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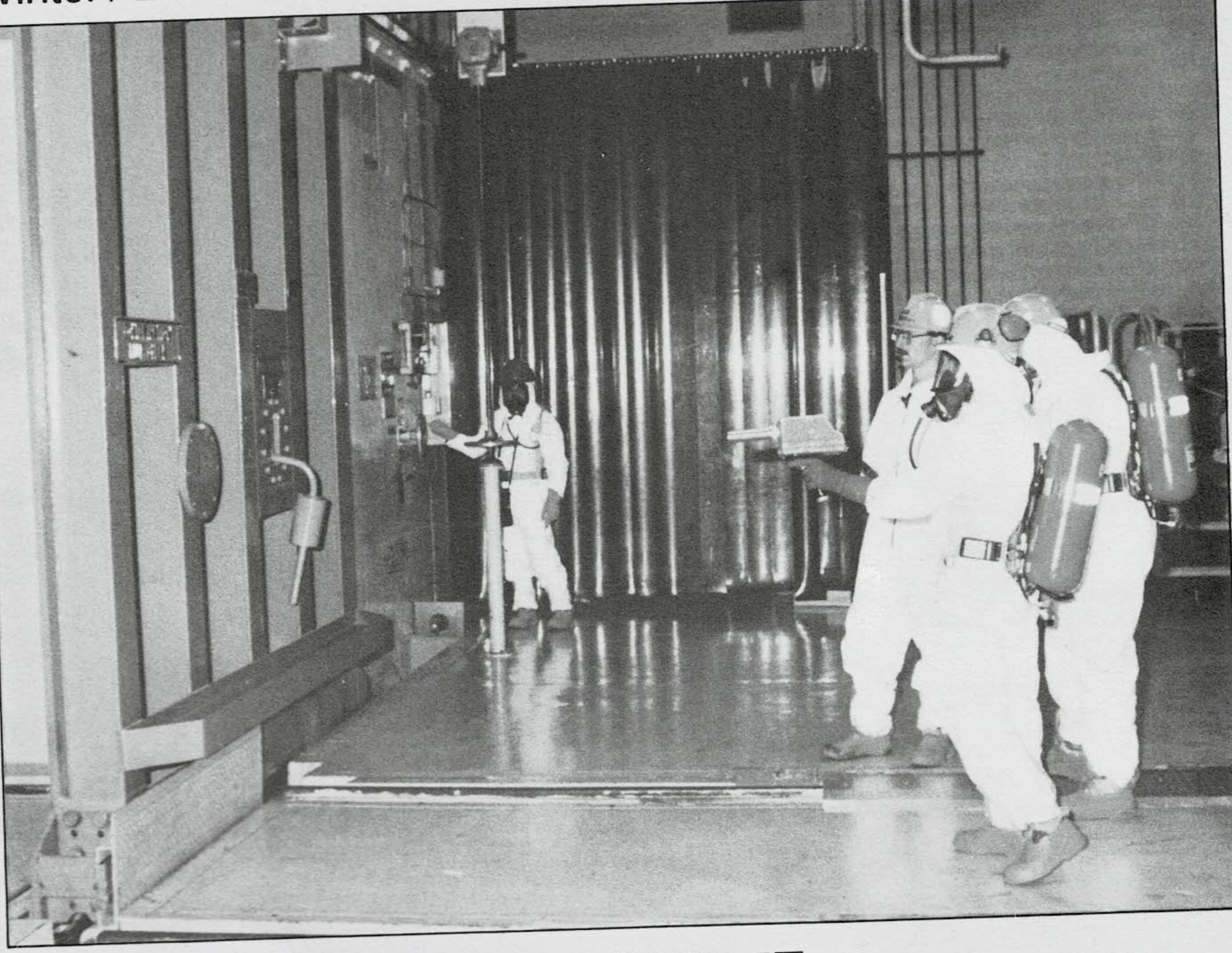

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PRINTED ON RECYCLED PAPER IMPRIME SUR PAPIER RECYCLE

Cover photo

The photograph on the cover was taken during an emergency exercise at Bruce NGS "A" in 1992 and shows an emergency response team preparing to enter the containment in a rescue mission.

(Photo courtesy of Ontario Hydro)

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Shifting the Paradigm

People, groups and whole societies can become trapped in a particular view of the world, adhering to "conventional wisdom" or, to use modern jargon, stuck in a certain "paradigm". Such appears to be the case with the linear dose-effect theory which has been the basis of radiation protection philosophy for four decades.

The theory has been the basis of the recommendations by the world-guiding International Commission on Radiological Protection since the 1960s. Now it is often used, even by scientists who should know better, to estimate thousands of deaths due to small releases of radioactive material.

Recently, however, more and more papers and articles are questioning the linear dose-effect relationship. There is little factual evidence of harm caused by small doses of radiation in the range of existing, let alone, the much lower dose limits proposed by the Atomic Energy Control Board. The epidemiological studies required to demonstrate the theory are impossibly large. In recent years there has been an increasing number of reports of some beneficial effects of small doses and some support for the competing theory of hormesis.

But, it appears that for the nuclear community in general, and those in radiation protection in particular, the linear dose-effect theory is like a religious belief. Most radiation protection practitioners appear unwilling to examine any evidence not fitting the accepted concept.

This is not just of academic interest or just of concern to radiation protection specialists. The costs inherent in applying the ALARA concept, for example, are very significant, not just for operators but also in many aspects of the design of nuclear facilities. These costs will be amplified when the new dose limits proposed by the AECB come into effect. The uranium industry is particularly concerned because of the practical difficulties they see, let alone the costs, of meeting the reduced limits, and has questioned, legitimately, the basis for them.

It would be unrealistic to expect the regulators to go counter to the conventional wisdom. Not only are they also caught up in the paradigm but they face considerable public and political pressure to err on the "conservative" side. Perhaps, however, some in the nuclear power or nuclear technology fields might recognize that it is not only scientifically honest, but also in the industry's interest, to question the existing paradigm.

In This Issue

The lead article this issue, the paper by Jatin Nathwani on **Managing Risks**, highlights society's inconsistent approach and proposes three principles to guide decision-makers on issues involving potential hazards to life or health. Some in the nuclear industry may liken Nathwani's message to the old adage of "carrying coals to Newcastle". However, given the many examples of how we are spending inordinate amounts to lower already small risks, all in the industry can benefit from an examination of the concepts presented.

Somewhat as a companion to the Nathwani paper there is one by the editor (no objectivity here!) on **The Canadian Approach to Reactor Safety**. As noted there, an original risk goal has been lost in favour of pragmatic (or arbitrary) requirements by the regulators which, more and more, appear to be seeking "absolute" safety.

While designing to minimize risk it is prudent to plan to deal with accidents if they should occur. Since nuclear power plants present a potentially significant hazard, extensive plans have been developed to cope with nuclear emergencies, and the utilities are on the front line. Thanks to Lesley Charlebois of Ontario Hydro we have a photo story **Emergency Response at Ontario Hydro** illustrating the arrangements within that utility for dealing with nuclear emergencies.

For a different perspective on the nuclear industry we are including, thanks to people at AECL Corporate and at Ernst & Young, the "executive summary" of the study done by that consulting firm on **The Economic Effects of the Canadian Nuclear Industry**. Perhaps those in the industry will not be surprised with the study's conclusions that the Canadian economy has benefitted considerably from our nuclear activities.

Another view of our industry and of our approach to safety can be gleaned from the notes by Gloria Evanytsky on the **Nuclear Liability Act Trial**. The last issue of the *CNS Bulletin* noted the beginning of the trial to hear the charges by Energy Probe and others that the Act was unconstitutional and violated human rights. Although the trial wrapped up the testimony before Christmas, some weeks earlier than anticipated, it still generated over 2,000 pages of oral evidence. The notes are much shorter than that.

It is disturbing when professionals feel coerced by their employers. This is especially so when the issue is safety. The short article **A David and Goliath Story** reports on the conclusion of the first stage of "Joe" Ahmad's suit against Ontario Hydro, and the judge's ruling in his favour. With Hydro's decision to appeal our original story has been condensed to the bare bones of the case.

Finally there is a smattering of other news and information which we hope might interest you.

As always we welcome your comments and input.

Letter to the Editor

INC '93 – A Retrospective

Now that the dust has settled on INC '93, the International Nuclear Congress and Exhibition held in Toronto last October, perhaps it is worth looking at just what was achieved.

For the record, INC '93 was sponsored by the Canadian Nuclear Society and the Canadian Nuclear Association. The 16 co-sponsoring or cooperating organizations included most of the world's major nuclear societies and associations together with international entities such as the International Atomic Energy Agency, the OECD Nuclear Energy Agency and the World Bank.

Back in 1989, INC '93 was conceived as a rather grandiose international nuclear conference with several thousand participants and a trade exhibition on a scale similar to that of the old Nuclex exhibitions. As time passed and after discussions with several nuclear societies and associations, a degree of realism prevailed and the sights were set on a much more modest conference and exhibition.

Nevertheless, the original goal remained the same. That goal was to create a dialogue among a broader community than the nuclear industry on the role of nuclear energy in meeting the future energy needs of the world. Traditionally, nuclear conferences have been little more than the nuclear industry talking to itself – great for patting oneself on the back but contributing little towards the future prospects for nuclear power. INC '93 was to be a break with tradition. Did we succeed?

In the end, well over 500 people from 27 countries participated in INC '93. Although this was fewer than had been hoped for, it was a goodly number considering the state of the economy and the proliferation of competing nuclear and other energy-related conferences which seemed to suddenly mushroom at around the same period of time. The most positive feature was the participation from abroad – there were 66 participants from the USA and 89 from other parts of the world and, of the 155 foreign delegates, less than 40 were specifically invited to attend. In fact, INC '93 truly was an international conference with two-thirds of the participants in the invited program and almost half of the papers in the contributed technical sessions coming from outside Canada.

Furthermore, to help create the dialogue which was the goal of INC '93, 14 of the invited participants had no direct connection with the nuclear industry and several were known to be openly opposed or sceptical of the value of nuclear power. Certainly, those who attended the Round Table on Economics of Electrical Generation and, to a lesser extent, that on Reactor Safety can testify that the position of nuclear power was more than adequately challenged. This was not the usual nuclear "love-in".

The goal of reaching out to a wider audience than the nuclear industry was achieved to a reasonable degree. It is always difficult to assess the affiliation of foreign delegates but, from Canada, there was strong representation from both government and private sector in the energy and environmental fields, from the academic community and organized labour. And, in my experience, there was a first for a nuclear conference, attendance by representatives of Canada's native peoples.

Virtually every session, whether invited or contributed, was well attended despite having, at times, several parallel sessions. In fact, in several cases the space allotted to the session was woefully inadequate to accommodate all who wished to participate. A tribute to the quality of the speakers and their contributions.

Overall, INC '93 was a successful conference and many favourable comments have been received from participants and the co-sponsoring organizations as to the style and organization of this conference. Perhaps the most telling testament is the preliminary planning of a second such conference, INC '96, in the UK. It would appear that one of the original concepts of INC '93, that of an ongoing series of such conferences, espoused by Jim Weller and Ken Talbot who started the ball rolling back in 1989, may yet be realised.

John Boulton

INC '93 Summaries

Copies of the "Technical Sessions Summaries" containing summaries of both invited and contributed technical papers from the INC '93 International Nuclear Congress held in Toronto, 3-6 October 1993, are available **free** to CNS members.

Send your request by mail or FAX to:

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Managing Risks

Three Principles to Guide Decision-Makers

Jatin S. Nathwani

Ed. Note: *The following paper is based on a presentation by Dr. Nathwani to the International Symposium on Managing Risks to Life and Health, held in Ottawa, October 1993, and sponsored by the Royal Society of Canada and the Canadian Academy of Engineering. Dr. Nathwani gave a similar talk to the Central Lake Ontario Branch of the CNS and the CNS Council at Darlington in September 1993. That talk also dealt with the application of these principles to energy issues, which will be covered in the next issue of the CNS* Bulletin.

Summary

The prospect of death and disease commands widespread attention resulting in much effort expended to reduce risk and promote safety. The principles described here are directed at decision-makers in government, industry and institutions responsible for the engineering and management of human safety. The aim is to develop practical and workable policies to deal effectively with the task of managing risks to life and health.

The three principles are as follows:

(i) Risks shall be managed to maximize the total expected net benefit to society;

(ii) The safety benefit to be promoted is quality-adjusted life expectancy (QALE);

(iii) Decisions for the public in regard to health and safety must be open and apply across the entire range of hazards to life and health.

The challenge is to ensure consistency between different efforts to control risk. There is sufficient evidence of erratic risk management resulting in large expenditures of resources that do not appreciably reduce risk. Much too much of policy-making in this area has suffered from lack of careful planning and assessment of the effectiveness of life saving schemes. The principles provide a general framework of reasoning for the management of activities involving risk. Maximizing the net quality-adjusted life expectancy across society as a whole is argued to be a sufficient and rational guide to assessing the effectiveness of activity, and also inactivity, in the area of health and safety.

Introduction

This paper is drawn from the report "Health and Safety Policies: Guiding Principles for Risk Management," prepared by the Joint Committee on Health and Safety of the Royal Society of Canada and the Canadian Academy of Engineering (Report JCHS 93-1, July 1993).*

In the report, three principles for risk management are proposed, directed at decision-makers in government, industry and other institutions charged with the responsibility for ensuring the health and safety of the public.

It should be noted that our proposals must be viewed as a working hypothesis; one step in the continual re-appraisal and re-thinking that will be necessary in the light of new circumstances. Although the conclusions may discomfort some it is our hope that discussion and further scrutiny of the proposed ideas will lead to concrete actions and improvements in risk management process.

Guiding Principles

The essence of our thinking is directed at the question of how to make decisions in the face of uncertainty; uncertainty that cannot be wished away, glossed over, or ignored. Uncertainty is not incidental; it is the essence of the problem.

We propose a framework for managing risks and then provide the rationale in support of using these principles.

The three principles are:

(i) risks shall be managed to maximize the total expected net benefit to society;

(ii) the safety benefit to be promoted is "quality-adjusted life expectancy" (QALE);

(iii) decisions for the public in regard to health and safety must be open and apply across the entire range of hazards to life and health.

Our fundamental thesis, however, is even simpler:

> In the management of natural or technological hazards in a society, the objective should be to serve the public interest in a rational manner.

Since not many will argue for irrational measures and it is not usually clear how to ascertain the concept of "public interest", I need to spell this out. We know that the prospect of disease and death can be emotionally upsetting. Human nature makes it easy for people to react in alarm. The three principles are directed at developing practical and workable policies so that decision-makers can deal effectively with managing risks to life and health.

Let me begin with the third principle.

Principle #3

> *Decisions for the public in regard to health and safety must be open and apply across the entire range of hazards to life and health.*

> Decisions in regard to risk levels for the public, if they are to be defensible and self-consistent, must cover the entire range of hazards under public regulation. The implication is that there must be rhyme and reason to how we approach the management of risk from one source as against another: asbestos vs PCBs vs radiation

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* The referenced report can be obtained from:
Institute for Risk Research, University of Waterloo, Waterloo, Ontario N2L 3G1
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vs dioxins vs sulphur dioxide and so on. The process for setting tolerable risk levels (or safety goals) should involve a thorough consideration of the cost and benefit, supported by explicit quantified comparison on a widely acceptable scale. Comparative risk assessments, performed to the highest standards, are a key ingredient in the developments required to answer the question: Is this a large risk or is this small enough to be ignored?

We observe that much too much of policy making in this area has suffered from lack of careful planning because risk is equated with outrage. The latest scare of the week rules the day. Let me give you some examples of the stark disparities in the way we allocate resources to manage risk:

- Air pollution: We impose stringent standards on industrial and automotive sources yet little attention is paid to indoor pollution which by far poses the greater risks. Pollutants in the outdoors are regulated to the extent that they pose a risk of premature death usually less than 0.001 per cent per year; while the risk from indoor pollution is about 100 times greater. I am not suggesting that we undo the gains we have made in improving the quality of air we breathe; I am however clear that we should pay much greater attention to consistency in standard setting and direct our resources at larger problems and not small ones.
- Radiation: The estimated lifetime risk for **regulated** radiation hazards varies by several orders of magnitude (depending on application – whether it is mine tailings or reactor operations or low level waste storage or high level waste disposal); often these risks are considerably less than essentially ***unregulated*** risks (i.e. risk of radon in homes), and in some instances the risks are way below what is generally regarded as negligible, i.e. less than one in a million. Vast regulatory efforts are directed at saving us from the risk of radiation; and yet the beneficial aspects are not clear at all. The driving force appears to be the questionable assumption that if a risk can be identified, then any reduction of the risk, however small, is desirable and under most circumstances an "undisputed" public good. That this type of reasoning leads to vast expenditure of resources with very little gain in terms of life-saving is a point that needs to be acknowledged.

Citing from the section on "Managing Risk Reduction Sensibly" in the 1992 Budget of the United States Government, I quote:

> "the cost effectiveness of regulatory action varies over more than eight orders of magnitude" when judged against the criterion of life saving potential;
>
> "The regulations targeted at occupational and environmental cancer risks have been extraordinarily costly. Many cancer risks from environmental exposures (excluding smoking and diet) are very small relative to other threats to human health. Nevertheless, about half of the significant regulations listed are aimed at reducing these small risks."

Many aspects of our gut responses to risk, whether it is an issue related to water, air or soil pollution, or some impressionable media sensitive event, reflect the lack of clear policy. I go a step further. It is not only the consistency aspect of risk regulation which bears comment. Nor can the comments be limited to observing that society's resources are not being properly allocated because reducing low risks is expensive. True as these concerns may be, there are some more fundamental philosophical issues which must also be addressed if we are to develop a reasonable perspective on these matters.

One basis for enhancing the openness and accountability of the safety management process requires a dispassionate assessment of the options. For a rational resolution of risk management problems, we need:

first, a decision-making process that is transparent and that satisfactorily addresses the concerns of the people through a process of consultation and consensus building; and

secondly, development of a single meaningful measure of safety that can be applied universally and consistently across a wide range of hazards for application in practical contexts.

There is, in our view, an ethical requirement that there be a clear indication of the process for managing risks in the public interest. This can be viewed as the foundation of a professional ethics for public risk management analogous to the Hippocratic oath. This view is in sharp contrast to the view that risk is not measurable in any meaningful way, that it is subjective, that its acceptability cannot be established in any credible way for society as a whole, and that each management situation is different from any other.

We do not believe that the nature of risk is interminably disputable. Decision-making is always a choice between alternatives and uncertainty is basic to the problem of risk management. It is, however, the first duty of those who manage risk to see that lives are saved efficiently, and not to merely create a perception of safety.

Principle #2

The safety benefit to be promoted is quality-adjusted life expectancy (QALE).

The goal is to ensure that all risk mitigation efforts maximize the net benefit to society in terms of the length of healthful life for all members at all ages: the safety benefit to be promoted being the quality adjusted life expectancy (QALE).

Why "Life Expectancy" and what is this "quality adjustment" all about?

We propose the use of social indicators to provide a quantitative measure for assessing the rationales and effectiveness of public decision-making. The Human Development Index (HDI) promoted by the United Nations Development Programme and the Life Product Index that we have developed (LPI) are two aggregate social indicators that relate to a quality-adjusted life expectancy. (see Fig. 1) Both are functions of mortality and economic productivity, reflecting a relative valuation of longevity with production and distribution of wealth in terms of goods and services. Although derived from different rationales, they show good agreement in application.

The basic rationale for the use of a social indicator such as life expectancy is derived from a consideration of the variables important in describing the process of human

UN Human Development Index (HDI)

$HDI = f(X_1, X_2, X_3)$

X_1 = Life Expectancy at Birth

X_2 = Adult Literacy

X_3 = Log Real GDP per Capita per Year

Life Product Index (LPI)

$LPI = g^w e$

g = Real DP per Person per Year

e = Life Expectancy at Birth

w = Parameter Reflecting Value Placed on a Reduction of Mortality in Terms of Economic Expenditure

Figure 1: Two Social Indicators

development. Human development is about enlarging people's choices. At all levels of development, the three essential factors are: to lead a long and healthy life; to have access to resources for a decent standard of living – to have access to the knowledge necessary for cultural enrichment. If these essential choices are not available, the rest is academic. Use of life expectancy as a principal indicator of human development rests on three considerations: the intrinsic value of longevity, its value in helping people pursue various goals and its association with other characteristics such as good health and nutrition.

Life expectancy is an appropriate measure of human safety. It aggregates the probability of survival of all age groups and is not influenced by the age-specific composition of any particular population. It provides an effective indicator of the level and potential for improvements in human safety. This is a quantitative measure allowing application of the scientific methods. When all costs and benefits, expected losses and harm, are expressed in terms of length of life or life expectancy, then it becomes possible to develop a meaningful perspective with respect to the total burden of risks.

If safety management were to be directed toward the goal of maximizing the quality-adjusted life years available to the public, then targets may be set and public accounts rendered for all major undertakings in a unified way. Furthermore, life expectancy allows a direct comparison of trends over time and among countries. It is also a concrete measurement that is meaningful in terms of individual experience.

Samuel Preston and Nathan Keyfitz, who have made important contribution to our understanding of social demography and causes of death state the case with lucidity. I quote:

> "The circumstances under which men die are closely related to the conditions under which they live. The extent of violence, poverty, and ignorance in a population is reflected in the statistics of its causes and ages of death. Vigorous attempts to delay death are so universal that accurate mortality statistics provide a reliable touchstone of a population's level of social organization and technological sophistication. Not only do mortality conditions mirror those in the general society, but they also have their own important social implications."

Life expectancy is a universal measure, valid for comparisons both within and among countries. It is a perfect alibi for safety.

Why GDP?

One measure of the quality of life is income at the national level (gross domestic product per person). The fact that wealth makes for health and longevity, while lack of wealth makes for sickness and short life is well documented. For this reason, it must be realized that large expenditures of money derived from taxation cost *life*, not just something abstract, *"money"*, that can be disdained. Though wealth is not specifically *identical* with health, it is so important an indicator of it that we can say that a society's ability to achieve improvements in the health status of the population is possible *if and only if* it has the wealth to do so. For our purposes, it is sufficient to suggest that income is a good proxy for all other human choices since access to income permits the exercise of almost all other options.

A rational evaluation of any technology option, its attendant risks and provision of safety programs in the public interest, requires that the impacts on life expectancy (including refinements such as the quality-adjusted life expectancy in terms of health) and the real gross domestic product be evaluated. Ideally, with time, and through public discourse, awareness of the general cost of extending the expectancy and quality of life (or whatever social indicator is used to express "value") will increase. This will provide the basis for informed debate and instruction to the professions in matters of safety.

Principle #1

Risks shall be managed to maximize the total expected net benefit to society.

The principle of maximizing the net benefit for the collective has certainly been expounded by many philosophers and economists; it is classic utilitarianism. It is not a new idea but it does attract its share of criticism, mainly related to the interests of the individual versus the good of the collective. Who benefits and who is hurt is an important question. Moreover, whether the hurt is distributed in reasonable proportion to the benefits is also a key feature of this debate. We have tried to address these important considerations in the report.

However, now I wish to show how quantitative criteria, when applied in the context of an appropriate framework, can be used to guide risk management decisions.

Total Social Cost vs Risk

Figure 2 shows an old but familiar idea: that diminishing returns prevail when attempts are made to reduce low risks. I have plotted the axes to show that the trade-offs are in terms of life expectancy gained versus life expectancy lost. We must explicitly account for expenditure of human effort and beware that the net benefit, in terms of human lives, is negative when large expenditures are incurred to reduce risks which are already very low.

Assessment of Net Societal Benefit

Figure 3 gives a graphical illustration of the steps in assessing net social benefits. I will not walk you through all the details. But I do want to give you the warm feeling that

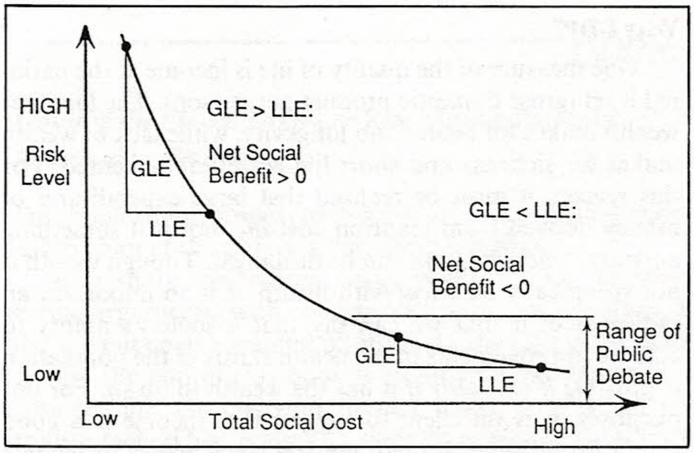

Figure 2: Total Social Cost vs Risk

what I propose to calculate is indeed calculable and that we can improve decision-making on the basis of such assessments.

We have proposed life expectancy as the measure of human safety. We further emphasize the need to include all direct and indirect monetary costs. In any society, the gains in life expectancy can occur directly from good risk management and indirectly from increase in wealth. Poor risk management practices (for example: inappropriate safety measures or lack of risk control) can lead to early deaths and increased illness and thus reduce life expectancy. Also, losses in life expectancy arise indirectly from a loss in real disposable income. This idea that making someone poorer is riskier is indeed controversial but it is also true.

The proposed indices (see Fig. 1) are intended to serve as an objective measure of benefit to the public. How can we use these indicators in practice? First, we propose a general criterion and then derive some specific values for the HDI and the LPI.

General Criterion

The governing criterion is again very simple.

> **Any project, program or regulation that materially affects the public by risk and expenditure will have an impact on the relevant social indicators.**
>
> **Acceptability is derived from a social indicator by the requirement that its increment, expressed as a function of the variables affected, is positive.**

Any project, program or regulation that materially affects the public by risk and expenditure will have some impact on the compound social indicators; if this impact is negative, the proponent should explain why the project nevertheless may be in the public interest. Conversely, if the impact is positive it lends support to acceptance. Thus *acceptability* is derived from a social indicator by the requirement that its increment, expressed as a function of the variables affected, is positive.

Results

The general criterion is satisfied if the net present value of the gain in life expectancy exceeds the net cost by a factor 1/K, specific to the indicator. The derived value of K equals about $48,000 for the HDI and $50,000 for the LPI per quality-adjusted life year gained. (Fig. 4)

Let us consider a specific example, the derivation of the economic radiation dose equivalent, the alpha value in the ICRP optimization process.

Low-level ionizing radiation is held to be harmful with respect to the risk of cancer and genetic damage in proportion to the effective dose equivalent received. The dose can be reduced by a variety of measures. The point beyond which the returns are not worth can be derived from the Life Product Index.

Is this reasonable? The values compare favourably with other similar efforts (by the US Nuclear Regulatory Commission, the AECB, NRPB). Is this simply fortuitous? And does it only apply to the case of radiation risks?

It is instructive to compare the results obtained by two independent paths.

N.C. Lind compared the amount of life time saved by a life-saving proposition with the amount of time consumed in its realization and found an approximate value of $2 million.

Another example from completely different considerations: a study of alternative medical treatments in Ontario has indicated that a treatment change was nearly always approved if the cost was less than $20,000 per quality-adjusted life year and was rarely approved if five times greater. (Life is priceless, indeed!) The Canadian Public Health Association's National Advisory Panel on Risk/Benefit Management of Drugs, has adopted the basic idea we put forth in the Life Product Index and come up with a value of $25,000 expenditure as being justifiable for a gain of one quality-adjusted life year.

For a broad set of implemented programs, documented in the U.S. Federal budget for 1992, we are able to show that the HDI and the LPI are remarkably consistent with the above criteria. Of the programs selected for implementation

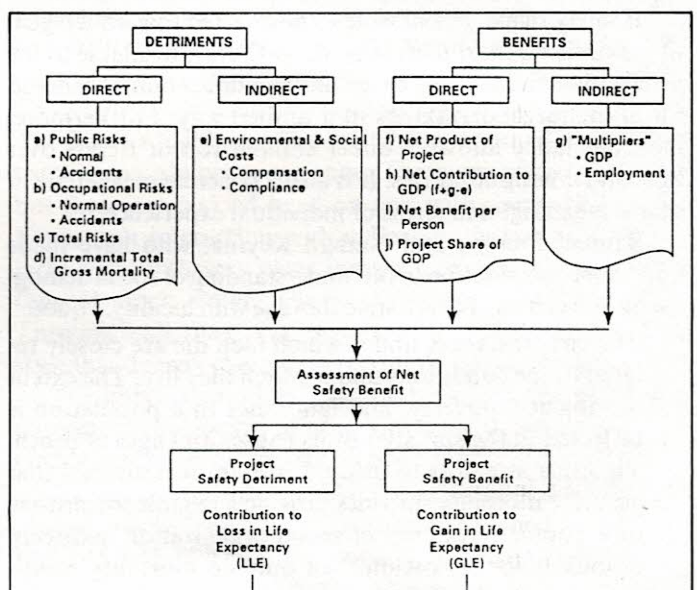

Figure 3: Assessment of Net Social Benefits

1. **Value of a Quality Adjusted Life Year**
   For HDI, ~ $48,000
   For LPI, ~ $50,000
   General criterion satisfied if the net PV of the Gain in Life Expectancy exceeds net cost by a factor 1/K specific to the indicator.
2. **Economic Radiation Dose Equivalent**
   α = $47,000 per Person - Sv
   (1991 Cdn, Real Discount Rate 3%)
   Comparisons
   $10,000 - $100,000 per Person Sv
   (O'Donnell, 1979, NUREG 1983, WARD 1988)
   $10,000 - $50,000 (AECB, 1985)

Figure 4: Results

by the Office of Management and Budget, all criteria are in agreement about which programs are justified and which are not (25 of the 26).

Have we reduced all this to a LIVES vs $ equation without any ethical qualms? On the surface it may appear to be so but that isn't the case. What we have put forward is a LIVES GAINED vs LIVES LOST proposition. As shown, Risk level is proportional to gains in Life expectancy. Here, there is much insight to be gained by adopting a definition of Total social cost consistent with Henry David Thoreau's view of life. Thoreau very succinctly states:

> "The cost of a thing is the amount of what I will call life which is required to be exchanged for it, immediately or in the long run."

If we don't meet the criterion that the Gains in Life Expectancy (GLE) exceeds the Loss of Life Expectancy (LLE) in Risk Management practices, we are needlessly throwing resources and lives away.

Conclusions

The net benefit criterion, derived from the social indicators, can be used for many types of studies: project evaluation, choosing among alternative technologies where RISK matters, evaluation of health and safety programs, or evaluation of effectiveness of pharmaceutical products.

There is a good potential for improving RISK Management practices but we need to get disciplined and not lose faith in the rational approaches to decision-making. We need to aim for policies that maximize the net benefit to society but not without a thorough consideration of issues related distributional justice and fairness. We need balanced perspectives to guide public policy making. The three principles that I have outlined above provide a framework of reasoning to make further advances in assisting the decision-maker.

Acknowledgements

I would like to acknowledge my colleague Jan Narveson and all the members of the Joint Committee on Health and Safety of the Royal Society of Canada and the Canadian Academy of Engineering who have contributed to the evolution of the ideas presented above.

Dr. Jatin Nathwani is with the CANDU Owners' Group (COG), responsible for R & D on nuclear safety, environmental effects and radiation protection. He is also an Adjunct Professor in the Department of Management Sciences at the University of Waterloo, a member of the Institute for Risk Research and secretary of the Joint Committee on Health and Safety of the Royal Society of Canada and the Canadian Academy of Engineering.

The Canadian Approach to Reactor Safety

A review of the past and a view of the future

Fred Boyd

***Ed. Note:** the following is based on a paper presented at the International Nuclear Congress, INC '93, in Toronto, October 1993.*

Introduction

The origins of the Canadian approach to nuclear safety go back to the work of the pioneers at the Montreal Laboratory during World War II. The Montreal Laboratory was established in late 1942, as a collaborative UK – Canada project including several senior scientists from Europe who had escaped the Nazi invasions. A factor in the decision to locate the project in Canada was the work by G.C. Laurence and B.W. Sargent in building a sub-critical "pile" of graphite and uranium oxide at the National Research Council in Ottawa over the years 1940-41. Laurence, who had studied under Rutherford and had been in charge of radium and X-ray dosimetry, became the senior Canadian at the Montreal Laboratory and subsequently a leader in reactor safety.

Fission had been reported only in early 1939 and after the beginning of World War II later that year the flow of scientific information essentially stopped. The Members of the Montreal Laboratory had, therefore, to develop the theories needed to provide a basis for the design of a heavy-water-moderated, natural-uranium-fuelled research and production reactor which became the focus of the project. Construction of the NRX reactor began at the remote site of Chalk river in late 1944 and it went into operation in 1948. A zero energy facility, ZEEP, was built and operated in 1945, and became the first reactor to operate outside the USA. Originally designed for 20 MW(th) NRX was upgraded to 30 MW(th) by 1952.

Although safety was not identified as a specific topic at the Montreal Laboratory it was inherent in much of the work as evidenced by papers on topics such as, reactor control, reactor dynamics, and radiation protection. In the last area, radiation protection, which is outside the scope of this paper, the concept of "ALARA" (as low as reasonably achievable) was developed, many years before it became the international creed, and dose limits were prescribed which were well below the practice in other countries at the time.

That those pioneers were very aware of the hazards of a nuclear reactor was reflected in the choice of the then remote site of Chalk River, the early atmospheric dispersion tests, and the numerous safety devices installed on the original NRX reactor.

Context

Although health and safety are normally within the purview of the provinces, the special nature of atomic energy enabled the federal government to pass the Atomic Energy Control Act in 1946, establishing the Atomic Energy Control Board (AECB) with very broad powers. That Act has had only one significant revision, in 1954, to allow for the establishment of the crown corporation Atomic Energy of Canada Limited to operate the nuclear program and to set the AECB as the nuclear regulatory agency.

When power reactors were first proposed, in the early to mid 1950s, the AECB marshalled the most experienced nuclear and conventional power and safety specialists in the Reactor Safety Advisory Committee (RSAC) which it created in 1956, with Laurence as its first chairman, and which, for the next two decades, determined reactor safety requirements. With the growth in numbers and competence of its staff, the AECB, in 1980, dissolved the RSAC and created two generic advisory committees on radiation protection and nuclear safety.

Origins

Despite the many safety devices incorporated in its design, NRX suffered a serious "runaway" accident in December 1952 which caused major damage to the reactor core. Although the calandria (reactor vessel) was replaced and the reactor repaired, to start up again, at an upgraded power of 40 MW(th), in 1954, the accident served as a catalyst for the development of much of the reactor safety approach that still prevails.

The accident led to incisive reviews of the safety of reactors and, in particular, to consideration of the goals and philosophy for the safety of power reactors on which studies had just begun. Some of this new perspective is implied in the official reports on the NRX accident by W.B. Lewis and D.G. Hurst.[1,2] However, a proposal by E. Siddall, in a seminal report in 1957,[3] to use "risk" as a basic criterion or goal marked the beginning of the Canadian approach to reactor safety.

Siddall looked at the accident death rate from alternative forms of producing electricity, especially coal-fired generating plants, and proposed that nuclear plants be significantly better. On that basis he suggested that a risk of one death per six years for a 200 MW(e) nuclear power plant should be acceptable.

About the same time Laurence was also pursuing the "risk" approach and proposed a design target of 10^{-5} serious accidents per year, derived from a goal of less than one death per 100 reactor years and a presumption that a major accident could result in up to 1,000 fatalities.[3] The goal and approach were adopted by the designers of the small (20 MW(e)) Nuclear Power Demonstration (NPD), Canada's first nuclear power plant, which began operation in 1962 and for the prototype, 200 MW(e), Douglas Point generating station. This use of a numerical risk goal became the foundation of Canadian reactor safety philosophy.

Laurence argued that such a low probability could not be achieved, and, particularly, could not be demonstrated, with single systems. He proposed that the target could be achieved, with realistic designs, if there were adequate separation between, and independence of, the operating systems, the protective devices and the containment provisions.

If there were adequate independence of those three divisions of the plant, and if a serious release required failure of all three, the frequency of such a release would be the product of the frequency of the initiating process failure and the unavailabilities of the safety systems. Laurence showed that the desired low frequency of a serious release could, therefore, be achieved with practical, demonstrable, values for process failures and safety system unavailabilities.

In the mid 1960s, at an early stage of the design of the large, four-unit, Pickering (A) plant, these concepts were formalized into a set of criteria that came to be called the "Siting Guide". Subsequently the approach was modified to consider the plant as having two sets of systems; the operating "process" systems, and the "special safety systems" comprising the reactor shutdown systems, the emergency ency cooling systems, and the containment.

The basic requirements, as last formally modified in 1972,[5] set limits on the frequency of serious failures of the process systems* and on the unavailability of the special safety systems. They further stipulated maximum values for the calculated dose of ionizing radiation to members of the public for any serious process failure (single failure) and for any combination of a serious process failure and failure of a special safety system (dual failure). (See Table 1)

It was clearly implied that the special safety systems must be sufficiently separate from and independent of the process systems and of each other that the likelihood of a cross-linked failure will be less than that calculated for coincident events (dual failures).

The reference dose limits of the basic requirements were determined against the assumed maximum frequencies of the events. The maximum frequency for 'single failures" (serious process failures) was taken as one per three years and the reference dose limits for individuals were chosen as equal to the one-year regulatory limits for members of the public. For "dual failures", with assumed maximum frequency of one per 3,000 reactor years, the reference dose limits for individuals were chosen as those judged tolerable at the time, by the UK Medical Research Council, for a "once-in-a-lifetime" emergency dose.

Associated with these reference dose limits were some additional criteria such as:

- the design, construction and operation of all components, systems and structures essential to the safety of the reactor shall follow the best applicable codes, standards or practice and be confirmed by independent audit;
- the quality and nature of the essential process equipment shall be such that the total of all serious failures should not exceed one per three years;
- each special safety system shall be readily testable as a system, and be tested, to demonstrate that its unavailability is less than 10^{-3}.

To achieve testability as well as reliability many safety systems were triplicated and operated on a two out of three auctioneering arrangement.

* A serious process failure was defined as one that, in the absence of special safety system action, could lead to fuel failure or the release of radioactive material to the environment.

The requirement for separation of systems, the specification of maximum unavailabilities, and the reference dose limits, were all a means towards an end – an appropriately low probability of a significant release of radioactive fission products – in the absence of credible probabilistic analytical techniques.

In the early 1970s, the difficulty in analyzing a "runaway" accident, i.e., an anticipated transient without scram (ATWS), led to the requirement for two shutdown systems. These must be conceptually different and sufficiently separate and independent of each other that they can be considered as distinct "special safety systems". With this requirement an ATWS is not a design-basis accident.

If the criteria of the "Siting Guide" are met a major release of radioactive fission products would occur only if there were a "triple" failure, i.e., if two special safety systems failed coincident with a serious process failure. If the requirements for independence and unavailability are met such an event should have a probability of the order of 10^{-7} per year.

The matrix of dual failures defines the requirements for the special safety systems. For example, a loss-of-coolant accident (LOCA) plus failure of the emergency core cooling system will lead to the release of fission products from the fuel (the "source term") that must be accommodated by the containment. Similarly, a LOCA with impaired containment sets the effectiveness required of the ECCS.

Relationship to Design

Exploiting the successful experience of NRX, and the subsequent larger NRU, research reactors, the heavy-water-moderated, natural-uranium-fuelled reactor concept was pursued for power applications. The original design of the NPD demonstration plant incorporated a pressure vessel but this was abandoned in favour of the pressure tube concept, that became a characteristic of the CANDU design, when zirconium alloys were shown to be suitable.

The large size of CANDU plants resulting from the use of heavy water as a moderator made it easier to incorporate

Situation	Assumed maximum frequency	Meteorology to be used in calculation	Maximum individual dose limits, mSv	Maximum total population dose limits, Sv
Normal operation		Weighted according to effect, i.e., frequency times dose for unit release	5/yr, whole body 30/yr, thyroid	100/yr, whole body 100/yr, thyroid
Serious process equipment failure (single failure)	1 per 3 yr	Either worst weather existing at most 10% of time or Pasquill F condition if local data incomplete	5, whole body 30, thyroid	100, whole body 100, thyroid
Process equipment failure plus failure of any special safety system (dual failure)	1 per 3x10³ yr	Either worst weather existing at most 10% of time or Pasquill F condition if local data incomplete	250, whole body	10⁴, whole body 10⁴, thyroid

Table 1: Operating Dose Limits and Reference Dose Limits for Accident Conditions

the separate shut-down systems dictated by the safety philosophy. On-power fuelling, made practicable by the pressure tube design, reduces the need for large reserves of excess reactivity and eases the control problem.

Practical lattice arrangements result in small but positive reactivity power coefficients. This provided added impetus to the development of automatic control systems which have been a feature of all CANDUs. Automatic control also frees the human operators from being a mundane link in the control loop so that they may make full use of their knowledge and judgement.

Canadian expertise and experience in concrete structures influenced the early choice of concrete containment buildings. This, in turn, led to the use of dousing systems and, for the multi-unit stations, attached vacuum buildings, to minimize the containment building pressure in the event of a LOCA. While such designs did not deviate from the safety approach they did complicate the containment provisions which became a set of systems.

Developments in Approach

Although this single/dual failure approach provided functional requirements for the special safety systems some concerns and reservations arose. Among these were:

- the difficulty of separating safety support systems or dealing with their failures;
- the fact that some special safety systems must continue to operate for some time after an accident;
- the inability to take into account (provide allowance for) the great variation in frequency of various failure scenarios;
- the problem of common-cause events such as earthquakes.

In the mid 1970s the CANDU designers proposed using a safety design matrix (SDM) concept to deal with matters of inter-dependency through the support systems and long-term actions including operator intervention. The SDM approach, which uses fault-tree and event-sequence analyses of specific systems, has contributed significantly to a better understanding of system behaviour and interaction.

The designers also developed a "two-group" approach to system layout to minimize the dangers from common cause events, wherein key plant functions and the special safety systems are divided into two groups that are kept physically quite separate from each other.[6]

In a desire to extend and improve the safety approach various groups, since the late 1970s, have reviewed the situation and proposed a further evolution of reactor safety requirements. With the development of probabilistic analyses these groups have proposed using such techniques while still retaining the concept of independent special safety systems as a practicable means of achieving the objective.

Reflecting this movement, the AECB issued in 1980, a "consultative document", C-6, "Requirements for the Safety Analysis of CANDU Nuclear Power Plants", which created six categories of accident sequences and assigned reference dose limits to each. However, no frequency was stated for the various categories making it difficult to assign a limit to an unlisted accident sequence. The AECB required that C-6 be applied, on a "trial" basis, in the licensing of the Darlington generating station. In the Darlington "trial", however, the Ontario Hydro analysts proposed frequencies for the categories which were accepted by the AECB. (Darlington also had to meet the single/dual failure criteria.)

Darlington was also the subject of an extensive probabilistic analysis, the Darlington Probabilistic Safety Evaluation (DPSE), which was proposed and conducted by the utility. Although the DPSE was submitted to the AECB, the regulatory agency did not consider it as a "licensing document" and, therefore, did not review it closely.

In 1983 the AECB's Advisory Committee on Nuclear Safety produced their report, ACNS-4, "Recommended General Safety Requirements for Nuclear Power Plants", which continued the requirements for the special safety systems but proposed a set of accident sequence categories with frequency and consequence (dose) ranges. Although this was developed with considerable consultation with both industry and AECB staff it has not been adopted by the AECB.

Current Situation

AECB staff have been working on a revision of C-6 for some time which they expect to issue for comments in early 1994. The ACNS is working on a revision of ACNS-4.

Meanwhile, industry personnel complain that the AECB is demanding more and more "ad hoc" requirements which do not always appear consistent with one another. The old adage of the AECB staff of, "they propose, we dispose", has been pursued without any obvious overall or underlying philosophy. In fact, there are increasing trends of demanding "absolute" safety.

In the case of off-shore projects, the foreign nuclear regulatory agencies which have agreed to follow the Canadian approach are finding it difficult to do so, partly because of the difficulty of determining the underlying rationale for AECB decisions but largely because of the lack of documentation. Other than the regulatory documents R-7, R-8, R-9, spelling out the requirements (as broadly set out in the "Siting Guide") for containment, shutdown systems, and emergency core cooling systems, respectively, there are very few documented requirements. (See Table 2.)

A number of industry standards have been developed and issued by the Canadian Standards Association (Table 3) but these fall far short of the sets of standards in the USA, France or Germany.

Ironically, the United States Nuclear Regulatory Commission (USNRC), which has a large set of prescriptive regulations, is now seriously examining what it calls "risk-based"

R-7	Requirements for Containment Systems for CANDU Nuclear Power Plants	1991
R-8	Requirements for Shutdown Systems for CANDU Nuclear Power Plants	1991
R-9	Requirements for Emergency Core Cooling Systems for CANDU Nuclear Power Plants	1991
R-10	Use of Two Shutdown Systems in Reactors	1977
R-77	Overpressure Protection Requirements for Primary Heat Transport Systems in CANDU Power Reactors	1987
R-90	Policy on the Decommissioning of Nuclear Facilities	1988

Table 2: AECB Regulatory Documents Related to Power Reactors

regulation for nuclear power plants. The USNRC has a major study underway on this topic with initial objectives being:

- to improve "technical specifications" (the key descriptive part of a nuclear power plant licence) through identification of the most risk significant equipment and procedures;
- to modify existing rules where the requirements are shown [by PRA techniques] not to be commensurate with the safety benefits;
- to develop rules for the future, using a performance based approach.

The USNRC work is being conducted with contributions from, and in cooperation with, many groups representing the industry.

While it is acknowledged that the transition to such a style of regulation will take many years it is intriguing to see that large respected organization pursuing an approach which Canada pioneered three decades ago.

CAN3-N285.0,1,2,3,4,6	Requirements for Pressure Retaining Systems and Components in CANDU Nuclear Power Plants
CAN3-N286.0 to N286.5	Quality Assurance Requirements for Power Plants
CAN3-N287.1 to N287.7	Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants
CAN3-N288.1	Guidelines for Calculating Derives Release Limits for Radioactive Material in Airborne and Liquid Effluents from Normal Operation of Nuclear Facilitaies
CAN3-N288.3.2	High Efficiency Air Cleaning Assemblies for Normal Operation of Nuclear Facilities
CAN3-N289.1 to N289.4	Requirements for Seismic Qualifications for CANDU Nuclear Power Plants
CAN3-N290.1	Requirements for the Shutdown Systems of CANDU Nuclear Power Plants
CAN3-N290.4	Requirements for the Reactaor Regulating Systems for CANDU Nuclear Power Plants
CAN3-N290.6	Requirements for Monitoring and Display of CANDU Nuclear Power Plant Status in the Event of an Accident
CAN/CSA-N293	FIre Protection for CANDU Nuclear Power Plants

Table 3: Canadian / CSA Standards

Concluding Observations

As indicated by the USNRC initiative towards "risk-based" regulation, the concept of risk or probabilistic safety goals is gaining wider acceptance throughout the world nuclear community. Canada adopted such a philosophy almost 30 years ago. Given the absence of practical, credible, verifiable probabilistic evaluation techniques at that time the approach of separate, independent, testable safety systems was developed and augmented by risk based criteria.

Unfortunately, the approach was not pursued with sufficient vigour in the evolving CANDU designs nor enforced by the regulator. One consequence is many potential cross-links, especially through the support systems, between the supposedly independent safety systems. The SDM analytical technique and the Two Group design layout only partially compensate for this basic deficiency.

In recent years the regulator has concentrated more and more on details while, apparently, ignoring the basic objective. If the original risk goal is to be abandoned and its attendant criteria and requirements are to be dropped, there must be a logical, comprehensive, approach to replace them. All in the nuclear power industry should be involved, not just the regulator.

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4. Laurence, G.C., "Required Safety in Nuclear Reactors." AECL – 1923 1961.
5. Hurst, D.G. and Boyd, F.C. "Reactor Safety and Licensing Requirements." AECB – 1045 1972.
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Deadline

The deadline for the next issue of the CNS *Bulletin*, Vol. 15, No. 1, is 25 March for publication in early April.

1994 Membership

Membership fees for 1994 were due the end of December.

If you have misplaced your renewal form, use the one included in this issue of the CNS *Bulletin*.

Emergency Planning at Ontario Hydro

Lesley Charlebois

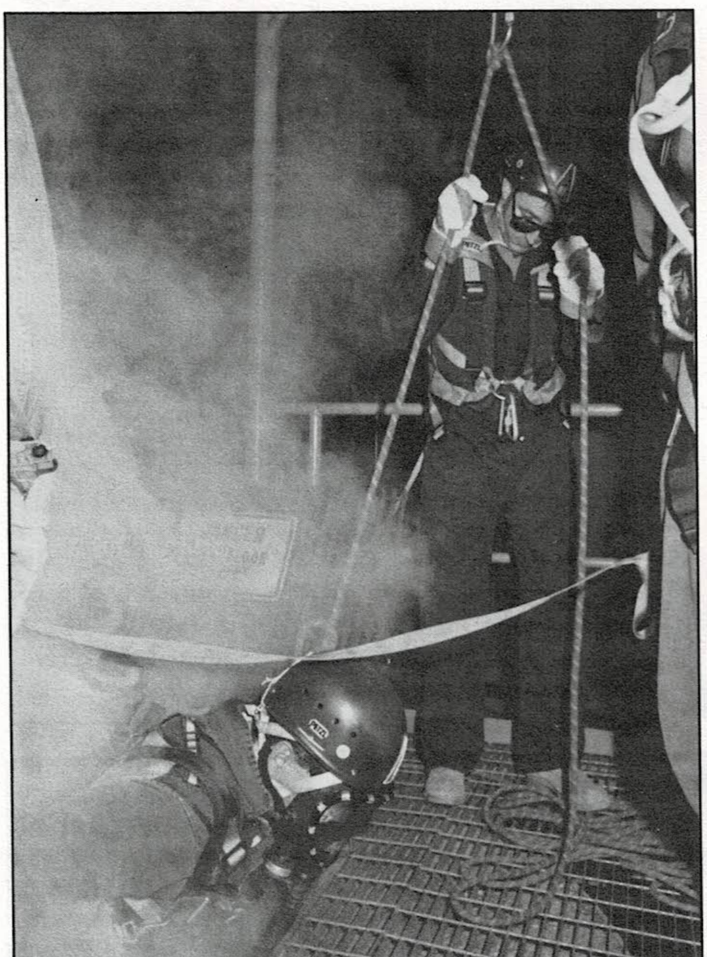
When people think of a nuclear emergency, they usually envision an explosion and fire, similar to the one that took place at the Chernobyl Nuclear Power Plant in the former Soviet Union, on April 26, 1986.

Concern over the Chernobyl disaster increased the awareness and raised the profile of emergency planning efforts around the world, as well as here in Canada.

The design and operating standards of Ontario Hydro's nuclear facilities ensure that this type of accident could **not** happen here. However, there are still many lessons to be learned. The Chernobyl disaster reinforced the need to have emergency plans in place to deal with any type of accident that could possibly occur.

Preparing for the consequences of an accident is the primary focus of the emergency preparedness organization at Ontario Hydro.

Emergency planning has always been an integral part of the operation of Ontario Hydro nuclear stations, in compliance with the Provincial Nuclear Emergency Plan. The corporate Emergency Preparedness Section forms a centralized group that works closely with government agencies in the areas of public safety, community awareness and emergency planning.



An Ontario Hydro nuclear emergency response team demonstrates confined space rescue techniques in a smoky environment.

"Much of our effort is aimed at minimizing the consequences of an accident; in other words, we look at the potential impact of an accident on the surrounding population," says Linda Liik, Technical Superintendent of the Emergency Preparedness Section.

To do this, Ontario Hydro works directly with emergency planners in the Provincial government and with local municipalities near the nuclear stations. Should an accident occur at any one of Hydro's nuclear facilities, emergency plans are in place to protect the staff, the public and the environment.

External Response Organization

In the event of a nuclear emergency that requires prompt action, the local Municipal Control Group (MCG) assembles and implements protective actions based upon recommendations made by the nuclear facility. Such measures may include:

- alerting the public (warning alerts, radio / TV broadcasts)
- sheltering or evacuation
- controlling traffic along designated evacuation routes
- establishing reception / evacuation centres
- directing emergency services (police, fire, ambulance)

The MCG decides what actions should be taken until the Province takes over and assumes control, at which point the MCG reverts to carrying out the directives of the Province.

Ontario Hydro concentrates its efforts on managing the on-site emergency, repairing the damage, preventing injuries, ensuring worker safety, and recovery operations.

Throughout the incident, Ontario Hydro continues to provide technical information to the Province so that protective action decisions can be made to protect the public.

If necessary, residents living in sectors near the station will be evacuated to reception centres.

At the Reception Centre, evacuees are monitored by Hydro staff for radioactive contamination and, if need be, directed to decontamination areas. Registration and public concerns are dealt with by Social Services personnel.

Once registered, evacuees are directed to Evacuation Centres where they are provided with food, accommodation, and other sheltering needs. It is at this location that families can be reunited with relatives and school-age children.

Hydro employees assist with the operation of these municipally-run centres, as well as Exposure Control Centres. Here, they monitor and check for contamination of police, fire, and ambulance workers who enter and work in potentially hazardous areas.

"All emergency workers are required to return through a series of monitoring stations for thorough checking and removal of contamination from their clothing and vehicles," explains Dave Grice, of the Emergency Preparedness Section.

Information centres are quickly established to issue news releases to the media, monitor announcements and provide information to the public.

Station Response Organization

Each nuclear generating station has its own local emergency response organization with specially-trained emergency response crews and teams. Their responsibilities include:

- emergency notifications
- initial off-site recommendations
- first aid / medical treatment (contaminated casualties)
- search and rescue (confined space rescue techniques)
- fire-fighting capability
- radiological survey teams (monitoring on-site and off-site radiological hazards
- damage assessment
- emergency operations and maintenance

Ontario Hydro Emergency Operations Centre (OHEOC)

Within the first hour after an emergency is declared, the **Ontario Hydro Emergency Operations Centre**, in Toronto, is activated. Ontario Hydro technical experts and senior management gather at this facility to support emergency recovery on behalf of the station and the corporation.

The **OHEOC** also becomes an information source and a communication link between the affected station and other organizations.

"The centre is well staffed and equipped to handle a crisis," explains Frank Kolinek, OHEOC Coordinator. "We have emergency telephone lines, information status boards, a computer-based radiation dose projection program and a clear strategy to deal with any incident."

Information from the station is transmitted to the Province and the OHEOC, then relayed to the various Ontario Hydro departments, Provincial / municipal authorities, news media, and external agencies.

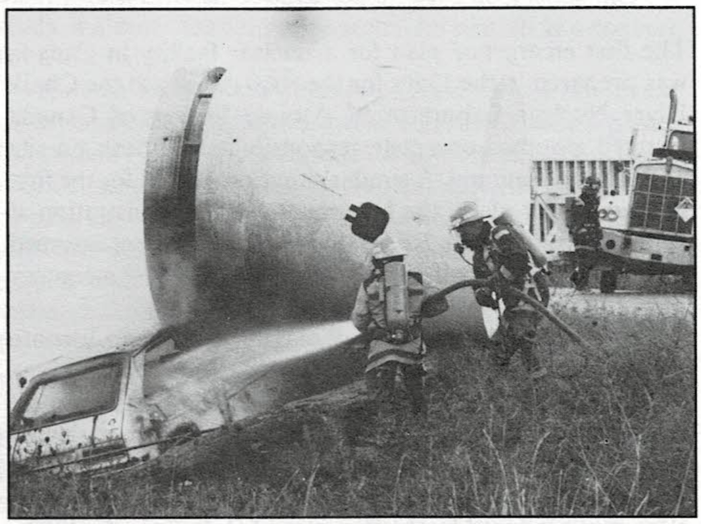
A view of Ontario Hydro's emergency Operations Centre in Toronto during an exercise.

Training Essential

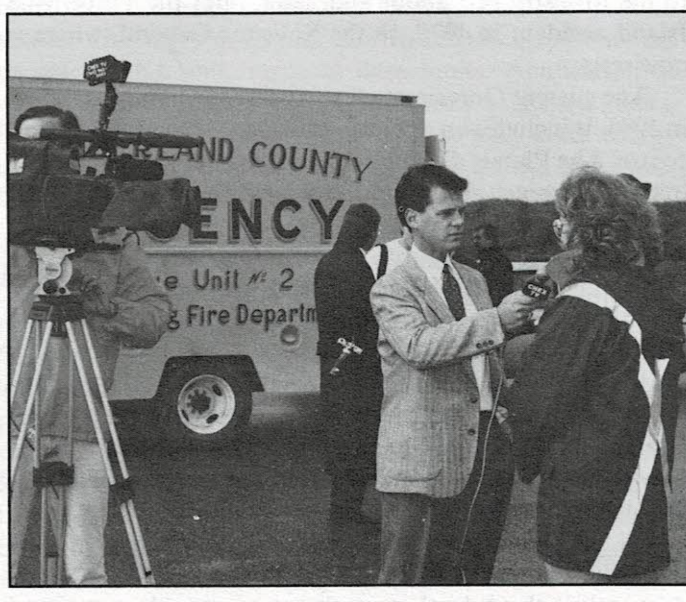
Communicating with the public, the media and with emergency workers is a crucial part of Hydro's emergency procedures. To this end, Hydro has been active in supporting external worker training programs. Specialized training packages and information seminars have been developed and delivered to provincial and municipal emergency organizations.

Public Education

Ontario Hydro and the Ministry of the Solicitor General published an emergency preparedness booklet to inform residents what to do in the event of an emergency. Information on evacuation routes, location of reception centres, radio and television stations to listen to, and emergency procedures, is outlined in the brochure, which is routinely distributed to all residents living within a 10 km area around the site.



An Ontario Hydro emergency response team tackles a transportation accident involving radioactive materials in a simulation exercise.



Even media relations are practised in nuclear emergency exercises.

Reviews and Tests

At Ontario Hydro, emergency response procedures are reviewed and tested regularly to ensure their effectiveness.

"Exercises give us the chance to practise and assess our own emergency response capability," says Peter Kimball, Exercise Co-ordinator in the Emergency Preparedness Section.

"We routinely test our emergency plans by designing realistic exercise scenarios. These exercises test the response capability of station personnel as well as external emergency services. We conduct annual exercises and drills, and then evaluate and critique the overall exercise ... we look at what went well and what improvements we need to make the next time."

Emergency exercises are often designed to involve the participation of police, fire departments, ambulance and medical personnel and the media. Each responding group has a crucial role to play in safely managing the accident situation.

Kimball adds: "We have an on-going program with provincial agencies to train police, fire and ambulance personnel to respond safely to a situation involving radioactive material. An exercise provides an additional training opportunity for all participating emergency response agencies; it gives them a chance to act out their roles under simulated conditions."

"At Ontario Hydro, we recognize that emergency preparedness is more than just a good investment. It is the best way of ensuring the safety of our operations and the security of our customers," concludes Allan Lew, Senior Technical Engineer at Ontario Hydro.

Nuclear Emergency Preparedness in Canada

The first emergency plan for a nuclear facility in Canada was prepared in the 1950s for the NRU reactor at the Chalk River Nuclear Laboratories. Atomic Energy of Canada Limited assumed complete responsibility for both on-site and off-site planning. A similar situation existed for the first nuclear power plant, the Nuclear Power Demonstration at Rolphton (near Chalk River). Station management assumed responsibility for off-site as well as on-site emergency planning.

With the building of the Pickering NGS near Toronto the Atomic Energy Control Board (AECB) urged the province of Ontario to develop plans which would encompass the various municipalities concerned and involve the many provincial departments having a natural role. The first provincial nuclear emergency plan, focused on the Pickering NGS, was produced by the Province of Ontario in the 1960s.

Initially, the Ministry of Health was designated as the lead provincial ministry responsible for coordinating off-site planning. This responsibility was subsequently transferred to the Ministry of Labour and, later, after the Three Mile Island accident in 1979, to the Solicitor General, where it now rests.

The current Ontario nuclear emergency plan was issued in 1986. It includes an operations centre and an information centre. The Plan is divided into two phases; the first for the initial emergency response, the second for the control and restoration activities.

In Quebec, the Sécurité civile du Québec (using its current name) was named as the lead provincial agency for off-site emergency planning and response in the 1970s, while Gentilly-2 was under construction.

In New Brunswick, the provincial Emergency Measures Organization was assigned the responsibility for off-site planning for the Point Lepreau station in 1975. Those plans were officially approved in 1982 just before the start up of the plant.

At the federal level organized planning began in 1979 when the Province of Ontario, prompted by the TMI accident, asked the federal government to provide a national focal point for nuclear emergencies. In 1984 the Prime Minister designated the Minister of National Health and Welfare as the lead minister and his department as the lead department. The first Federal Nuclear Emergency Response Plan was issued that same year. A revision was produced in 1991. A further review is underway.

Through its licensing function the AECB requires the operators of nuclear facilities to develop and maintain comprehensive on-site emergency response plans and capability. The operators are required to cooperate with the provincial agencies involved and to coordinate their plans with the provincial one. This involves some off-site action during the early phase of an emergency before the provincial response can be activated.

Much of the above was drawn from the report "Nuclear Emergency Preparedness in Canada" prepared jointly by the two advisory committees to the Atomic Energy Control Board, the Advisory Committee on Radiological Protection and the Advisory Committee on Nuclear Safety, published in 1993, which is available from the AECB as document INFO-0443-1.

CANDU Chemistry Course

A course on **"Introduction to CANDU Chemistry"** will be presented in Toronto, 29, 30 March 1994.

This course, sponsored by the Design and Materials Division of the Canadian Nuclear Society, is designed to provide the fundamentals of chemical issues associated with CANDU nuclear power plants.

Registration: CNS members $315.; non-members $365.

Contact:

CNS, 144 Front St. W., Ste. 725, Toronto, ON M5G 2L7
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The Economic Effects of the Canadian Nuclear Industry

Tony Going
Ernst & Young

Tony Going

Ed. Note: *In November 1993, the management consulting firm Ernst & Young released their report on The Economic Effects of the Canadian Nuclear Industry which they had conducted for Atomic Energy of Canada Limited. Following is the Executive Summary of that report, courtesy of AECL and Ernst & Young.*

Tony Going, the author of the report, is head of Ernst & Young's Business Policy Group in Ottawa. In that capacity he has undertaken over a hundred market and economic impact analyses. He has also completed several studies related to the use of nuclear technolgy for irradiation of manufactured goods and food products in Hungary, the Czech Republic, Cote d'Ivoire and Mexico.

Executive Summary

A. Study Objectives

The objective of Ernst & Young with this study was to document the economic contribution of the nuclear industry in Canada and abroad to the Canadian economy. Therefore, the major costs and benefits associated with government investment, largely federal, in the nuclear industry were documented.

In more immediate terms, another goal was to update the previous study of the effects of the Canadian nuclear industry completed by Leonard and Partners Limited in 1978.

B. Study Scope

The term "nuclear industry" was defined to include all activities directly related to the design, construction, equipment supply and operation of nuclear power facilities. This covered activities such as research and development, engineering, manufacturing, uranium mining and refining and maintenance services.

For the purposes of this study, the scope did not include activities in spin-off industries such as health sciences or agriculture that rely on nuclear technology. The only exceptions to this were Nordion International Inc. and Theratronics International Ltd., both of which were divisions of Atomic Energy of Canada Limited (AECL) until 1989. Beyond a qualitative discussion, our definition of economic effects also did not attempt to financially quantify the environmental and medical benefits from the use of nuclear technology.

We defined "government investment" as federal government expenditures on the nuclear industry including appropriations and write-offs. We recognize that this federal investment is incremental and has been leveraged by other public and private sector investments which together have resulted in the effects described in this study.

With respect to effects, both economic and non-economic effects in aggregate form, i.e., for the nation as a whole, were sought. Impacts on specific regions/communities are presented only where such information/analysis was readily available.

C. Study Methodology

The information required to conduct this impact study was collected using the following five methods.

- Mail survey of 154 Canadian companies which supply products and/or services to the nuclear industry (a response rate of 50% was achieved),
- Interviews with 35 industry stakeholders,
- Review of 150 relevant reports and documents,
- Case studies of five successful companies, and
- Input-output analysis using Statistics Canada's Open Output Determination Model.

The methodology was designed to obtain the most up-to-date and reliable data directly from the primary sources. Where it was necessary to use secondary data, we have cross-checked/verified them with the primary sources to the extent possible. All sources, whether primary or secondary, have been referenced accordingly in the report. Limitations with the data have also been identified where relevant.

D. Major Findings

The major findings of our study are quantified where possible and, in our view, represent conservative, minimum estimates of effects. All calculations are shown in Section Three of the full report.

Energy Supply

1. The Canadian nuclear industry plays a significant role in the provision of energy in Canada.
   - Between 1962 and 1992, nuclear energy production in Canada rose from 22 GWh to 76,022 GWh (GW = Gigawatt = 10^9 watt)
   - In 1992, nuclear energy supplied 15% of Canada's electricity requirements. Forty-eight percent of Ontario's electricity needs, 30% of New Brunswick's and 3% of Quebec's were met by nuclear energy last year.
   - The industry produced electricity valued at $3.7 billion in 1992.
   - With the completion of the Darlington station in 1993, nuclear energy provides almost 20% of Canada's electricity.

Economic Effects

2. In developing Canada's nuclear energy capability, the federal government has appropriated a net amount of $4.7 billion to AECL since 1952 in as-spent dollars.

The economic effects of these appropriations are as follows:

- ***Overall Impact on GDP***

Using Statistics Canada's Open Output Determination Model, we conservatively estimate that the total contribution of the nuclear industry to Canada's Gross Domestic Product (GDP) from 1962 to 1992 was at least $23 billion.[1] In simple terms, over 90% of the industry inputs required to generate electricity from nuclear power (valued at $3.7 billion in 1992) are sourced in Canada. This means that imports constitute less than 10% of the inputs and Canadian products and services constitute over 90% of the inputs.

The GDP contribution was calculated using the value from the nuclear generation of electricity and the Canadian content of all CANDU reactors sold abroad. It does not reflect nuclear research and development activities. If these were included, the impact of the nuclear industry on Canada's GDP would be even greater.

- ***Direct Employment***

We estimate direct employment in the nuclear industry in 1992 at about 30,000 jobs. Survey results suggest that approximately 90% of these jobs are full-time. Part-time employees work an average of 35-40% of their time on nuclear-related activities.

Between 1989 and 1992, direct employment increased by approximately 9%. The distribution of direct employment in 1992 by area of activity is estimated as follows:

Ontario Hydro	12,000[2]
Hydro-Quebec	650
New Brunswick Power Corp.	450
AECL	4,500
Private sector suppliers	8,500
Uranium	2,200
Public sectoradministration	350
Construction at Darlington	870
Other	350
TOTAL	**30,000 jobs (approximately)**

Construction, refurbishing and/or maintenance activities associated with CANDU reactors are reflected in the private sector suppliers' employment numbers.

- ***Indirect Employment***

In addition to direct employment, the nuclear industry also helps support other jobs in the Canadian economy. More specifically, we conservatively estimate that a minimum of 10,000 jobs in other sectors indirectly depend on the nuclear industry. This level of indirect employment is sustained even when there are no reactors under construction at home or overseas.

Based on analysis of the recently signed Wolsong 3 and 4 contracts, Industry and Science Canada (ISC) estimates the domestic employment multiplier to be 2.5 for the construction phase of a new export reactor project. This means that indirect employment in Canada will rise by 2,500 when each new CANDU export project is being built abroad.

Induced employment was not calculated. Induced employment is that which is created through the spending of disposable income. However, jobs in the Canadian economy do depend on the purchases made by the employees of the nuclear industry when they spend their pay cheques.

- ***Sales***

In 1993, Canada holds 7% of the world's market share of nuclear reactors and 10% of the market share of nuclear reactors under construction. A twin reactor order from South Korea, valued at over $1.0 billion was Canada's single largest export order in 1992.

Based on our survey analysis, we estimate that private sector companies who supply nuclear products and services have generated total sales of $9.4 billion between 1988 and 1992. Compared to sales of $350 million in 1977, this represents a compounded growth of 23% annually. In real terms, it represents approximately a 17% compounded annual growth rate.

At present, the split between domestic and export sales from private sector suppliers is 60%/40%. In the future, the industry expects this split to reverse. More specifically, exports are expected to account for 60% of total sales by 1998.

In addition to these private sector sales, AECL generated revenues of approximately $1.3 billion in the five years between 1988 and 1992 and $335 million in 1992. The breakdown of these revenues is as follows:

Commercial nuclear operations
= $808 million (1988-1992)
= $209 million (1992)

Cost sharing and commercial
= $484 million (1988-1992)

R&D activities = $126 million (1992)

- ***Tax Revenues***

Our study estimates that the federal government receives approximately $700 million in tax revenues annually from the nuclear industry in the form of income and sales taxes. This figure excludes corporate income taxes.

- ***Exports***

Annual exports of nuclear products and services in 1991 were approximately $550 million. This comprised:

Uranium exports = $290 million
AECL exports = $100 million
Other exports (i.e. Theratronics) = $100 million
Nuclear electricity exports by the utilities
= $61 million

With respect to CANDU project sales, the confirmed sale of two additional CANDU 6 reactors to South Korea is expected to result in more than $1.5 billion in new business in Canada during the construction lifetime of the entire 4-unit Wolsong project (1976 to 1999). Ninety percent of the products and services for these exports to South Korea will be sourced in Canada (excluding construction).

- ***Positive Trade Balance***

Canada's nuclear industry has a positive trade balance given its significant exports and limited imports. Specifically, the nuclear industry imports approximately $50 million worth of specialized equipment each year and special metals and alloys like zirconium for use as fuel bundle cladding or sheathing materials.

Estimates of the size of the positive trade balance vary. Using the figures referred to above and subtracting imports of approximately $50 million, our study estimates that the nuclear industry in 1991 generated a positive trade balance of $500 million.

Based on its definition of the high technology components of the nuclear industry, Industry and Science Canada estimated that the nuclear industry generated a trade surplus of $250 million in 1991. In fact, by ISC calculation, nuclear and aerospace were the only two Canadian industries in the high technology area with surplus trade balances. All other high technology areas including telecommunication and biotechnology had trade deficits.

Industry	**$millions**
Aerospace	$950
Nuclear	**$250**
Biotechnology	($60)
Opto-electronics	($190)
Weapons	($280)
Material Design	($500)
Computers and Telecommunications	($3800)
Computer Integrated Manufacturing	($1300)
Electronics	($1500)
Life Sciences	($1900)

Source: Industry and Science Canada, 1992

However, among the exports defined as high-tech is natural uranium oxide, which has the lion's share (98%) of the nuclear positive trade balance. The remainder consists of nuclear reactors, or parts of, and instrumentation, fuel elements and other special uranium compounds.

- ***Foreign Exchange Savings or Positive Contribution to the Current Account Deficit***

Ontario Hydro estimates that, from 1965 to 1989, nuclear energy has saved the Canadian economy approximately $17 billion (1989 dollars) in foreign exchange. In the absence of nuclear energy, this money would have been spent on importing coal from the United States to Ontario and importing oil or coal into Quebec and the Atlantic provinces.

Ontario Hydro estimates that, in the 1990s, foreign exchange savings will amount to approximately $1 billion a year.

- ***Regional Development***

The nuclear industry is dynamic and opportunities for private companies emerge in cycles depending on whether new CANDU reactors are being constructed. For this reason, the number of companies vary from year to year. In 1992, we estimate that there were 154 Canadian companies that supplied manufactured or engineered products and/or services to AECL and the electric power generating utilities.

Fifty-eight percent of the companies we identified are based in Ontario, 14% in Alberta and 12% in Quebec. Companies located in Alberta are mainly small suppliers who provide products and services to the uranium industry. The remaining provinces have 16% of the private-sector suppliers. Sixty-six percent of these companies are in manufacturing, 30% in engineering and design, and 16% in R&D.

Survey results reveal that one quarter of these companies are new entrants to the nuclear industry, i.e., they started supplying nuclear products and services in the last ten years. In terms of percentage growth, New Brunswick has seen a doubling of suppliers since 1978 (albeit from a small base), Quebec has seen a 22% growth, Ontario has seen an 18% growth, and Alberta has seen a 14% growth.

Spin-Off Benefits

3. In addition to the economic benefits identified above, the nuclear industry has realized several "spin-off" benefits that have created new industries and domestic and export markets for Canada in the following three major areas: medical sciences, environment and agriculture.

For example, Theratronics (formerly the Medical Products Division of AECL) has built over 1,300 of the world's cobalt therapy machines. Every year, an estimated one-half million people are treated for cancer, in 70 countries, using these machines.

Nordion, also a former division of AECL, is the world's leading supplier of Cobalt-60 irradiation facilities used in the sterilization of medical and surgical equipment. Nordion supplies and markets most of the radioisotopes used in medical diagnosis. About seven million people benefit from these isotopes every year.

Irradiation is also used to sterilize insects, to improve the nutritional characteristics of feed livestock and to gauge optimal hormone levels and breeding times. The combined result is more productive and disease-resistant livestock.

In terms of environmental benefits, nuclear energy is a clean form of energy, particularly in comparison to fossil sources such as coal and oil. Because there is no combustion during the nuclear reaction, nuclear energy does not emit acid gases or carbon dioxide (CO_2). This helps avert acid rain and reduces global warming (the "greenhouse effect").

In addition, the demanding quality assurance processes developed in and for the nuclear industry have had a very broad and beneficial impact in many sectors.

Enhanced Competitiveness

4. According to the Canadian companies surveyed, participation in the nuclear industry has helped enhance their competitiveness in the following ways.
   - it has helped improve the quality of products and services for 33% of supplier companies surveyed,
   - it has facilitated increased access to foreign nuclear markets for 22%,
   - it has facilitated increased access to new markets in non-nuclear areas for 20% of companies, and
   - it has improved the safety standards of 12% of the companies surveyed.

E. Summary of Benefits

In summary, government appropriations for AECL were $167 million in 1992. This investment levered other public and private sector investments which together resulted in the following economic effects:

- Produced energy valued at $3.7 billion in 1992
- Directly employed 30,000 people in 1992
- Created indirect employment of at least 10,000 in 1992
- Generated federal tax revenues of $700 million in 1992
- Generated nuclear trade surplus of $500 million in 1991
- Generated revenues of $335 million for AECL from commercial nuclear operations and R&D activities in 1992
- Resulted in foreign exchange savings of approximately $1 billion in 1992

F. Conclusions

We conclude that the economic effects of the Canadian nuclear industry have been substantial. Over the past 31 years, the GDP contributions of the nuclear power generation industry has been at least $23 billion (as-spent dollars). The GDP contributions for 1992 were $3.5 billion.

The nuclear industry also supports at least 40,000 direct and indirect Canadian jobs associated with both nuclear research and CANDU technology. Spin-off benefits from the nuclear industry have augmented Canadian technological and commercial capabilities in other sectors such as agriculture, medicine and the environment. For example, commercial operations such as Theratronics are directly linked to the government's decision to appropriate funds for the development of nuclear applications.

Increased quality standards for Canadian manufacturing companies are a result of the stringent standard demanded for goods produced for nuclear application. Such standards have allowed companies supplying the industry to gain a competitive advantage in technical design and engineering.

Until recently, AECL had focused primarily on enhancing the capacity of the domestic market. At the present, nuclear power is supplying close to 20% of Canada's electricity needs. However, there are no concrete plans for developing new nuclear generating plants in Canada and, with the temporary decline for new domestic nuclear capacity, the industry is pursuing export opportunities. This strategy has been successful as seen by the recent signing of the Wolsong 3 and 4 contracts with South Korea.

Based on our study, we conclude that the Canadian nuclear industry has the capability to sustain current levels of economic activity through export projects assuming the current base of 22 nuclear reactors in Canada is maintained. Our findings indicate that there is an excess of electricity on the national market at present. However, assuming that this situation will transform into a long term trend is ill-advised. Long term predictions show electricity needs will increase as the Canadian economy either stabilizes or grows. Since nuclear is an important component in Canada's electricity mix, substitution by an alternative fuel type would be costly in both economic and environmental terms.

In 1992, the nuclear industry had a positive trade balance of $250 million, one of the two industries within the high technology sector to do so. The industry must continue to find new opportunities abroad to maintain the technological advances and ensure qualified human resources remain trained in the nuclear field. This will help maintain Canada's nuclear capability for future use when domestic demand for nuclear energy strengthens. Future nuclear exports will help safeguard Canada's investment in the nuclear industry and will maintain nuclear as a viable energy option.

References

1. This contribution is based on estimates of the value of electricity generated from nuclear sources and the value of the Canadian content of exports of CANDU reactors. The first year that commercial volumes of electricity from nuclear sources were generated was 1962.
2. The employment data do not reflect the recent layoffs at Ontario Hydro. The total impacts of these layoffs are still unknown.

Deadline

The deadline for the next issue of the CNS *Bulletin*, Vol. 15, No. 1, is 25 March for publication in early April.