis for sound planning.

b.4 Training

HOSPITAL STAFF

In the hospitals, both treatment protocols and standards and support for training seem to be lacking. Again, this reflects a lack of planning and consideration of the medical aspects of preparedness more than anything else. The MOH is identified in the plan as having the responsibility for training, yet this has not been encouraged nor funded by the MOH. Hydro's agreement to occasionally send some staff to the United States for training is both commendable and pathetic. Clear provincial training standards for staff working in both primary and tertiary hospitals dealing with victims of radiation incidents are necessary. These should be provincially developed with specific requirements related to the type of reactors in use in the province, the provincial health care system, and the geography of Ontario taken into consideration. Such programs should be solely or jointly funded by Hydro and/or the MOH, and staff of those hospitals should be required and supported to undertake this training. The care of radiation illness and contaminated casualties is a highly specialized field, and the knowledge necessary to care for these patients is not generally available among physicians and other health providers in the province.

AMBULANCE WORKERS
The knowledge and skills necessary to care for such casualties is also not part of the basic Emergency Medical Care Attendant training program in the province. Yet these workers are to be asked to care for and transport victims in the case of such an incident. At a recent exercise at Bruce, attendants refused to transport a contaminated seriously injured worker until the hospital had decontaminated him. This reflects the lack of training and knowledge in the field that is the rule rather than the exception among ambulance workers in the province. A training program specific to Ontario circumstances needs to be developed, and standards for such training implemented. Attendants working in services in the areas of nuclear facilities should be required and funded to undertake such training. Further, such ambulance workers should be funded to take part in regular exercises of their local plans and of the provincial plan. To continue to ignore this need places Hydro workers and Ontario citizens in general at unnecessary risk.

b.5 Other Provincial Ambulance Issues

DECONTAMINATION STANDARDS
It would seem that the facility bears the responsibility for decontamination for any on site incident, except when transport to hospital takes precedence for medical reasons. When the transport of contaminated casualties is necessary, the vehicle and equipment will become contaminated. No standards exist regarding how to decontaminate such a vehicle, and when it is safe to use it again. In the case of multiple casualties, would the vehicle be decontaminated between patients? Is this possible or desirable? Are the ambulance services involved equipped or trained to undertake such a decontamination? Do facilities exist for the disposal of contaminated materials and water resulting from such a procedure?

AIR AMBULANCE ROLE/UTILIZATION
Among the more disturbing findings of the recent exercise at Bruce NPD was that the provincial air ambulance system is neither equipped nor prepared to transport contaminated casualties. If a single worker were to become seriously injured and contaminated today, he or she would not be transported by air ambulance to a tertiary care facility (even if one existed that was prepared to accept the worker). The Air Ambulance personnel have no standards, procedures nor protocols to care for such a patient, the staff have no relevant training, and there is no procedure for decontamination of the vehicle. There are no standards at the provincial or the federal level for what is an acceptable decontamination procedure. This is of particular relevance if the province designates only one tertiary care hospital in the province for these cases. Transport times for a seriously injured casualty by land from Chalk River or Bruce to Toronto are unacceptably long. This again places Hydro workers at significant risk and disadvantage.

c. Bruce NPD State of Readiness

c.1 General Comments

Lane visited the Bruce Nuclear Power Development on Sept. 28, 1992. He did not meet with the Regional Medical Officer of Health but received his written comments on medical preparedness at the site. He spoke to a local ambulance operator and met with a physician for Kincardine Hospital, the designated primary hospital.

Many of the issues identified above with respect to the overall provincial plan are reflected at the Bruce site. These include such things as inadequate definition of responsibilities, lack of training of health care providers, volunteerism at the primary hospital, lack of any designated tertiary hospital willing to accept contaminated injured patients, lack of air ambulance availability, etc. The comments herein then are in addition to those, and are specific to the Bruce site. The degree to which they can be generalized to other sites is currently unknown.

Preparedness will be considered in two contexts: preparedness for an incident involving one or more contaminated injured casualties, and preparedness for casualties who may be contaminated but have suffered no physical injury.

c.2 Contaminated Casualties

c.2.1 The Facility

IDENTIFICATION
Presumably, Hydro bears the responsibility for the identification of any injuries that occur on site, whether or not they involve contamination. Despite the fact that Bruce is a much larger site geographically than others, and transport times are of necessity much longer, there is no reason to believe that there would be any unnecessary delay in identification.

RESCUE & FIRST AID
These responsibilities are handled on site by an Emergency Response Crew. This crew is comprised of workers on each shift who have undertaken special training and been certified in CPR, in first aid (St. John's Ambulance) and in site procedures and protocols. At any one time, there are approximately 100 such crew on site, in all areas. Their response time to any incident would likely be less than 5 minutes. They are trained to extricate an injured worker from any danger, to assess injuries and begin life saving procedures as necessary, to remove the worker to a decontamination room and begin decontamination if appropriate, and then to transport or summon the ambulance. They are not ambulance attendants, and have no advanced life support skills or equipment. However, they appear to be appropriately trained and supervised, and to have an effective notification and dispatch procedure.

SUMMONING AMBULANCES

The Emergency Crew members have the responsibility to then decide whether to summon an ambulance or to transport the patient(s) themselves in their own vehicle. The Hydro vehicle does have oxygen, suction, and some airway management and first aid equipment. It is, however not equipped to provincial standards. Until very recently, all patients were to be transported by the Hydro vehicle. An understanding has now been reached with the local ambulance operator to call them to transport patients, but no criteria exist to assist the crew in making the decision. There is a distinct lack of clarity as to whether the ambulance should be called for seriously injured patients because of their need for a more advanced level of care, or whether in fact these patients should be transported by Hydro out of concern for the time necessary to summon an ambulance. This is a deficit that should be cleared up

immediately. In the recent Bruce exercise involving an injured contaminated worker, the ambulance was not called.

SEND TECHNICAL SUPPORT WITH PATIENT

Hydro does have provisions to send "green men" with any transported casualty. These staff are trained and equipped to assess and monitor any contamination, and would act to assist hospital staff in this regard.

c.2.2 Municipal Emergency Response Agencies

The other emergency response agencies would likely have a minor role in such a scenario. The rescue function normally performed by firefighters is filled by on-site personnel. For a small number of injured casualties, the police would not likely be involved, other than perhaps at the level of a crash report if it involved a motor vehicle.

c.2.3 Ambulance Service

RESPONSE TO SITE

No guidelines or protocols exist to define when and how an ambulance is to be called to the site. Until recently, the ambulance service was not called at all, but relations seem to be improving. Response times to the site are approximately 15 minutes, which is remarkably good considering the size of the site and its distance from the town. However, the lack of defined protocols for triage including when to summon an ambulance should be rectified.

TRIAGE, ONSITE CARE, AND CARE IN TRANSIT

Ambulance staff in the Kincardine and neighbouring ambulance services number approximately 90 personnel. The MOH, the Ministry of the Solicitor General and Hydro are all unwilling to accept responsibility for training. Hydro recently conducted a very limited seminar on a voluntary basis for staff that was well attended. Basically, ambulance attendants would have to draw on knowledge and skills from the Basic Trauma Life Support training, and from their general understanding of the management of patients exposed to hazardous materials. Again, specific training standards and programs are necessary; they should be regularly reviewed; regular exercises should be conducted; and these should be fully supported. It would appear from the provincial master plan that this is the MOH's responsibility.

ASSESS AND DECONTAMINATE STAFF AND VEHICLE AS NECESSARY
This is one of the principal worries of the ambulance staff. Again, without training and standards in the area, fear and unwarranted caution are the rule. During the recent exercise, a crew refused to transport a seriously injured patient to London until he was fully decontaminated. Standards must be developed at the provincial level regarding protective equipment for staff, storage/disposal of contaminated wastes, decontamination of vehicles and staff, etc. Both attendants and dispatch staff must be fully familiar with these standards and requirements so that informed decisions can be made expeditiously in an emergency situation.

c.2.4 Primary Care Hospital

The Kincardine Hospital has done a great deal considering their dependence on medical and other staff to volunteer their services to work on the development of the plan. The plan contains the appropriate provisions for hospital staff to triage (if multiple casualties), to perform an emergency assessment and the stabilization of injuries, to undertake external and wound decontamination, to ascertain the necessity to transfer to the tertiary facility for treatment of injuries, to assess for Acute Radiation Syndrome [ARS], and for need to transfer for further treatment of ARS, if appropriate to notify and transfer to the tertiary facility, and finally, to treat and discharge to holding facility those with minor injuries. The plan is currently under revision to meet some of these requirements. There appears to be an excellent working relationship at the staff level between hospital staff and medical and emergency preparedness staff from BNPD, and this is to be commended.

The ability however of largely untrained hospital staff to care for a radiation casualty has to be questioned. A few of the medical staff and a few of the nursing staff have been sent at Hydro's expense to the United States for training. Of necessity, however, this training does not take into account the specifics related to an incident involving a CANDU reactor in the Ontario setting. Again, as the primary hospitals themselves have recognized and recommended, standards, protocols and training programs should be developed, staff should be funded to undertake such training, and regular reviews and exercises should be conducted.

c.2.5 Interhospital Transport Agency

AIR AMBULANCE
The provincial air ambulance service, funded by the Emergency Health Services division of the MOH operates five dedicated air ambulances in the province, including helicopters based in Buttonville north of Toronto, and in Sudbury, and a fixed wing Citation jet in Timmins. Charter vehicles, both fixed and rotary wing, are also used, based among other places in London. Any one of these vehicles could be used to transport an injured patient from Kincardine to London or Toronto.

However, Emergency Health Service [EHS] authorities have stated that an air ambulance vehicle would not be dispatched to transport such a patient because of the necessary down time required for decontamination, rendering this precious Emergency Health Service resource out of service for a prolonged period of time. Hydro officials, frustrated by this attitude, quite appropriately point out that the EHS branch has nothing on which to base this decision, as there are no existing standards for decontamination of air (or land) vehicles.

EHS staff need to take advantage of the technical expertise available at Hydro to develop standards and protocols and an agreement needs to be reached. Transport times by land from Bruce (or Chalk River) to Toronto or London are unacceptably long when contemplating the care of a seriously injured patient in need of complex tertiary care.

Quite aside from the vehicle, the skills and training of the staff are a significant consideration. The dedicated air ambulances are staffed by fully trained Critical Care Attendants, equipped and trained to provide an intensive care unit level of care in transit - intubation, ventilation, shock management, cardiac monitoring, defibrillation, advanced pharmacological intervention, etc. These are advanced level paramedics and in the vast majority of injured patients, their presence obviates the need for a physician, unfamiliar with the vehicle and the environment, to accompany the patient. Whether or not the aircraft is the actual transport vehicle, these attendants are by far the best providers of in-transit care in the province. Yet again, they have not been trained in any way to care for radiation casualties, and would not likely be in a position to do so today. The development of standards, protocols, training programs, review and exercises is again evident with this "link in the chain".

LAND AMBULANCE
As noted above, the land ambulance system is a poor second option for long distance interhospital transport of the critically ill and injured. We should be able to do better in Ontario in the 1990s. As noted, land ambulance staff lack the training, equipment and protocols to transport such patients. Transport times of from at least 2 hours (to London) to almost 4 hours (to Toronto) place the patient at an unacceptable risk. Because of the lack of advanced life support skills and equipment, medical and nursing personnel from the Kincardine hospital would be required to accompany and care for such a patient in transport. Hospital staff are unfamiliar and uncomfortable with the constraints of providing care in this very different environment. In addition, appropriate monitoring and therapeutic equipment is not available in the vehicle and must be borrowed from the hospital. Again, hospital based equipment is usually ill suited to the transport environment. The best planned "checklist" of equipment and drugs usually omits an essential component when developed by those unfamiliar with the environment. Two hours into a transport with a critically ill patient travelling at 100 km/h through rural Ontario is not the time to discover that the oxygen tank is empty, the monitor batteries are dead, or an essential drug or intravenous fluid is not available.

c.2.6 Tertiary Referral Hospital

The roles of the tertiary care facility here are to provide specialized care for physical injuries, and to assess, monitor, decontaminate and treat for ARS. TTH has indicated its willingness to accept this role for exposed patients but not for those who have been contaminated and injured. Staff at Bruce NPD and at Kincardine hospital understandably look to their tertiary referral centre for trauma patients, Victoria Hospital in London being the tertiary facility to which such patients would be referred. However, no formal agreement or understanding exists with Victoria Hospital, and the facility has only a very rudimentary plan as to how to care for radiation casualties, involving surface decontamination in the morgue which is situated next to the emergency department. Staff have no specialized training or expertise in the field, and the hospital would currently find it very difficult to cope with a contaminated casualty in its operating room, X-ray department, and intensive care unit. These are no doubt the same difficulties faced by TTH, and without funding for some renovations, medical leadership, the development of protocols, training programs, and exercises, the situation will not improve. This should be immediately clarified with at least one tertiary care hospital being designated to accept injured contaminated casualties, agreeing to do so, being appropriately funded, and proceeding to develop standards, protocols, training programs, exercises, etc.

c.3 Contaminated Non-Injured Casualties

Here, the major issues are decontamination and assessment for exposure. The Bruce site appears to be well prepared for on-site decontamination, with a number of designated decontamination rooms (although these were not directly viewed during the visit). In addition, the facility has the equipment and personnel to assess exposure and contamination.

What is less clear is how any off-site decontamination would be accomplished. Presumably, the only likely scenario in which this might occur is a transportation incident. The most appropriate action would be to transport such individuals to the site for decontamination, but such a provision was not articulated.

c.4 Exposed Cases

Here, the needs are for case identification, transport, and the establishment of a Diagnostic and Holding Facility. Case identification and transport for on-site exposure would seem to be the responsibility of Hydro, and would not pose a problem. Case identification for off site exposure and transport is not defined. The MOH draft contingency plan assigned the responsibility for the establishment of the Diagnostic and Holding Facility to the primary hospital. The provincial workshop on medical preparedness in June 1992, quite appropriately felt this to be unrealistic. Such a facility should be established separate from the Kincardine Hospital. Its role should be to assess the degree of exposure, to dispense prophylactic therapy such as potassium iodide, as necessary, and to identify those cases requiring transport to the tertiary care facility for assessment and treatment of significant radiation exposure. Such a facility should also anticipate and provide for the counselling required by both those exposed and those who are fearful of having been exposed.

d. Summary and Conclusions

The original request from the PHC was for an opinion with respect to the "status of medical emergency preparedness in the event of a nuclear accident". Those active in the fields of trauma care and injury control in fact avoid the term "accident" as it implies an event that is "unexpected" and "unavoidable". Ultimately, all injury is preventable, and all injury-producing events have predictable and avoidable causes. Injury-producing events at Ontario's nuclear generating facilities are no exception: they have predictable causes and frequencies of occurrence, which must be anticipated and planned for. An essential part of that planning is the province's ability to care for those suffering illness and/or injury as a result of an incident involving radiation. It is negligent to procrastinate and evade the responsibility to plan for such incidents.

Some aspects of the provincial plan are very well thought through indeed. Yet those dealing with medical issues and concerns are either simply not developed or are inadequate. There has been a lack of input in the planning phases from the medical community, and this is reflected in both the local and provincial plans. Health authorities are relegated to advisory roles, remote from the command structure.

In interviews with those involved as well as in the documentary review, there is a lack of definition of roles and responsibilities. When multiple agencies are involved with varying interests and resources, the lead agency must be defined as must the roles and responsibilities of others. Where such responsibilities have been defined, such as in the area of training of hospital and prehospital personnel, they appear not to have been accepted.

In Lane's report, a number of issues and discrepancies have been noted, in areas of standards, training, funding of facilities and personnel, designation of facilities, collaboration with other agencies and services, etc. These issues and problems are all capable of resolution if the agencies involved cooperate and give the effort sufficient priority and resources. But without such an effort and without sufficient resources devoted to emergency planning, the current state of inadequate medical preparedness will continue. We have been fortunate in the province that no major incident has occurred to date, but this good fortune may not continue.

The major deficiency is the lack of any comprehensive plan to care for injured and/or contaminated casualties of an incident. Problems exist, as articulated herein, with respect to transport from the site, standards, protocols and training of prehospital care personnel, training and standards at the level of the primary hospitals, funding of the primary hospitals, interhospital transport, and the designation of a tertiary care facility to care for the victim(s) of such an incident.

Ontario today is ill prepared to care for victims of an incident at a nuclear facility particularly if it were to involve injured contaminated casualties. As this would appear to be a much more likely scenario than an incident involving the release of a large amount of radioactive material endangering large numbers of the population, it would be prudent to plan for this now. It is also concluded that the agencies involved can resolve these issues if they recognize the need, assign sufficient priority to such planning and are willing to devote the time and resources required.

RECOMMENDATION 9.1: The PHC recommends that the provincial and federal governments resolve existing conflicts between federal and provincial jurisdictions regarding the monitoring and regulation of public and worker health and safety issues arising from Hydro's nuclear program.

RECOMMENDATION 9.2: The PHC recommends that the government of Ontario and Hydro revise the provincial nuclear emergency plan to include advice from qualified public health and emergency health professionals regarding health issues associated with nuclear emergencies.

RECOMMENDATION 9.3: The PHC recommends that the government of Ontario and Hydro collaborate with local health agencies and public hospitals to develop emergency plans for incidents in nuclear facilities with particular emphasis on the care and treatment of contaminated and injured workers and members of the public.

Chapter 10 Recommendations

10.1 Introduction

As noted in the explanatory note, the PHC's recommendations fall into three broad categories: recommendations respecting the undertaking, its alternatives and alternative methods; recommendations respecting conditions to be imposed should the Board approve Hydro's undertaking; and third, other recommendations, which, strictly speaking, are beyond the mandate of the Board but which arise out of the PHC commissioned studies.

In this chapter, the conclusions are grouped in the order set out above.

10.2 Recommendations Respecting the Inadequacy of Hydro's Environmental Assessment

The PHC submits that Hydro has failed to give an adequate description of the effects, including health effects, that will be caused or might reasonably be expected to be caused. Further, the PHC submits that Hydro has failed to set out actions necessary to mitigate or remedy the adverse health effects, as required by Section 5 of the Environmental Assessment Act.

> RECOMMENDATION 10.1: **The PHC recommends that the Board not give approval to proceed with the undertaking.**

10.3 Recommendations Respecting the Undertaking

> RECOMMENDATION 3.1: **The PHC recommends that an alternative based on the nuclear option should not be approved. There are unacceptable adverse health effects and associated health costs, including excess cancer deaths, non-fatal cancers, genetic and teratogenic effects arising from the nuclear option.**

> RECOMMENDATION 4.1: **The PHC recommends that an alternative based on the fossil fuel option should not be approved. There are unacceptable adverse health effects and associated health costs, including respiratory diseases, arising from the fossil fuel option.**

> RECOMMENDATION 5.1: **The adverse health effects and associated health costs arising from the hydraulic option are less costly than options based on either nuclear or fossil fuel. However, the cost is borne disproportionately by affected native populations. The PHC supports recommendations made by Native groups to mitigate adverse health effects and recommends that alternative energy options be explored.**

RECOMMENDATION 7.1 : The PHC recommends that the conserver society option is the best alternative to Hydro's undertaking in the short term. In the long term, the best alternative is investment in sustainable life compatible technologies.

10.4 Recommendations Respecting Terms and Conditions

RECOMMENDATION 3.2: The PHC recommends, if an alternative based on the nuclear option is to be approved, that as a condition of approval Hydro be required to conduct research into sustainable life compatible alternative technologies, reduce radioactive emissions including tritium, carbon-14 and other radioactive emissions, and prepare a comprehensive and ongoing health impact assessment of nuclear power production.

RECOMMENDATION 3.3: The PHC recommends, if an alternative based on the nuclear option is to be approved, that as a condition of approval Hydro develop the following: a system to better monitor radionuclide emissions including the noble gases, correlated stack and ground monitoring systems for airborne radionuclide emissions from all Hydro facilities, and similar systems for waterborne radionuclides.

RECOMMENDATION 3.4: The PHC recommends, if an alternative based on the nuclear option is to be approved, that as a condition of approval Hydro be required to establish a comprehensive database consistent with the U.S. and U.K. databases for the follow-up of all Hydro workers employed for at least three years in jobs involving radiation exposure.

RECOMMENDATION 4.2: The PHC recommends, if an alternative based on the fossil fuel option is to be approved, that as a condition of approval Hydro be required to use low sulphur coal and install flue desulphurization methods to reduce SO_x emissions and that Hydro be required to modify its combustion process at all FFGS to reduce NO_x emissions.

RECOMMENDATION 5.2 : The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that Hydro be required to monitor the health effects on all workers whether directly or indirectly employed by Hydro and to assess the health costs, including the health costs to the public respecting the effects of methylmercury, actually incurred as a separate identifiable cost source.

RECOMMENDATION 5.3 : The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that Hydro obtain worker health data and costs from other utilities including Quebec Hydro and Manitoba Hydro so that a more accurate assessment of costs can be obtained and included in assessing the cost of power purchases.

RECOMMENDATION 6.1 : The PHC recommends that Hydro be required to practice "prudent avoidance" in the location of new transmission lines as well as in the location of transmission and distribution lines of Hydro's associated municipal utilities and other customers.

The current and emerging evidence respecting the adverse health effects of EMFs is sufficient to justify the adoption of a policy of prudent avoidance in the location of transmission lines, shielding, breadth of transmission line corridors and land use in the vicinity of transmission line corridors.

RECOMMENDATION 6.2: The PHC recommends that Hydro and its associated municipal utilities and other customers establish work practices which minimize the exposure of their workers to EMFs.

RECOMMENDATION 6.3: The PHC recommends that Hydro be obliged to minimize its use of herbicides in transmission line corridors and to replace herbicides by manual clearing wherever feasible.

RECOMMENDATION 7.2: The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that as a condition of approval Hydro be required to conduct a more extensive review of sustainable life compatible alternative technologies and the conserver society options for both the short and long term.

RECOMMENDATION 7.3: The PHC recommends, if Hydro's undertaking based on the hydraulic option is to be approved, that Hydro be required to undertake a health impact assessment of sustainable life compatible alternative technologies and the conserver society option for both the short and the long term.

10.5 Other Conclusions

10.5.a The Need for Explicit Mention of Health Effects in the Environmental Assessment Act

The PHC invites the Board to consider recommending amendments to the Act to include an explicit requirement that health effects be included in any environmental assessment.

RECOMMENDATION 10.2: The PHC recommends that the Environmental Assessment Act be amended to include an explicit reference to health effects.

The PHC further invites the Board to recommend that, should the Act not be amended, that public health issues be included in all future Hydro planning processes.

RECOMMENDATION 10.3: The PHC recommends that public health issues be included in much greater detail in all Hydro future planning processes.

10.5.b Costs

Hydro has restricted its computation of health costs to those health costs borne directly by it. The PHC recommends that all health costs, including those borne by the province, be included in energy planning.

RECOMMENDATION 10.4: The PHC recommends that all relevant and quantifiable health costs attributable to a component of Hydro's operations be allocated to that component to reflect the true contribution of each component to the cost of electricity.

RECOMMENDATION 10.5: The PHC recommends that costs be distinguished between the portion of cost borne by Hydro and the portion of cost paid by the province in the form of health and other costs.

10.5.c Process

The PHC is concerned about the current environmental assessment process which limits complete consideration of health and other issues. The adversarial process whereby scientific issues are canvassed through counsel does not readily permit full consideration of the nuance and uncertainties inherent in a health effects study. Moreover, the environmental assessment process is limited to a particular time and a particular set of issues, whereas environmental and health effects data and the consequences of Hydro operations present ongoing issues.

RECOMMENDATION 10.6: The PHC recommends that an agency be created by the government of Ontario to conduct ongoing research into and provide policy advice on the public health and environmental effects of Hydro's operation and planning. The agency could be composed of representatives of the public, other interested stakeholders, including government, Hydro and regulatory agencies. The agency could be a vehicle for measured discussion in a collegial setting of areas of uncertainty, for the development of protocols to explore these areas and to provide a forum to assess and weigh the findings. The agency could operate on an ongoing basis.

10.5.d A Proposed Agency

The proposed agency could consider matters as set out in the following PHC recommendations.

RECOMMENDATION 10.7: The PHC recommends that the proposed agency develop a health impact assessment model similar to the one described in Chapter 1 of this report to monitor emissions and to monitor adverse health effects on affected populations including members of the population at particular risk.

RECOMMENDATION 3.5: The PHC recommends that the proposed agency perform appropriate dispersion modeling studies for radionuclide emissions from all Hydro nuclear facilities. The studies should move toward site-specific dose reconstructions. The studies should enable the development of more accurate human radiation dose estimates, as well as the confirmation of or proposals to modify performance standards (i.e. DELs) for all such facilities.

RECOMMENDATION 3.6: The PHC recommends that the proposed agency recommend the time frame to be considered in determining radiation doses to future generations arising from current emissions of Hydro nuclear facilities. The agency should consider the time frame to be incorporated into its methodology for determining site-specific DELs.

RECOMMENDATION 3.7: The PHC recommends that the proposed agency discuss and research the issue of low dose, low dose rate effects of ionizing radiation and monitor the literature emerging in this area.

RECOMMENDATION 3.8: The PHC recommends that the proposed agency undertake a study of radionuclide dilution, persistence and elimination rates in fresh water lakes to determine an appropriate guideline for effluence releases into Ontario's lakes.

RECOMMENDATION 4.3: The PHC recommends that the proposed agency develop an acid aerosol network to monitor and evaluate this pollutant and its associated environmental effects and costs.

RECOMMENDATION 6.4: The PHC recommends that the proposed agency conduct ongoing research programs to evaluate health effects associated with EMFs.

10.5.e Recommendations Respecting Government

The PHC is concerned about jurisdictional issues respecting regulations, enforcement and emergency planning which require participation by several levels of government. The PHC invites the Board to consider making the following recommendations to both the federal and provincial governments:

RECOMMENDATION 9.1: The PHC recommends that the provincial and federal governments resolve existing conflicts between federal and provincial jurisdictions regarding the monitoring and regulation of public and worker health and safety issues arising from Hydro's nuclear program.

RECOMMENDATION 9.2: The PHC recommends that the government of Ontario and Hydro revise the provincial nuclear emergency plan to include advice from qualified public health and emergency health professionals regarding health issues associated with nuclear emergencies.

RECOMMENDATION 9.3: The PHC recommends that the government of Ontario and Hydro collaborate with local health agencies and public hospitals to develop emergency plans for incidents in nuclear facilities with particular emphasis on the care and treatment of contaminated and injured workers and members of the public.

Acronyms and Abbreviations

AC	Alternating Current
ADRI	Acceptable Daily Intake
AECB	Atomic Energy Control Board
AECL	Atomic Energy Canada Ltd.
AGR	Air-Cobled Graphite Moderated Pile
ALARA	As Low As is Reasonably Achievable
ARS	Acute Radiation Syndrome
BEIR	American National Research Council's Committee on the Biological Effects of Ionizing Radiation
BNPD	Bruce Nuclear Power Development
BRC	Below Regulatory Concern
CANDU	Canadian Deuterium Uranium
CCOHS	Canadian Centre for Occupational Health and Safety
CEDE	Collective Effective Dose Equivalent
CEDEC	Collective Effective Dose Equivalent Commitment
CEG	Coalition for Environmental Groups
CF	Concentration Factor
CI	Confidence Intervals
CSC	Conventional Steam Cycle
CSS	Conserver Society Scenario
CTU	Combustion Turbine Units
dBA	Decibel level of noise, a measure of intensity
DEL	Derived Emission Limit
DREF	Dose Rate Effectiveness Factor
DSP	Demand Supply Plan
DTO	Tritiated Heavy Water
EAB	Environmental Assessment Board
EASFBTA	Economic and Social Factors Being Taken Into Account
EDP	Electric Power Database
EEI	Electrical Efficiency Improvement
EHS	Emergency Health Services
ELF	Extremely Low Frequency Fields
EMF	Electromagnetic Fields
EMR	Electromagnetic Radiation
FFGS	Fossil-fuelled thermal electric power Generating Stations
GWa	A gigawatt of electrical energy produced over a year
H_2S	Hydrogen Sulphide
HD	Hodgkin's Disease
HLW	High Level Waste
HWE	Healthy Worker Effect
HWR	Heavy Water Reactors
IARC	International Agency for Research on Cancer

ICD-9	WHO's International Classification of Diseases (Ninth Revision)
ICRP	International Commission of Radiological Protection
ILW	Intermediate Level Waste
IPPSO	Independent Power Producers Society of Ontario
K_{OW}	Octanol-Water Partition Coefficient
LC_{50}	Median Lethal Concentration
LD_{50}	Median Lethal Dose
$LD_{50/30}$	Lethal Dose
LET	Linear Energy Transfer
LLW	Low Level Waste
LSS	Life Span Study
MAC	Maximum Allowable Concentrations
MIR	Maximum Individual Risk
MOE	Ministry of the Environment
MOH	Ministry of Health
MPA	Maximum Planning Accident
MPD	Maximum Permissible Dose
MPL	Maximum Permissible Concentration
NBS	National Bureau of Standards
NDMA	N-nitrosodimethylamine
NGS	Nuclear Generating Station
NHL	Non-Hodgkin's Disease
NIHL	Noise Induced Hearing Loss
NIR	Non-Ionizing Radiation
NPD	Nuclear Power Development
NRC	National Research Council
NUG	Non-Utility Generation
OBT	Organically-Bonded Hydrogen or Tritium
OR	Odds Ratio
ORNL	Oak Ridge National Laboratory
OSCC	Oxford Survey of Childhood Cancer
PAH	Polyaromatic Hydrocarbons
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofurans
PNGS	Pickering Nuclear Generating Stations
PYR	Person Years of Risk
Q	Quality Factor
RBE	Relative Biological Effectiveness
RERF	Radiation Effects Research Foundation
ROW	Rights of Way
RR	Relative Risk
RSAC	Reactor Safety Advisory Committee
SMR	Standardized Mortality Ratio
STS	Soft Tissue Sarcoma
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin

TLD	Thermoluminescent Dosimeters
TMI	Three Mile Island
TRF	Tritium Removal Facility
TSP	Total Suspended Particulate
TTH	The Toronto Hospital
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VOCs	Volatile Organic Compounds
WCB	Workers' Compensation Board
WCRE	Worst Credible Radiation Emission
WCREA	Worst Credible Radiation Emission Accident
WHO	World Health Organization

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